NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1985

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1985

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL 1985

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. More predominantly, however, the need for more efficient, economical, and safer highway transportation and the importance of meshing with other modes and other societal concerns leads to national problems of increasing complexity. A coordinated program of high-quality cooperative research provides a highly effective approach to such problems.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. AASHTO's program is supported on a continning basis by funds from participating member states of the Association and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer AASHTO's research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; and it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

Research programs are developed annually by AASHTO on the basis of research needs identified by chief administrators of the highway and transportation departments, by committees of AASHTO, and by the Federal Highway Administrator. The programs are then referred for administration through the Transportation Research Board, and research projects addressing the specific needs are defined by the Board on the basis of the AASHTO problem statements. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out under contract, and administration and surveillance are responsibilities of a Board-appointed staff.

The needs for highway research are many, and the National Cooperative Highway Research Program is an efficient mechanism for providing timely solutions to problems of mutual concern to many responsible groups. The Program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

THROUGH 1984

INTRODUCTION

The National Cooperative Highway Research Program (NCHRP) was established in 1962 to provide a continuing program of highway research. It is sponsored by member departments of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA), U.S. Department of Transportation, and carried ont nnder a three-way agreement among these agencies and the National Academy of Sciences. AASHTO annually proposes specific research problems for inclusion in the NCHRP fiscal year activities. At least two-thirds of the member departments must approve the research problems and agree to their financial support before they can be brought into the Program. Following balloting by the member departments, the approved problems are referred to the Academy, where they are reviewed to determine their acceptability to the Academy for administration by the Transportation Research Board. Each State annually contracts with the Academy to commit an amount equal to 4½% of its 1½% Federal-aid highway planning research (HPR) funds. Under the Surface Transportation Assistance Act of 1982, these funds presently make available a cooperative pool of about $8.0 million for NCHRP's administrative and contract research operations.

Once accepted, the problems making up the program are assigned to project panels or committees made up of persons knowledgeable in each particular problem area. They analyze the problems, outline particular projects and their objectives, and then prepare research project statements by which proposals are solicited from qualified private and public research agencies. They review the proposals, recommend contract awards, and provide counsel to the NCHRP staff responsible for surveillance of work under the research contracts. Finally, they review final reports for acceptability and for accomplishment of the approved research plan. There are presently some 684 members on these panels coming from 44 States, the District of Columbia, and Canada.

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the many research areas encompassed by the Program are responsible for administrative and technical surveillance of the contracts. In addition to reviewing quarterly progress reports and monthly progress schedules and maintaining telephone contacts, each engineer regularly visits his assigned projects throughout their contract periods. He discusses with each principal investigator the project's status to learn if the research is being pursued in line with the approved research plan. If necessary, frequent meetings involving the staff, panel, and agency personnel are held to review project progress and provide guidance for continuing work. Finally, the projects engineer and the panel evaluate the completed research to determine the degree of technical compliance with the contract and the acceptability of the final report to the Board and the Academy.

The research findings are published in either of two regular NCHRP report series. Each highway administrator receives a copy immediately on publication, and some 3,500 to 5,500 copies are formally distributed through the Transportation Research Board's selective distribution system.

Another means for bringing research findings before the practicing engineer consists of the *NCHRP Research Results Digest*—a series of flyers published at frequent intervals in the interest of providing an early awareness of the research results emanating from the various projects. By making these results known as they are developed and prior to publication of the final reports, it is hoped that their early use in practice will be encouraged.

Over the years, 63 detailed progress reports have been submitted by the NCHRP to the sponsors to provide them with current information on the specifics of technical progress of the projects, as well as the specifics of administrative matters relating to Program operation. These reports are supplemented by publication of an annual summary of progress that is made available at the end of each year to both the sponsors and the public at large. The twentieth issue covers the Program from its inception through December 31, 1985, and illustrates in detail how the NCHRP functions.

Although research in the NCHRP is presently sponsored by AASHTO, the Program is designed to administer research for other agencies as well. However, the follow-

ing description of how projects are formulated and research is administered applies specifically to research sponsored by the AASHTO.

HOW NCHRP PROGRAMS ARE FORMULATED

Research problems from the AASHTO are initiated on an annual basis, and there are many steps (refer to Figure 1) between initiation and the time that the final reports are published. Each fiscal year's program must start with the *identification of critical problems* by:

- The chief administrative officers of the member state highway and transportation departments.
- The chairmen of subcommittees under AASHTO's Standing Committee on Administration.
- The chairmen of subcommittees under AASHTO's Standing Committee on Highways.
- The Executive Committee of AASHTO.
- The Federal Highway Administrator.

The many problems received from these sources each year are first screened to determine:

- If the proposed problem is of mutual interest to all or many of the States and whether it can be handled more effectively under a cooperative program than by an individual member department.
- If the proposed problem represents an immediate research need in the transportation field.
- If similar efforts are already under way, or if satisfactory answers are already available. In these respects, a search is made of the relevant literature stored in the Board's automated Highway Research Information Service.
- The probability of success of completing the problem according to its scope, estimated cost, and time for completion.

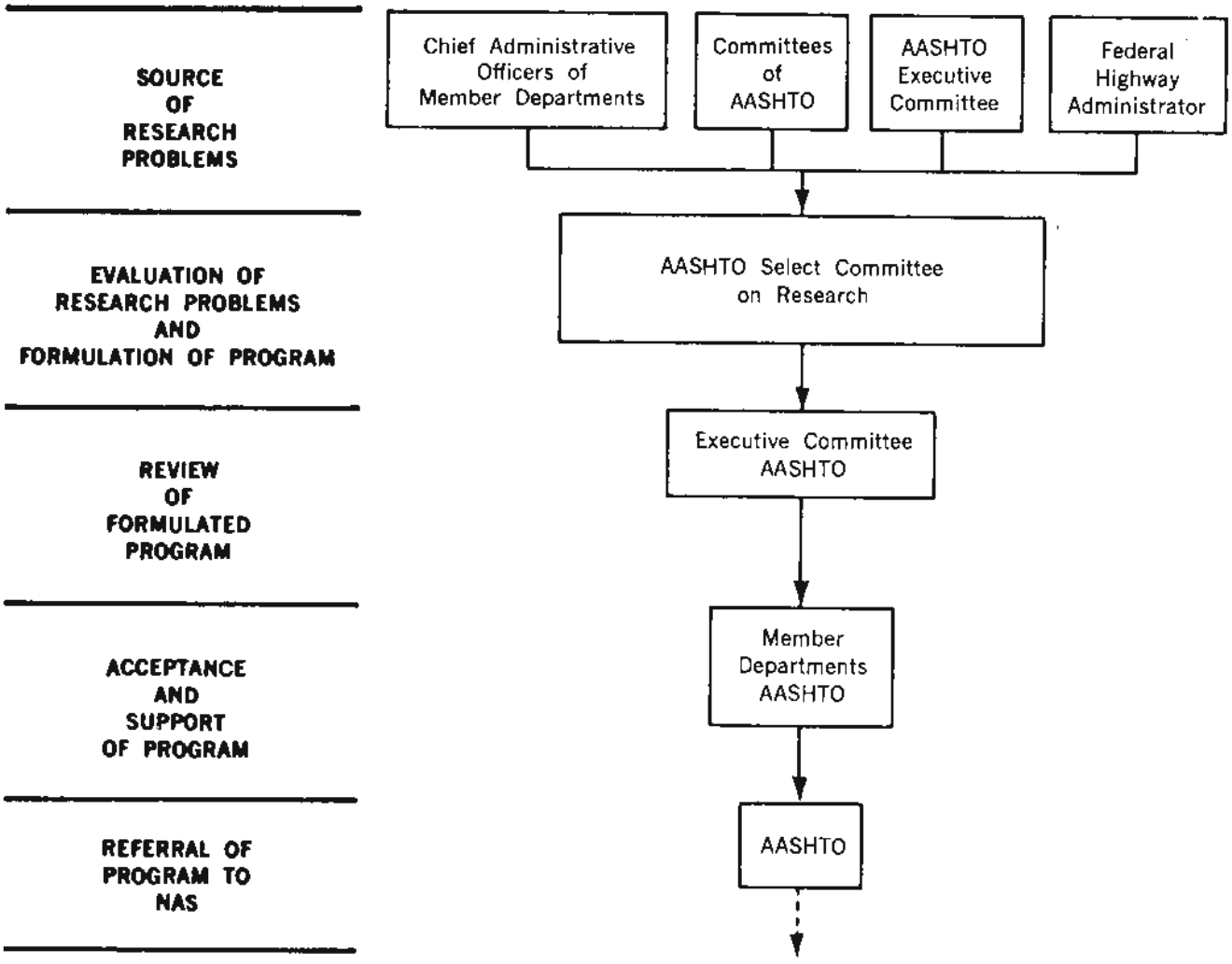

FIGURE 1

Flow Diagram for Each Program from Initiation to Referral by AASHTO to the National Academy of Sciences

The technical merits of the problems that survive this initial screening are then evaluated in depth by the AASHTO Select Committee on Research. Final priorities are placed on them during an annual meeting that is held specifically to formulate research programs for the NCHRP. Based on the funding anticipated to be available from the Federal apportionment for the given fiscal year, the Committee carries out two major activities. First, a review is made to determine which completed or on-going projects should receive additional funding for further work. During this part of program development the committee receives NCHRP recommendations for continuations and has detailed status reports available on each project in the Program since FY '63. Also available are reports from the NCHRP, TRB, and Federal Highway Administration research staffs dealing with appropriateness of the proposed research in light of other research that is under way in this and other research programs.

Following allocation of funds to the projects selected for continuation, the committee's second major activity is to determine which new problem submittals should receive the highest priority for programming within the remaining available funds.

The complete program, made up of continuations and new problems, is sent immediately to the AASHTO Executive Committee for review, approval and/or modification, and acceptance.

After the program is approved, it is sent by AASHTO's Executive Director to the member departments for balloting. The final program for each fiscal year consists of those problems that have received a favorable vote by two-thirds or more of the member departments.

Each year's final program is then referred by AASHTO to the Academy for review and acceptance (refer to Figure 2). At the same time it is also sent to the Federal Highway Administration for its review. Concurrently, the NCHRP staff reviews each item to again ensure that there will be no duplication of either on-going or completed research.

PROGRAMS RECEIVED TO DATE

Through most of NCHRP's history, each year's program generally has consisted of from 7 to 10 new problems, each with funding usually ranging between $150,000 and $300,000 and a like number of continuations of projects funded in earlier years. Measured against the large number of research needs, as evidenced by the list that has ranged as high as 104 problems submitted for evaluation in a single year, the funds made available to the NCHRP each year have been far too limited. For about 15 years, annual funding for the NCHRP remained nearly constant at just below $5 million, while, during this period, the purchasing power of the research dollar was severely reduced by inflation. This decline was reversed with enactment of the Surface Transportation Assistance Act of 1982 which resulted in an approximately 50 percent funding increase for NCHRP.

Because of this increase, and because of the accumulation of balances from earlier fiscal years, the FY '87 program, formulated in September 1985, is the largest ever, comprising some 27 new projects and continuations, funded at more than $7.25 million. Funding for NCHRP research is expected to drop back and hold steady at about $6 million starting in Fiscal Year 1988.

In 1984 AASHTO referred the twenty-fourth program (FY '86) of research problems. From all programs through FY '86, 429 research projects have resulted, on which contracts written through December 1985 total some $70.7 million. The subject matter of the projects ranges across the full spectrum of concern within the transportation industry and evidences the sponsor's immediate interest in acquiring answers at an early date to the many acute problems facing administrators and engineers. The twenty-fifth group of research problems (FY '87 program) was selected in September 1985, and will be referred to the Academy following the States' ballot on the recommended problems. AASHTO's initial step toward development of the twenty-sixth research program (FY '88) was taken in October 1985.

FINANCING THE PROGRAM

Each year each State contracts with the National Academy of Sciences to support the Program. The agreement commits the State to 4½ percent of its 1½ percent Federal-aid planning and research (HPR) funds. A member department's contribution, if so elected and when authorized by the Federal Highway Administrator, may be financed directly from the Federal-aid monies without State matching funds. On the other hand, the member department's contribution may be financed from both Federal and State matching funds or entirely from State funds. From these contributions a cooperative pool of about $7.0 to $8.0 million is presently made available each year in varying amounts under the Surface Transportation Assistance Act of 1982 for NCHRP's administrative and contract research operations. Funds are scheduled to become available such that research can begin by the first of each year.

HOW THE NCHRP IS ORGANIZED TO ADMINISTER RESEARCH PROGRAMS

In line with the Board's responsibility for administering the NCHRP, a TRB Executive Committee Subcommittee for the NCHRP considers all matters relating to policies and procedures required for the planning and administration of the Program. This committee is drawn from the officers and ex-officio members of the Executive Committee.

In addition, the Board has established eight broad research fields under which project panels are organized to deal with research in specific problem areas falling within the broad fields (refer to Figure 3). For example, in the broad subject field of Design, each project falling within

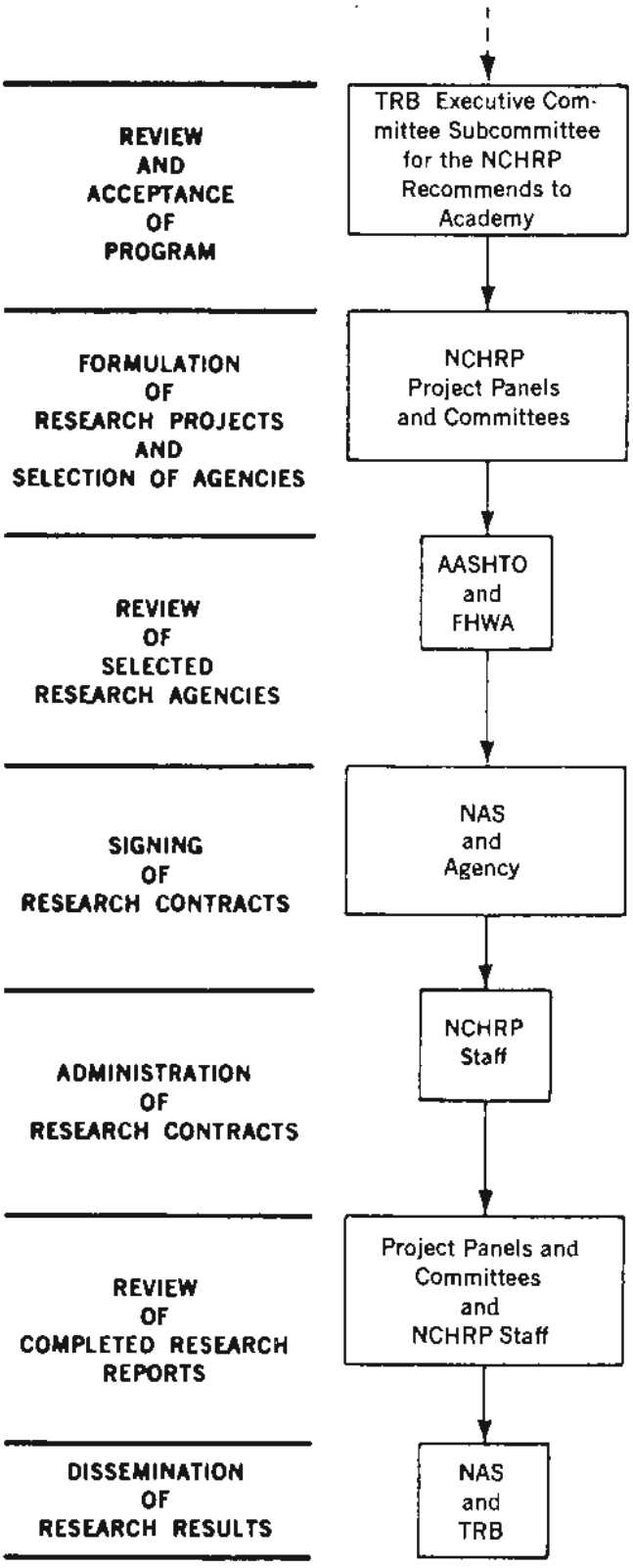

FIGURE 2

Flow Diagram for Each Program After Referral to the National Academy of Sciences

the more specific subject area of Bridges is assigned a project panel to provide technical guidance throughout the research and reporting phases. Those projects that do not conveniently fit under one of the first seven general fields are assigned to the eighth one, Special Projects.

In terms of generalized subject areas, the distribution of all projects through FY 1986 within the fields of Figure 3 is as follows:

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
46	8.9	Socio-economic and environmental issues
53	13.8	Urban issues
11	3.0	Multimodal issnes
76	15.7	Safety and accident prevention
19	0.8	Legal studies
19	17.0	Special projects (including in-house)
31	6.7	Improved materials quality and performance
26	4.8	Highway maintenance
52	10.5	Specifications, tests, aud construction control
85	18.8	Structural design and performance

Members of the project panels do not act as consultants or advisors to project investigators. Members may not submit proposals for research. Some 684 individuals serve without compensation on these project panels, and their total yearly contribution runs to thousands of man-days. Members are drawn from the agencies given in Table 1, and they come from 44 States, the District of Columbia, and Canada. State highway and transportation department employees constitute a significant portion of panel membership, presently 45 percent. The duties and responsibilities of the membership include:

- Developing an operation plan geared to reaching the major problem area objective, including estimates of total cost and time to achieve the objectives.
- Drafting definite statements of objectives for projects within the problem area and within the funds allotted.
- Reviewing research proposals and making recommendations regarding selection of research agencies.
- Reviewing research progress.
- Providing guidance regarding technical aspects of the research.
- Reviewing and evaluating project reports as to the accomplishment of objectives and suitability for publication.
- Making recommendations as to whether or not studies of problems included in prior fiscal year programs should be continued.

NCHRP RESEARCH FIELDS AND AREAS

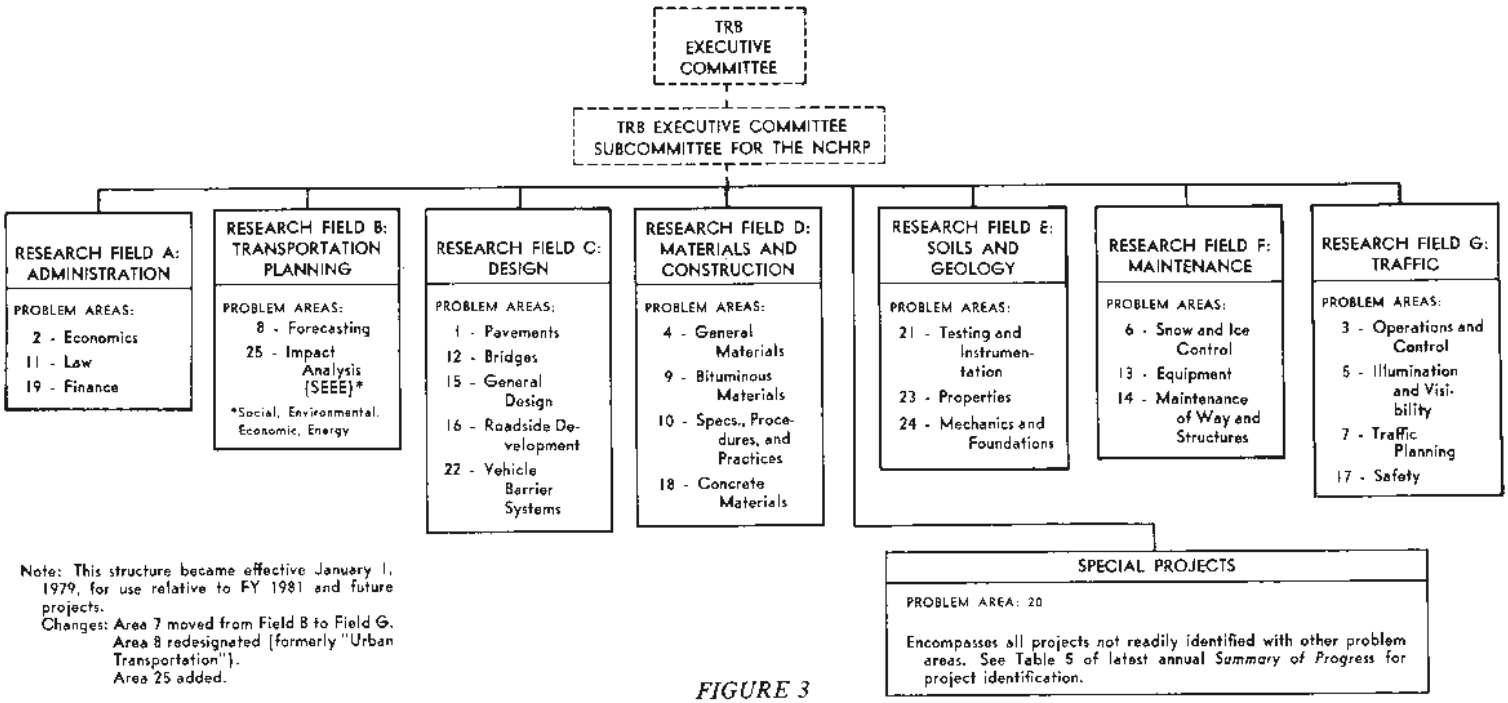

FIGURE 3

Following the NCHRP staff review made after program referral, the recommended program is referred to the TRB Executive Committee Subcommittee for the NCHRP for comments as to the critical need for the research, the availability of other suitable sponsors, and whether or not the research items are appropriate to be identified with the Academy. Unacceptable problems are returned to the AASHTO Executive Committee with the reason for rejection and, when appropriate, with a recommendation for disposition.

HOW THE PROJECTS ARE PLACED UNDER CONTRACT

It is important to note that the NCHRP is not in the business of awarding grants for basic research. Rather, the Program calls for contract research with specific objectives that, if achieved, will result in solutions that are practical and readily usable. As the NCHRP officially gets each year's program under way, the project panels meet to write research project statements based on the research problems referred by AASHTO.

These statements are then sent automatically to a mailing list of some 3,000 research agencies ranging from individuals to large corporations. Because of deadlines the NCHRP must meet, proposals must be submitted according to fixed deadlines, and extensions simply cannot be granted. Submittals have ranged from 2 to 35 per project, while the average rate of return per project has ranged from 6 to 17 (refer to Table 2). An individual agency has submitted as many as 11 proposals during a particular year's program; however, most agencies submit only one (refer to Table 3).

Contracts have been let to agencies headquartered in more than one-half of the States and the District of Columbia (refer to Table 6). In certain instances, the Board conducts NCHRP research directly in its Special Projects Division.

TABLE 1

DISTRIBUTION OF PROJECT PANEL AND COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	309	371
Federal Highway Administration	92	142
Special transportation and other governmental agencies	56	61
Educational institutions	85	102
Research institutes	8	8
Industry, consultants, and trade associations	121	137
Professioual societies and service organizations	3	4
Transportation Research Board	10	85
All	684	910

TABLE 2

NUMBER OF PROPOSALS SUBMITTED

ITEM	'62-'85 AVE.	'62-'85 LOW	'62-'85 HIGH	'80	'81	'82	'83	'84	'85*
No. of projects advertised	15	2	34	10	11	10	2	20	19
Proposals submitted	142	15	233	83	94	98	15	136	127
Proposals rec'd per project (ave.)	10	6	17	8	9	10	7	7	7

* Calendar Year

TABLE 3

NUMBER OF AGENCIES SUBMITTING ONE OR MORE RESEARCH PROPOSALS

NO. OF PROPOSALS SUBMITTED	NUMBER OF AGENCIES SUBMITTING PROPOSALS '62-'85 AVE.	'62-'85 LOW	'62-'85 HIGH	'80	'81	'82	'83	'84	'85*
1	64	15	103	61	48	68	15	62	69
2	16	0	29	11	18	10	0	14	20
3	6	1	14	0	2	1	0	6	4
4	3	0	8	0	1	0	0	5	0
5	1	0	5	0	0	0	0	0	0
6	1	0	4	0	0	0	0	0	1
7	<1	0	4	0	0	1	0	0	0
8	<1	0	2	0	0	0	0	1	0
9	<1	0	1	0	0	0	0	0	0
10	<1	0	2	0	0	0	0	0	0
11	<1	0	1	0	0	0	0	0	0
All				72	69	80	15	88	94

* Calendar year

TABLE 4

TYPES OF AGENCIES SUBMITTING PROPOSALS

TYPE OF AGENCY	NO. OF AGENCIES SUBMITTING '62-'85 AVE.	'62-'85 LOW	'62-'85 HIGH	'80	'81	'82	'83	'84	'85*
Educational institutions	34	6	53	23	18	25	6	41	43
Research institutes	12	1	26	5	7	6	1	4	7
Industry, consultants, and trade associations	43	7	72	42	42	44	7	42	44
Professional societies and service organizations	<1	0	2	0	0	0	0	0	0
State highway and transportation departments	1	0	3	0	1	2	1	0	0
Special transportation and other governmental agencies	1	0	3	2	1	3	0	1	0
All				72	69	80	15	88	94

* Calendar year

The opportunity to propose is open to anyone possessing extensive, demonstrated capability and experience in the problem areas in question; never are projects developed with the intent that they go to particular agencies. Because the projects are seeking practical remedies for pressing operational problems, it is expected that only the highest level of agency capability will be applied in meeting the commitments of the proposal—capability cannot be developed at project expense. Consonant with the goal of providing practical, readily usable solutions to pressing problems, time and experience have led to the development of fairly stringent specifications for proposals and agency attributes that are acceptable to the mission-oriented nature of the NCHRP. The types of agencies responding with proposals for the 24 programs to date are given in Table 4.

The staff and panel members evaluate all proposals in a uniform manner, with primary consideration given to:

- The understanding of the problem and the merit of the research plan and approach.
- The experiment design and the promise of fulfilling the objectives of the project statement.
- The qualifications of the principal investigator(s).
- The adequacy of the facilities.

The proposed budget is not one of the primary factors because the funds available for reseach are announced in the project statement. The budget does not enter the evaluation process leading to agency selection, except when specific items are reviewed to better determine manpower allocations. When the proposed cost exceeds the funds stated to be available, the proposal is rejected on receipt.

A panel meeting is held to select an agency for each project and a review is made of all known aspects of performance of the proposers on other research projects under NCHRP or elsewhere. The successful proposals are retained by the panel members for use in monitoring the research. Proposals are considered to be privileged, and the information in them is not released outside the Academy unless explicit approval is obtained from the agency. Policy also holds that panel notes, deliberations, etc., are privileged.

Following the selection meetings, a list of recommended research agencies is transmitted to the AASHTO Select Committee on Research and the Federal Highway Administration for their review and approval, following which the AASHTO Executive Committee is advised of the approval Action. Contracts between the Academy and the research agencies are executed, and research is begun. Again, it should be emphasized that the NCHRP is a program of *contract* research—it does not operate on a grant basis. Further, proposals can be received only in response to advertised project statements, as the funds available each year to the Program are earmarked in their entirety for research problems specified by the sponsor—AASHTO. New research areas can be recognized only through the previously described AASHTO procedures.

The policy of the NCHRP is to provide a debriefing to unsuccessful proposers. The initiative for obtaining a debriefing lies with the proposers and must be requested in writing. The debriefing is intended to indicate to the proposers the technical areas in which their proposals were judged weak and deficient and how the weaknesses or deficiencies were factors in their not having been selected. All debriefings are conducted in a scrupulously fair, objective, and impartial manner, and the information given the unsuccessful proposers is absolutely factual and consistent with the evaluations by the NCHRP panels. The factors constituting the basis for selection of the successful agency are identified, but the debriefing does not include a point-by-point comparison of all the elements considered in the evaluation criteria. Neither is there any revelation of confidential business information, trade secrets, techniques, or processes of the other proposers, nor is there any indication of the relative merits or technical standings of the unsuccessful proposers.

The 429 projects included in the 24 fiscal year programs conducted to date are listed in Table 5. There are 156 projects in traffic planning research, 210 in physical research, and 63 in the special projects area. To date, 352 of the projects have been completed.

The Academy's research contract is either:

- Cost-Reimbursement (CR)
- Cost-Reimbursement Plus Fixed Fee (CRPFF)
- Fixed Price (FP)

The Academy decides, in agreement with the agency, which type of contract will be used in each case.

The research agency's proposal is made a part of the contract. Thus, in addition to the specific research objectives outlined in the contract, the research agency's cost estimates are also recognized as being part of the agreement. However, the principal investigator does have flexibility in conducting the research, if it is consistent with the general scheme of the proposal.

About two years elapse between the time problems are solicited from AASHTO's member departments and committees and the time that contracts are signed. This appears at first glace to be excessive; however, it is not. It provides for the *advance planning* that is necessary for the orderly development of projects relevant to states' need and ensures that program development meshes appropriately with the apportionment of Federal-aid funds for any given year. This permits smooth progression from year to year in planning and activating annual programs.

KEEPING TRACK OF RESEARCH IN PROGRESS

A professional staff is assigned to NCHRP by the Board. Currently, five projects engineers with wide-rang-

TABLE 5
SUMMARY OF STATUS THROUGH DECEMBER 31, 1985 FOR FY '63 THROUGH FY '86 PROJECTS

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA ONE: DESIGN—PAVEMENTS		
1-1(1)	Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements	HRB	42,800*
1-1(2)	Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase	HRB	11,356*
1-2	Comparison of Different Methods for Evaluating Pavement Conditions	Purdne U	29,957*
1-3(1)	Factors Influencing Pavement Performance—Regional	Purdue U	45,982*
1-3(2)	Factors Influencing Pavement Performance—Local	Northwestern U	19,850*
1-3(3)	Factors Influencing Pavement Performance	U of California	19,800*
1-4(1)	Extension of Road Test Performance Concepts	Georgia Tech	10,000*
1-4(1)A	Extension of Road Test Performance Concepts	Dnke U	19,924*
1-4(2)	Extension of Road Test Performance Concepts	Purdue U	12,243*
1-5	Detecting Variations in Load-Carrying Capacity of Flexible Pavements	Cornell Aero Lab	49,011*
1-5(2)	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements	Texas A & M	49,428*
1-6	Standard Measurements for Satellite Program—Measurement Team	Texas A & M	61,353*
1-7	Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces	Penn State U	24,815*
1-8	Factors Involved in the Design of Asphalt Pavement Surfaces	Materials R & D	23,255*
1-9	Evaluation of Studded Tires	Cornell Aero Lab	24,998*
1-10	Translating AASHO Road Test Findings—Basic Properties of Pavement Components	Materials R & D	99,803* 103,291*
1-10A	Systems Approach to Pavement Design—Implementation Phase	Texas A & M	100,000*
1-10B	Development of Pavement Strnctural Subsystems	Woodward Clyde	450,000
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	63,720* 20,205*
1-12	Determination of Pavement Friction Coefficients Required for Driving Tasks	Franklin Inst	309,244*
1-12A	Wet-Weather Skidding Accident Reduction at Intersections	Ohio DOT	199,955
1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques	Penn State U	319,000*
1-12(3)	Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces	Materials R & D	261,955*
1-13	Effects of Studded Tires on Highway Safety	Calspan Corp	208,898*
1-13(2)	Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions	U of Michigan	39,450*
1-14	Influence of Combined Highway Grade and Horizontal Alignment on Skidding	U of Michigan	69,968*
1-15	Design of Continuously Reinforced Concrete Pavements for Highways	U of Texas	151,870*
1-16	Evaluation of Winter-Driving Traction Aids	Penn State U	304,400*
1-17	Guidelines for Recycling Pavement Materials	Texas A&M	199,470*
1-18	Calibration and Correlation of Response-Type Road Roughness Measuring Systems	U of Michigan	250,000*
1-19	Development of a System for Nationwide Evaluation of PCC Pavements	U of Illinois	225,000*
1-20	Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance	Texas A & M	200,000*
1-21	Repair of Joint-Related Distress in Portland Cement Concrete Pavements	U of Illinois	300,000
1-22	Shoulder Geometrics and Use Guidelines	Hugh Downs—RK&K	100,000*
1-23	Pavement Roughness and Rideability	KETRON, Inc	249,990
1-23(2)	Pavement Roughness and Rideability—Field Evaluation	JMJ Research	200,000
1-24	Revision of AASHTO Interim Guide for Design of Pavement Structures	McCullough-Finn	558,200
1-26	Mechanistic-Empirical Pavement Design Methods	—	—
	AREA TWO: ADMINISTRATION—ECONOMICS		
2-1	Criteria for Highway Benefit Analysis	U of Washington	101,948*
2-2	Guidelines for the Determination of Community Consequences	U of Washington	48,873*
2-3	Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements	Cornell Aero Lab	155,972*
2-4	The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed	Texas A & M	77,100*
2-5	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Catholic U	49,998* 51,265*
2-5A	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Paul J. Claffey	35,000* 30,665*
2-6	Warranted Levels of Improvement for Local Rural Roads	Stanford U	40,000*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
3/1/63	2/29/64	Completed—Published as NCHRP Reports 2, 2A	1-1(1)
3/1/64	8/31/65	Contract terminated—No report	1-1(2)
2/15/63	2/28/65	Completed—Init. ph. publ. as NCHRP Rep. 7; final rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-2 1-2
2/15/63	9/30/67	Completed—Published as NCHRP Report 132	1-3(1)
9/1/63	9/30/64	Completed—Published as NCHRP Report 22	1-3(2)
4/1/64	10/31/65	Completed—Published as NCHRP Report 35	1-3(3)
10/1/63	9/30/64	Completed—Published as NCHRP Report 10	1-4(1)
2/1/65	9/30/66	Completed—Published as NCHRP Report 97	1-4(1)A
2/1/64	1/31/66	Completed—Published as NCHRP Report 30	1-4(2)
1/15/64	7/15/65	Completed—Published as NCHRP Report 21	1-5
9/1/66	6/30/68	Completed—Published as NCHRP Report 76	1-5(2)
3/31/64	1/31/67	Completed—Published as NCHRP Report 59	1-6
6/15/65	12/15/66	Completed—Published as NCHRP Report 37	1-7
1/1/65	2/28/66	Completed—Published as NCHRP Report 39	1-8
10/1/66	6/30/67	Completed—Published as NCHRP Report 61	1-9
9/12/66	3/11/68	Completed—Report included in NCHRP Reports 139, 140	1-10
12/1/68	12/31/70	Completed—Published as NCHRP Reports 139, 140	1-10
3/1/72	12/31/73	Completed—Published as NCHRP Report 160	1-10A
2/1/74	7/31/82	Phase I report in review stage; Phase II research completed; report in review stage	1-10B
10/23/67	6/30/70	Completed—Published as NCHRP Report 128	1-11
8/1/70	4/30/71	Completed—Published by AASHTO	1-11
8/25/69	6/8/73	Completed—Published as NCHRP Report 154	1-12
7/1/75	7/1/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-12A
9/16/70	5/15/73	Completed—Published as NCHRP Report 151	1-12(2)
11/1/71	9/30/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-12(3)
4/19/71	8/20/74	Completed—Published as NCHRP Report 183	1-13
2/15/72	5/31/73	Completed—Published as NCHRP Report 176	1-13(2)
10/15/72	1/14/74	Completed—Published as NCHRP Report 184	1-14
8/1/72	8/31/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-15
6/3/74	10/31/81	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	1-16
11/1/76	9/30/79	Completed—Published as NCHRP Report 224	1-17
10/1/77	9/30/80	Completed—Published as NCHRP Report 228	1-18
1/23/78	3/15/85	Completed—Published in NCHRP Report 277	1-19
5/1/79	7/16/84	Completed—Published as NCHRP Reports 268 and 269	1-20
5/15/80	3/31/85	Completed—Published as NCHRP Report 281	1-21
9/8/81	4/7/83	Completed—Published as NCHRP Report 254	1-22
1/4/82	11/30/84	Completed—Pnblished as NCRP Report 275	1-23
1/6/86	10/5/87	Research to begin January 6, 1986	1-23(2)
—	—	Being conducted uuder Project 20-7, Task 24	1-24
—	—	In developmental stage	1-26
6/1/63	11/30/67	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	2-1
7/1/63	8/31/64	Completed—Published as NCHRP Report 18	2-2
6/1/63	8/31/66	Completed—Published as NCHRP Report 47	2-3
6/1/63	8/31/66	Completed—Published as NCHRP Report 33	2-4
6/1/63	8/31/64	Completed—Published as NCHRP Report 13	2-5
6/1/65	12/31/66	Completed—Report included in NCHRP Report 111	2-5
7/1/67	12/31/68	Completed—Report iucluded in NCHRP Report 111	2-5A
8/11/69	8/10/70	Completed—Report included in NCHRP Report 111	2-5A
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWO (*Continued*)		
2-7	Road User Costs in Urban Areas	Catholic U	99,376*
2-8	Estimation and Evaluation of Diverted and Generated (Induced) Traffic	Northwestern U	40,000*
2-9	Effect of Highway Landscape Development on Nearby Property	Franklin Inst	149,103*
2-10	Future Needs for Oversize-Overweight Permit Operation on State Highways	Jorgensen & Assoc	99,655*
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	HRB	110,000*
2-12	Highway User Economic Analysis	Stanford Res Inst	90,074*
			9,995*
2-13	Multilane Design Alternatives for Improving Suburban Highways	Midwest Research Inst	100,000
2-14	Public/Private Partnerships for Financing Highway Improvements	Kimley-Horn & Assoc	125,000
2-15	Identifying, Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas	KLD Associates	220,000
	AREA THREE: TRAFFIC—OPERATIONS AND CONTROL		
3-1	Development of Criteria for Evaluating Traffic Operations	Cornell Aero Lab	78,965*
			79,913*
3-2	Surveillance Methods and Ways and Means of Communicating with Drivers	Cornell Aero Lab	246,756*
3-3	Sensing and Communication Between Vehicles	Ohio State U	163,190*
3-4	Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location	Airborne Instr	78,517*
			49,474*
3-5	Improved Criteria for Designing and Timing Traffic Signal Systems	Planning Res	123,030*
			48,155*
			93,717*
3-6	Effect of Regulatory Devices on Intersectional Capacity and Operation	De Leuw, Cather	153,175*
3-7	Establishment of Standards for Highway Noise Levels	Bolt Beranek	144,920*
			69,930*
			49,927*
			307,486*
3-8	Factors Influencing Safety at Highway-Rail Grade Crossings	Voorhees & Assoc	17,171*
			74,250*
3-9	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control	Jorgensen & Assoc	23,760*
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	41,520*
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick	258,331*
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	198,655*
			100,500*
			99,821*
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways	Texas A & M	149,293*
3-14	Optimizing Flow on Existing Street Networks	Edwards & Kelcey	990,000*
3-15	Weaving Area Operations Study	Poly Inst of NY	300,000*
3-16	Freeway Lane Drops	System Dev Corp	99,789*
			76,815*
3-17	Improving Traffic Operations and Safety at Exit Gore Areas	Penn State U	79,983*
3-18(1)	Improved Control Logic for Use with Compnter-Controlled Traffic	Stanford Res Inst	323,998*
			57,662*
3-18(2)	Traffic Control in Oversaturated Street Networks	Poly Inst of NY	200,000*
3-18(3)	Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems	JHK & Assoc	123,267*
3-18(4)	Methodology for Performance Evaluation of Signalized Network Control Strategies	Computran	148,705*
3-19	Grade Effects on Traffic Flow Stability and Capacity	Midwest Res Inst	220,443*
3-20	Traffic Signal Warrants	KLD Associates	120,000*
			81,935*
3-20A	Peak-Hour Traffic Signal Warrants	JHK & Assoc	150,000*
3-21	Motorist Response to Highway Guide Signing	BioTechnology	272,071*
3-21(2)	Effectiveness of Changeable-Message Displays in Advance of High-Speed Freeway Lane Closures	BioTechnology	170,993*
3-22	Guidelines for Design and Operation of Ramp Control Systems	Stanford Res Inst	199,030*
3-22A	Guidelines for Design and Operation of Ramp Control Systems	Texas A & M	249,538*
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	308,779*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
2/1/64	5/31/66	Completed—Report included in NCHRP Report 111	2-7
5/1/64	8/31/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	2-8
11/8/65	1/31/68	Completed—Published as NCHRP Report 75	2-9
11/1/66	4/30/68	Completed—Published as NCHRP Report 80	2-10
1/1/67	7/31/70	Completed—Published as NCHRP Report 122	2-11
4/1/74	10/31/75	Completed—Report not published	2-12
10/11/76	5/31/77	Completed—Report published by AASHTO	2-12
7/18/83	3/31/85	Completed—Report in editorial and publication process	2-13
1/1/86	7/31/87	Research to begin January 1, 1986	2-14
24 months		Contract pending	2-15
2/15/63	2/29/64	Completed—Report included in Phase II report	3-1
7/2/64	2/28/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-1
2/15/63	4/30/66	Completed—Published as NCHRP Reports 9, 28, 29	3-2
2/15/63	11/30/65	Completed—Published as NCHRP Report 51	3-3
3/1/63	3/31/65	Completed—Published as NCHRP Report 6	3-4
7/1/65	12/15/66	Completed—Published as NCHRP Report 40	3-4
3/1/63	12/31/65	Completed—Published as NCHRP Reports 3, 32	3-5
7/1/66	7/31/67	Completed—Published as NCHRP Report 73	3-5
8/1/68	12/31/69	Completed—Published as NCHRP Report 124	3-5
4/1/63	8/15/66	Completed—Published as NCHRP Reports 11, 41	3-6
2/1/64	4/30/67	Completed—Published as NCHRP Report 78	3-7
10/14/68	1/15/70	Completed—Published as NCHRP Report 117	3-7
4/1/71	6/30/72	Completed—Published as NCHRP Report 144	3-7
9/1/72	11/30/74	Completed—Published as NCHRP Reports 173, 174	3-7
12/1/63	12/31/64	Completed—Report included iu NCHRP Report 50	3-8
4/1/65	1/6/67	Completed—Total project published as NCHRP Report 50	3-8
10/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10
9/1/66	9/30/68	Completed—Published as NCHRP Report 110	3-11
10/1/66	12/31/67	Completed—Report included in NCHRP Report 123	3-12
4/1/68	12/1/69	Completed—Report included in NCHRP Report 123	3-12
3/29/71	12/11/72	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-12
9/1/67	11/30/69	Completed—Published as NCHRP Report 93	3-13
10/1/67	1/10/70	Completed—Published as NCHRP Report 113	3-14
10/1/69	12/31/73	Completed—Published as NCHRP Report 159	3-15
11/1/69	4/30/71	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-16
5/1/72	10/31/73	Completed—Published as NCHRP Report 175	3-16
1/1/71	11/30/72	Completed—Published as NCHRP Report 145	3-17
7/15/71	5/15/74	Completed—Report included in Phase II report	3-18(1)
4/15/75	6/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-18(1)
9/1/71	6/30/75	Completed—Published as NCHRP Report 194	3-18(2)
5/1/75	4/15/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-18(3)
7/21/77	11/20/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-18(4)
9/1/71	8/31/74	Completed—Published as NCHRP Report 185	3-19
9/1/72	4/15/74	Completed—Report included in Phase II report	3-20
11/1/74	12/31/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-20
6/23/80	7/31/82	Completed—Published as NCHRP Report 249	3-20A
4/1/74	1/31/76	Completed—Rep. not publ.; for avail., see project writeup iu latest Sum. of Prog.	3-21
12/1/79	8/31/81	Completed—Published as NCHRP Report 235	3-21(2)
4/15/74	12/31/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-22
2/1/77	3/31/81	Completed—Published as NCHRP Report 232	3-22A
4/8/74	7/28/77	Completed—Rep. not publ.; for avail., see project writeup iu latest Sum. of Prog.	3-23

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA THREE (*Continued*)		
3-24	Determine the Luminous Requirements for Retroreflective Highway Signing	U of Michigan	100,000*
3-25	Cost and Safety Effectiveness of Highway Design Elements	Jorgensen Assoc	260,576*
3-26	Investigation of Selected Noise Barrier Acoustical Parameters	Penn State U	224,494*
3-27	Guidelines for Selecting Traffic Signal Control at Individual Intersections	Voorhees & Assoc	150,000*
3-28	Development of an Improved Highway Capacity Manual	JHK & Assoc	161,000*
3-28A	Two-Lane, Two-Way Rural Highway Capacity	Texas A & M	157,492*
3-28B	New Highway Capacity Manual	Poly Inst of NY	283,440
3-28(2)	Urban Signalized Intersection Capacity	JHK & Assoc	331,000*
3-29	Traffic Signal Display Complexity	Systems Tech Inc	199,628
3-30	Intersection Channelization	Jack Leisch Assoc	130,000
3-31	Guidelines for Evaluating Alternatives for Replacing a Grade-Separated Rail/Highway Crossing	Ernst & Whinney	200,000
3-32	Temporary Pavement Marking for Work Zones	Texas A & M	150,000
3-33	Capacity and Level-of-Service Procedures for Multilane Rural and Snburban Highways	JHK & Assoc	400,000
3-34	Feasibility of a National Heavy-Vehicle Monitoring System	Arthur D. Little	399,985
3-35	Speed-Change Lanes	JHK & Assoc	250,000
	AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS		
4-1	Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents	U of Illinois	114,991*
4-2	A Stndy of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines	Purdue U	63,990*
4-3(1)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	V P I	20,000* 23,337*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	56,457* 49,756*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	14,790*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	64,105*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	25,000*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	P C A	100,000* 50,000*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	V P I	55,254*
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	95,248*
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	190,177* 70,860*
4-8(4)	Predicting Moisture-Induced Damage to Asphaltic Concrete—10-year Field Evaluation	U of Idaho	25,000
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah DOT	93,494*
4-9	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah DOT	144,837*
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	50,000*
4-10A	Waste Materials as Potential Replacements for Highway Aggregates	Valley Forge Lab	53,663*
4-11	Buried Plastic Pipe for Drainage of Transportation Facilities	Simpson Gumpertz	200,000*
4-12	Upgrading of Poor or Marginal Aggregates for PCC and Bituminous Pavements	Penn State U	149,941*
4-13	Temporary Pavement Marking Systems	Sw Research Inst	49,500*
4-13A	Temporary Pavement Marking Paint Systems	Georgia Tech	69,971*
4-14	Coating Systems for Painting Old and New Structural Steel	Georgia Tech	198,302*
4-15	Corrosion Protection of Prestressing Systems in Concrete Bridges	Wiss, Janney, Elstner	250,000
4-16	Cost and Service Life of Pavement Markings	Penn State U	200,000
4-17	Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA)	U of Washington	199,943
	AREA FIVE: TRAFFIC—ILLUMINATION AND VISIBILITY		
5-2(1)	Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents	Yale University	124,319* 21,530*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	81,187*
5-2(3)	Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	37,460*
5-3	Visnal Information Needed by the Driver at Night	Ohio State U	100,940*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
9/1/74	4/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-24
7/15/75	4/16/78	Completed—Published as NCHRP Report 197	3-25
12/1/76	2/28/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-26
11/15/76	7/31/79	Completed—Published as NCHRP Report 233	3-27
12/15/77	8/15/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-28
5/1/80	2/28/83	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-28A
7/1/82	3/31/85	Completed—Pnblished as Highway Capacity Manual (TRB Special Report 209)	3-28B
10/1/79	8/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	3-28(2)
7/1/83	12/30/85	Research in progress	3-29
7/1/83	5/15/85	Completed—Published as NCHRP Report 279	3-30
9/4/84	3/3/86	Research in progress	3-31
5/1/85	10/31/86	Research in progress	3-32
6/1/85	7/31/88	Research in progress	3-33
11/1/85	10/31/87	Research in progress	3-34
30 months		Contract pending	3-35
6/1/63	10/31/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-1
2/15/63	11/30/66	Completed—Pnblished as NCHRP Report 98	4-2
3/1/63	9/30/64	Completed—Published as NCHRP Report 12	4-3(1)
7/1/65	3/31/67	Completed—Published as NCHRP Report 65	4-3(1)
3/25/63	1/31/65	Completed—Published as HRB Special Report 80 and NCHRP Report 15	4-3(2)
7/1/65	8/3/67	Completed—Published as NCHRP Report 66	4-3(2)
3/1/63	4/15/64	Completed—Published as NCHRP Report 8	4-4
2/15/63	8/31/65	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-5
3/1/65	11/30/66	Completed—Published as NCHRP Reports 74, 74A, 74B	4-6
10/1/67	2/28/70	Completed—Report included in NCHRP Report 164	4-7
2/1/71	8/31/73	Completed—Report included in NCHRP Report 164	4-7
1/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
4/1/71	6/30/73	Completed—Published as NCHRP Report 172	4-8(2)
9/1/71	3/31/74	Completed—Published as NCHRP Report 192	4-8(3)
8/1/75	1/31/82	Completed—Published as NCHRP Report 246	4-8(3)
6/1/85	11/30/86	Research in progress	4-8(4)
10/1/68	6/30/71	Completed—Report included in Phase II report	4-9
10/1/72	12/31/79	Completed—Rep. not publ.; for avail., see project writenp in latest Sum. of Prog.	4-9
10/15/69	3/31/71	Completed—Published as NCHRP Report 135	4-10
9/1/72	11/30/73	Completed—Published as NCHRP Report 166	4-10A
9/16/74	1/26/79	Completed—Published as NCHRP Report 225	4-11
12/1/76	5/31/79	Completed—Published as NCHRP Report 207	4-12
11/1/76	2/28/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-13
4/1/78	9/30/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	4-13A
1/1/78	12/31/81	Completed—Rep. not publ.; for avail, see project writeup in latest Sum. of Prog.	4-14
7/1/82	11/30/85	Agency interim report available for loan.	4-15
10/1/84	9/30/88	Research in progress	4-16
1/7/85	8/6/87	Research in progress	4-17
2/15/63	5/31/66	Completed—Report included in NCHRP Report 60	5-2(1)
2/1/67	7/31/67	Completed—Report included in NCHRP Report 60	5-2(1)
2/15/63	8/31/65	Completed—Report included in NCHRP Report 60	5-2(2)
2/20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
9/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA FIVE (*Continued*)		
5-4	Economic Stndy of Roadway Lighting	Franklin Inst	19,412*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	50,000*
			100,000*
5-5A	Development of Optimum Specifications for Glass Beads in Pavement Markings	Penn State U	99,350*
5-5B	Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing Is Prevalent	Texas A & M	200,000*
5-6	Highway Fog	Cornell Aero Lab	99,955*
5-6A	Highway Fog	Sperry Rand	93,540*
5-7	Roadway Delineation Systems	Penn State U	469,526*
5-8	Warrants for Highway Lighting	Texas A & M	198,875*
5-9	Partial Lighting of Interchanges	KETRON, Inc.	199,999*
	AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL		
6-1	Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles	IIT Research Inst	40,000*
6-2	Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures	Jorgensen & Assoc	25,000*
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Mem Inst	58,557*
6-4	Evalnation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Mem Inst	39,330*
6-5	Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents	U of Illinois	72,500*
6-6	To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete	Ohio State U	69,393*
6-7	Estimation of Disintegration in Concrete Structures	Geotechnics	8,547*
6-7A	Estimation of Disintegration in Concrete Structures	IIT Research Inst	44,614*
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Tallamy Assoc	25,000*
6-9	Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks	U of Illinois	200,000*
6-10	Develop Improved Snow Removal and Ice Control Techniques at Interchanges	Tallamy Assoc	95,000*
6-11	Economic Evaluation of the Effects of Ice and Frost on Bridge Decks	Midwest Res Inst	50,000*
			50,000*
	AREA SEVEN: TRAFFIC—TRAFFIC PLANNING		
7-1	The Influence of Land Use on Urban Travel Patterns	Louis E. Keefer	62,674*
			66,894*
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	24,652*
			24,844*
7-3	Weighing Vehicles in Motion	Franklin Inst	73,391*
7-4	Factors and Trends in Trip Lengths	Voorhees & Assoc	89,250*
			61,730*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Yale University	99,675*
7-6	Multiple Use of Lands Within Highway Rights-of-Way	Barton-Aschman	24,220*
7-7	Motorists' Needs and Services on Interstate Highways	Airborne Instr	99,267*
7-8	User Cost and Related Consequences of Alternative Levels of Highway Service	Stanford Res Inst	99,070*
7-9	Development of Models for Predicting Weekend Recreational Traffic	Midwest Res Inst	74,983*
7-10	Peak-Period Traffic Congestion	Remak/Rosenbloom	49,624*
7-10(2)	The Institutional Aspects of Implementing Congestion-Reducing Techniques	Remak/Rosenbloom	74,703*
7-11	Low-Cost TSM Projects—Simplified Procedures for Evaluation and Setting Priorities	Multiplications Inc	199,988*
7-11A	Low-Cost TSM Projects—Simplified Procedures for Evaluation, Phase II	Texas A & M	150,000
	AREA EIGHT: TRANSPORTATION PLANNING—FORECASTING		
8-1	Social and Economic Factors Affecting Travel	Vogt, Ivers	94,558*
8-2	Factors Influencing Modal Trip Assignment	IIT Research Inst	298,033*
8-3	Individual Preferences for Various Means of Transportation	U of Penn	63,282*
8-4	Criteria for Evaluating Alternative Transportation Plans	Northwestern U	89,900*
8-4A	Criteria for Evaluating Alternative Transportation Plans	U of Illinois	5,000*
8-5	Transportation Aspects of Land-Use Controls	Victor Gruen	25,967*
			99,571*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
7/20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
3/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
7/15/67	9/15/69	Completed—Published as NCHRP Report 85	5-5
5/1/71	6/30/73	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	5-5A
9/1/71	12/31/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	5-5B
10/2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6
9/1/70	5/31/73	Completed—Published as NCHRP Report 171	5-6A
10/1/68	6/30/71	Completed—Published as NCHRP Report 130	5-7
3/16/70	2/15/73	Completed—Published as NCHRP Report 152	5-8
12/1/80	1/31/83	Completed—Published as NCHRP Report 256	5-9
2/15/63	9/30/64	Completed—Published as NCHRP Report 19	6-1
2/15/63	2/29/64	Completed—Published as NCHRP Report 4	6-2
3/1/63	2/28/65	Completed—Published as NCHRP Report 16	6-3
3/1/63	4/30/65	Completed—Published as NCHRP Report 23	6-4
3/1/63	8/31/65	Completed—Published as NCHRP Report 27	6-5
3/1/63	2/28/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	6-6
3/1/63	8/31/64	Contract terminated—no report; research resumed under Project 6-7A	6-7
2/1/65	7/31/66	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	6-7A
2/15/63	2/29/64	Completed—Published as NCHRP Report 1	6-8
1/1/65	6/15/68	Completed—Published as NCHRP Report 101	6-9
9/1/67	9/30/70	Completed—Published as NCHRP Report 127	6-10
9/1/70	11/30/71	Completed—Report included in Phase II report	6-11
9/12/72	9/11/74	Completed—Published as NCHRP Report 182	6-11
2/1/64	1/31/66	Completed—Published as NCHRP Report 24	7-1
4/1/66	9/30/67	Completed—Published as NCHRP Report 62	7-1
2/1/64	3/15/65	Completed—Report included in NCHRP Report 44	7-2
5/1/65	5/31/66	Completed—Total project published as NCHRP Report 44	7-2
2/1/64	8/31/67	Completed—Published as NCHRP Report 71	7-3
2/1/64	10/31/66	Completed—Published as NCHRP Report 48	7-4
10/23/67	1/10/69	Completed—Published as NCHRP Report 89	7-4
2/1/64	11/30/66	Completed—Published as NCHRP Report 58	7-5
2/1/66	2/28/67	Completed—Published as NCHRP Report 53	7-6
1/1/66	12/31/67	Completed—Published as NCHRP Report 64	7-7
9/1/70	4/15/72	Completed—Published as NCHRP Report 133	7-8
9/1/72	5/15/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	7-9
4/1/74	3/31/75	Completed—Published as NCHRP Report 169	7-10
4/1/75	11/30/78	Completed—Published as NCHRP Report 205	7-10(2)
4/6/81	11/30/83	Completed—Published as NCHRP Report 263	7-11
3/4/85	3/3/86	Research in progress	7-11A
2/1/64	9/23/66	Completed—Published as NCHRP Report 70	8-1
2/1/64	8/31/66	Completed—Published as NCHRP Report 57	8-2
2/1/64	3/31/65	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-3
2/1/65	8/1/67	Completed—Report included in NCHRP Report 96	8-4
10/14/68	1/10/69	Completed—Published as NCHRP Report 96	8-4A
4/1/65	5/31/66	Completed—Published as NCHRP Report 31	8-5
8/7/67	1/15/70	Completed—Published as NCHRP Report 121	8-5

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA EIGHT (*Continued*)		
8-6	Individual Preferences for Alternative Dwelling Types and Environments	U of N Carolina	99,897*
8-7	Evalnation of Data Requirements and Collection Techniques for Transportation Planning	Creighton-Hamburg	190,000*
8-7A	Data Requirements and Transportation Planning Procedures in Small Urban Areas	U of Tennessee	98,005*
8-8(1)	The Impact of Highways upon Environmental Values (Stndy Design)	M I T	29,654*
8-8(2)	The Impact of Highways upon Environmental Values (Study Design)	Daniel, Mann et al	28,950*
8-8(3)	The Impact of Highways upon Environmental Values	M I T	470,000*
8-9	Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems	Creighton-Hamburg	100,000*
8-10	Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities	Wilbur Smith	149,907*
8-11	Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility	DACP, Inc	364,363*
8-12	Travel Estimation Procedures for Quick Response to Urban Policy Issues	Metro Wash COG	39,895*
8-12A	Travel Estimation Procedures for Quick Response to Urban Policy Issues	Comsis Corp	239,331*
8-13	Disaggregate Travel Demand Models	Chas River Assoc	100,000*
8-13(2)	Disaggregate Travel Demand Models	Chas River Assoc	200,000*
8-14	New Approaches to Understanding Travel Behavior	Boston College	149,860*
8-14A	New Approaches to Understanding Travel Behavior: Phase II	Chas River Assoc	221,250*
8-15	State and Regional Transportation Impact Identification and Measurement	Bigelow-Crain	80,000*
8-15A	Economic Impacts of State Transportation Policies and Programs	Reg Sc Res Inst	117,852*
8-16	Guidelines for Public Transportation Levels of Service and Evaluation	U of Tennessee	489,952*
8-17	Freight Data Requirements for Statewide Transportation Systems Planning	R. Creighton Assoc	231,147*
8-18	Techniques for Evaluating Options in Statewide Transportation Planning/Programming	Plng Envr Int/AMV	300,393*
8-19	The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel	Cambridge Syst Inc	199,954*
8-20	Improved Methods for Vehicle Counting and Determining Vehicle-Miles of Travel	Hamburg & Assoc	200,000*
8-21	Guidelines for Use of Vanpools and Carpools as a Transportation System Management Technique	Geo Washington U	265,486*
8-22	Transportation Financing Within the Context of Energy Constraints	System Des Concepts	100,000*
8-23	Fuel Supply Limitations and Passenger Travel	Chas River Assoc	110,000*
8-24	Forecasting the Basic Inputs to Transportation Planning	Hamburg & Assoc	81,000*
8-25	Intercity Bus Transportation Planning	Peat, Marwick et al.	200,000*
8-26	Development of Highway Traffic Data for Project Planning and Design in Urbanized Areas	JHK & Assoc	100,000*
8-27	Cost-Effectiveness of Transportation Services for Handicapped Persons	U of Tennessee	199,543*
	AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS		
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000* 50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion	Montana College	101,903*
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Rensselaer	24,996*
9-4	Minimizing Premature Cracking of Asphaltic Concrete Pavements	Materials R & D	99,560*
9-4A	Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress	Woodward-Clyde	204,194*
9-5	Design of Emnlsified Asphalt Paving Mixtures	Asphalt Inst	155,199*
9-6(1)	Development of Asphalt Aggregate Mixtures Analysis System	—	350,000
	AREA TEN: MATERIALS AND CONSTRUCTION—SPECIFICATIONS, PROCEDURES, AND PRACTICES		
10-1	Development of Guidelines for Practical and Realistic Construction Specifications	Miller-Warden	25,000*
10-2	Evaluation of Construction Control Procedures	Miller-Warden	59,750*
10-2A	Evaluation of Construction Control Procedures	Materials R & D	70,945*
10-3	Effects of Different Methods of Stockpiling and Handling Aggregates	Miller-Warden	25,000* 30,000*
10-4	Rapid Test Methods for Field Control of Construction	Clemson U	30,000* 69,320*
10-5	Density and Moisture Content Measnrements by Nuclear Methods	Res Triangle Inst	28,801* 59,835*
10-5A	Optimization of Nuclear Density and Moisture Content Measurement Methods	N Carolina State U	51,214*
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	IIT Research Inst	108,821*
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	Ohio State U	24,310*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6
9/13/68	8/28/70	Completed—Published as NCHRP Report 120	8-7
6/1/73	6/14/75	Completed—Published as NCHRP Report 167	8-7A
9/16/68	3/14/69	Completed—Study design, not to be published	8-8(1)
9/9/68	3/7/69	Completed—Study design, not to be published	8-8(2)
9/15/69	7/31/74	Completed—Published as NCHRP Report 156	8-8(3)
9/1/71	1/31/73	Completed—Published as NCHRP Report 146	8-9
9/1/71	7/31/73	Completed—Published as NCHRP Reports 143 and 155	8-10
9/16/74	11/30/79	Completed—Phase I rep. not publ.; for avail., see project writeup iu latest Sum. of Prog. Phase II report published as NCHRP Reports 216 and 217	8-11 8-11
9/3/74	12/31/75	Completed—Results published in 8-12A report	8-12
11/1/75	10/31/78	Completed—Published as NCHRP Reports 186 and 187	8-12A
9/15/74	1/31/76	Completed—Phase I rep. not publ.; for avail., see project writeup iu latest Sum. of Prog.	8-13
5/1/76	12/31/80	Completed—Published as NCHRP Report 253	8-13(2)
1/1/75	4/30/77	Completed—Rep. uot publ.; for avail., see project writeup in latest Sum. of Prog.	8-14
1/1/78	6/30/82	Completed—Published as NCHRP Report 250	8-14A
9/1/74	5/31/76	Completed—Rep. uot publ.; for avail., see project writeup in latest Sum. of Prog.	8-15
10/1/77	3/31/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-15A
1/1/76	12/31/80	Completed—Publ. as NCHRP Rep. 208, 209, 210, 211, 212	8-16
7/15/75	2/15/77	Completed—Published as NCHRP Reports 177 and 178	8-17
9/1/75	6/30/78	Completed—Published as NCHRP Reports 179 and 199	8-18
12/1/76	11/30/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-19
1/2/78	7/31/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-20
3/1/79	6/30/81	Completed—Guidelines published as NCHRP Report 241; research rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-21
3/26/79	2/27/81	Completed—Published as NCHRP Report 231	8-22
4/2/79	9/1/80	Completed—Published as NCHRP Report 229	8-23
1/21/80	4/30/82	Completed—Published as NCHRP Report 266	8-24
4/1/80	1/31/82	Completed—Rep. not publ.; for avail., see project writeup iu latest Sum. of Prog.	8-25
5/15/81	12/31/82	Completed—Published as NCHRP Report 255	8-26
9/1/81	4/30/83	Completed—Published as NCHRP Reports 261 and 262	8-27
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
11/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	9-1
1/1/65	10/31/67	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
11/1/71	6/30/73	Completed—Published as NCHRP Report 195	9-4
9/15/75	11/1/78	Completed—Published as NCHRP Report 213	9-4A
4/1/80	6/30/84	Completed—Published as NCHRP Report 259	9-5
—	—	In developmental stage	9-6(1)
11/15/63	11/14/64	Completed—Published as NCHRP Report 17	10-1
11/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
7/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
10/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
10/15/64	10/16/65	Completed—Published as NCHRP Report 46	10-3
2/1/64	2/28/65	Completed—Report included in NCHRP Report 103	10-4
5/1/65	2/28/67	Completed—Published as NCHRP Report 103	10-4
1/15/64	1/31/65	Completed—Published as NCHRP Report 14	10-5
4/1/65	10/7/66	Completed—Published as NCHRP Report 43	10-5
2/1/68	1/31/70	Completed—Published as NCHRP Report 125	10-5A
2/1/64	10/31/66	Completed—Published as NCHRP Report 52	10-6
2/1/64	3/31/65	Completed—Published as NCHRP Report 25	10-7

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TEN (*Continued*)		
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	Pa Dept of Transp	151,982*
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	50,000*
10-10	Acceptance Criteria for Electroslag Weldments in Bridges	US Steel	300,000*
10-11	Development of a Performance Specification for Bridge Deck Joint-Sealing Systems	Howard, Needles et al	29,996*
10-12	Acceptance of Aggregates Used in Bituminous Paving Mixtures	Texas A & M	174,411*
10-13	Ultrasonic Measurement of Weld Flaw Size	The Welding Inst	126,000* 250,000
10-14	Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques	Georgia Tech	99,850*
10-15	Structural Strength Evaluation of Existing Reinforced Concrete Bridges	Engrg Comp Corp	125,000* 100,000
10-16	Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline	Byrd, Tallamy et al	150,000*
10-17	Use of Antistripping Additives in Asphaltic Concrete Mixtures	David G. Tunnicliff	349,809
10-18	Specifying and Obtaining Entrained Air in Concrete	Const. Tech Lab/PCA	73,585*
10-19	Adding Dust Collector Fines to Asphalt Paving Mixtures	Penn State U	49,926*
10-20	Elastomeric Bearings Design, Construction, and Materials	U of Washington	74,715* 150,000
10-21	Performance of Bridge Deck Concrete Subjected to Traffic-Induced Vibrations During Placement	TRB	25,000
10-22	The Performance of Weathering Steel in Bridges	Sheladia Assoc	74,963 99,998
10-23	Removal of Lead-Based Bridge Paints	Midwest Res Inst	81,118*
10-24	Rapid Replacement of PCC Pavement Segments	ARE, Inc.	240,000
10-25	Measurement of Cement and Water Content of Fresh Concrete	USACE Wtwys Exp Sta	149,995
10-25A	Instantaneous Determination of Water-Cement Ratio in Fresh Concrete	Wiss, Janney, Elstner	300,000
10-26	Data Bases for Performance-Related Specifications for Highway Construction	ARE Inc.	60,000*
10-26A	Performance-Related Specifications for Hot Mix Asphaltic Concrete	Penn State U	250,000
10-27	Determination of Asphaltic Concrete Pavement Structnral Properties by Nondestructive Testing	Texas A & M	200,000
10-28	A Method to Determine Deteriorated Areas in Portland Cement Concrete Pavements	Gulf Applied Res	199,784
10-29	Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders	U of Texas	240,000
10-30(1)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	U of Manchester	25,000
10-30(2)	Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables	SW Research Inst	25,000
10-31	Acceptance Criteria for Steel Bridge Welds	Matls Res Lab Inc	348,350
10-32	Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures	Const Tech Lab/PCA	100,000
10-33	Potential Benefits of Geosynthetics in Flexible Pavement Systems	Georgia Tech Res	100,000
10-34	Transient Protection, Grounding and Shielding of Electronic Traffic Control Equipment	Georgia Tech Res	180,000
	AREA ELEVEN: ADMINISTRATION—LAW		
11-1	Rnles of Compensability and Valuation in Highway Land Acquisition	U of Wisconsin	84,840*
11-1(1)	Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation	Real Estate Res	5,000*
11-1(2)	Recognition of Benefits to Remainder Property in Highway Valuation	Montano & Assoc	5,000*
11-1(3)	Taxation Aspects of Right-of-Way Acquisition	U of Tulsa	2,250*
11-1(4)	Compensation in the Nature of Additives to Market Value	U of Oklahoma	2,500*
11-1(5)	Rules of Discovery and Disclosure in Highway Condemnation Proceedings	Long, Mikkelborg	2,500*
11-1(6)	Valuation and Condemnation Problems of Selected Special Purpose Properties	Edward E. Level	7,500*
11-1(7)	Valuation and Compensability of Noise, Pollution, and Other Environmental Factors	U of Oklahoma	2,500*
11-1(8)	Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides	Harrison Lewis	7,500*
11-1(9)	Valuation and Condemnation Problems Involving Trade Fixtures	Edward L. Snitzer	5,000*
11-1(10)	Compensability and Valuation Aspects of Residential Displacement in Highway Programs	Ross, Hardies et al	5,000*
11-1(11)	Valuation Elements of Joint Development Projects, Including Air Rights	Real Estate Res	5,000*
11-2	Theory and Practice in Inverse Condemnation	Reg & Urban Plan	15,000*
11-3	Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements	Sutte, Jr. & Assoc	25,000*
11-3(1)	Public Control of Roadside Advertising Signs for Highway Beautification	Sutte, Jr. & Assoc	20,000*
11-3(2)	Public Control of Junkyards for Highway Beautification	Real Estate Res	13,300*
11-4	Elimination of Wide Divergence in Right-of-Way Valuation	Am Inst Rl Est App	24,959*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
3/2/70	7/31/73	Completed—Published as NCHRP Report 168	10-8
11/1/69	2/28/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	10-9
5/1/74	9/30/78	Completed—Published as NCHRP Report 201	10-10
12/1/76	4/30/78	Completed—Published as NCHRP Report 204	10-11
9/1/77	6/30/81	Completed—Rep. not pnbl.; for avail., see project writeup in latest Sum. of Prog.	10-12
7/1/79	10/31/81	Completed—Published as NCHRP Report 242	10-13
10/1/82	3/31/85	Report in review stage	10-13
4/2/79	5/1/81	Completed—Published as NCHRP Report 237	10-14
4/1/80	9/30/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	10-15
4/1/84	9/30/85	Report in review stage	10-15
2/16/81	12/1/82	Completed—Published as NCHRP Report 251	10-16
3/1/81	11/1/87	Research in progress; laboratory phase published as NCHRP Report 274	10-17
5/4/81	6/1/83	Completed—Published as NCHRP Report 258	10-18
3/1/81	11/30/82	Completed—Published as NCHRP Report 252	10-19
2/1/81	6/30/82	Completed—Published as NCHRP Report 248	10-20
6/1/83	5/31/86	Research in progress	10-20
2/1/80	9/30/81	Completed—Pnblished as NCHRP Synthesis 86	10-21
4/1/82	2/29/84	Completed—Published as NCHRP Report 272	10-22
7/23/84	4/22/86	Research in progress	10-22
7/1/82	6/30/83	Completed—Published as NCHRP Report 265	10-23
3/15/82	3/14/88	Research in progress	10-24
10/13/83	11/30/85	Report in review stage	10-25
6/1/85	8/31/87	Research in progress	10-25A
6/15/83	9/14/84	Completed—Rep. not publ., for avail., see project writeup in latest Sum. of Prog.	10-26
29 months		Contract pending	10-26A
9/17/84	3/16/86	Research in progress	10-27
11/1/85	10/31/87	Research in progress	10-28
36 months		Contract pending	10-29
7 months		Contract pending	10-30(1)
7 months		Contract pending	10-30(2)
36 months		Contract pending	10-31
1/6/86	7/5/87	Research to begin in Jannary 6, 1986	10-32
1/6/86	1/5/88	Research to begin in January 6, 1986	10-33
22 months		Contract pending	10-34
1/1/65	4/30/67	Completed—Published as NCHRP Report 104	11-1
9/2/68	2/28/69	Completed—Published as NCHRP Report 114	11-1(1)
10/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
9/16/68	4/30/69	No final report—Project terminated	11-1(3)
12/1/68	5/31/69	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-1(4)
9/15/68	4/14/69	Completed—Published as NCHRP Report 87	11-1(5)
9/2/68	11/28/69	Completed—Published as NCHRP Report 92	11-1(6)
10/1/68	3/31/69	Completed—Rep. not pnbl.; for avail., see project writeup in latest Sum. of Prog.	11-1(7)
10/15/68	1/15/70	Completed—Published as NCHRP Report 134	11-1(8)
3/15/69	12/1/69	Completed—Published as NCHRP Report 94	11-1(9)
3/15/69	9/15/69	Completed—Published as NCHRP Report 107	11-1(10)
2/24/69	8/25/69	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-1(11)
2/1/65	6/30/66	Completed—Published as NCHRP Report 72	11-2
11/1/66	12/15/67	Completed—Published as NCHRP Report 56	11-3
10/1/68	12/31/69	Completed—Published as NCHRP Report 119	11-3(1)
9/2/68	2/28/70	Completed—Published as NCHRP Report 112	11-3(2)
7/1/69	2/28/71	Completed—Published as NCHRP Report 126	11-4

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA ELEVEN (*Continued*)		
11-5	Valuation of Air Space	Daniel, Mann et al	49,800*
11-6	Valuation and Compensability of Noise Pollution	Jack Faucett Assoc	94,744*
	AREA TWELVE: DESIGN—BRIDGES		
12-1	Deformation of Steel Beams Related to Permitted Highway Bridge Overloads	U of Missouri	50,000*
12-2	Distribution of Wheel Loads on Highway Bridges	Iowa State U	79,512*
12-3	Development of Waterproof Roadway Joints for Bridges	Sw Research Inst	149,895*
12-4	Thermal Characteristics of Highway Bridges	Sw Research Inst	102,400*
12-5	Protection of Steel in Prestressed Concrete Bridges	U of Denver	173,255*
12-6	Prediction of Permanent Camber of Bridges	U of Missouri	82,253*
12-7	Effects of Weldments on Fatigue Strength of Steel Beams	Lehigh University	199,023* 200,000*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	28,793* 69,753*
12-9	Elastomeric Bearing Research	Battelle Mem Inst	84,800*
12-10	Analysis and Design of Bridge Bents	PCA	297,900*
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks	Materials R & D	206,025* 96,979*
12-12	Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings	US Steel	310,000*
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks	USS Eng & Consult	174,601*
12-13A	Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks	PCA	74,405*
12-14	Subcritical Crack Growth in Steel Bridge Members	US Steel	99,923*
12-15	Detection and Repair of Fatigue Cracking in Highway Bridges	Lehigh U	100,000*
12-15(2)	Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams	Lehigh U	150,000*
12-15(3)	Fatigue Behavior of Full-Scale Welded Bridge Attachments	Lehigh U	125,000*
12-15(4)	Steel Bridge Members Under Variable-Amplitnde, Long-Life Fatigue Loading	Lehigh U	150,000*
12-15(5)	Fatigue Behavior of Variable-Loaded Bridge Details Near the Fatigue Limit	Lehigh U	250,000
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbns	214,912*
12-17	Evaluation of Repair Techniques for Damaged Steel Bridge Members	Battelle Columbus	49,974*
12-17A	Guidelines for Evaluation and Repair of Damaged Steel Bridge Members	Shanafelt/Horn	99,950*
12-18	Development of an Integrated Bridge Design System	Multiplications Inc	224,985*
12-18A	Development of an Integrated Bridge Design System	Engrg Comp Corp	15,000
12-19	Cathodic Protection of Concrete Bridge Structures	Corrosion Eng & Res	250,000*
12-19A	Concrete Sealers for Protection of Bridge Structures	Wiss, Janney, Elstner	99,190*
12-19B	Cathodic Protection of Concrete Bridge Structnres	Wiss, Janney, Elstner	150,000
12-20	Bridges on Secondary Highways and Local Roads: Rehabilitation and Replacement	U of Virginia	119,923* 49,955*
12-21	Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members	G O Shanafelt Shanafelt/Horn	58,520* 129,934
12-22	Thermal Effects in Concrete Bridge Superstructures	Engrg Comp Corp	100,000
12-23	The Performance of Steel Grid Bridge Decks	—	100,000
12-24	Design of Multi-Beam Precast Bridge Superstructures	U of Washington	149,879
12-25	Fatigue and Fracture Evaluation for Rating Riveted Steel Bridges	Lehigh U	199,957
12-26	Distribution of Wheel Loads on Highway Bridges	Engrg Comp Corp	300,000
12-27	Welded Repair of Cracks in Steel Bridge Members	The Welding Inst	374,575
12-28(1)	Load Capacity Evaluation of Existing Bridges	Case Western Res U	225,000
12-28(2)	Bridge Management Systems	ARE Inc	225,000
12-28(3)	Fatigue Evaluation Procednres for Steel Bridges	Case Western Res U	200,000
12-28(4)	Methods of Strengthening Existing Highway Bridges	Iowa State U	149,986
12-28(5)	Standard Methodology for Conducting Condition Surveys of Concrete Bridge Components	New Mexico State U	98,338
12-28(6)	Distortion-Induced Fatigue Cracking in Steel Bridges	Lehigh U	250,000
12-28(7)	Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges	Modjeski and Masters	300,000
12-28(8)	Improving Bridge Load Capacity Estimates by Correlation with Test Data	U of Tennessee	199,994
12-28(9)	Methods of Flaw Detection in Concrete Bridge Components	—	—
12-28(10)	Guidelines for Determining Redundancy in Steel Bridges	Lehigh U	300,000
12-29	Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous	Constr Tech Lab/PCA	241,993
12-30	Fatigue of Cables in Cable-Stayed Bridges	Freeman Fox Ltd	124,975

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
10/1/70	5/31/72	Completed—Published as NCHRP Report 142	11-5
4/1/74	7/31/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	11-6
2/1/65	6/30/67	Completed—Report included in Project 12-6 report	12-1
6/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
12/15/65	3/14/69	Completed—Report available only to sponsors	12-3
12/15/65	3/31/68	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-4
9/15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5
2/1/67	4/30/72	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-6
10/1/66	1/31/70	Completed—Published as NCHRP Report 102	12-7
7/1/70	12/31/72	Completed—Published as NCHRP Report 147	12-7
3/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
1/2/70	6/30/71	Completed—Published as NCHRP Report 149	12-8
9/1/67	1/31/70	Completed—Published as NCHRP Report 109	12-9
1/1/70	12/31/73	Completed—Published as NCHRP Report 163	12-10
8/1/70	3/31/73	Completed—Published as NCHRP Report 165	12-11
7/15/73	9/30/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-11
10/1/70	10/31/75	Completed—Published as NCHRP Report 188	12-12
10/1/72	7/31/74	Completed—Published as NCHRP Report 180	12-13
8/1/75	5/15/81	Completed—Published as NCHRP Report 234	12-13A
10/1/72	6/30/74	Completed—Published as NCHRP Report 181	12-14
10/1/72	4/30/75	Completed—Published as NCHRP Report 206	12-15
6/1/76	11/30/78	Completed—Published as NCHRP Report 206	12-15(2)
2/1/78	7/31/80	Completed—Published as NCHRP Report 227	12-15(3)
4/1/80	9/30/83	Completed—Published as NCHRP Report 267	12-15(4)
9/1/83	8/31/87	Research in progress	12-15(5)
9/1/74	11/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-16
11/15/76	4/30/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-17
10/1/81	5/31/84	Completed—Published as NCHRP Report 271	12-17A
9/6/77	12/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-18
2/1/84	1/31/85	Completed—Agency has uot submitted a final report	12-18A
1/1/78	12/31/80	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	12-19
8/1/79	12/1/81	Completed—Published as NCHRP Report 244	12-19A
11/1/82	4/30/85	Completed—Published as NCHRP Report 278	12-19B
3/1/78	2/29/80	Completed—Published as NCHRP Report 222	12-20
6/1/80	11/30/81	Completed—Published as NCHRP Report 243	12-20
4/15/79	9/14/80	Completed—Published as NCHRP Report 226	12-21
5/15/82	7/8/85	Completed—Published as NCHRP Report 280	12-21
10/1/81	1/31/84	Completed—Published as NCHRP Report 276	12-22
Project failed states' ballot and withdrawn from program			12-23
8/1/83	1/31/86	Report in review stage	12-24
9/1/84	3/31/87	Research iu progress	12-25
4/15/85	7/15/87	Research in progress	12-26
10/15/84	10/14/87	Research iu progress	12-27
9/1/85	8/31/87	Research in progress	12-28(1)
6/24/85	6/23/87	Research in progress	12-28(2)
7/1/85	6/30/87	Research iu progress	12-28(3)
7/1/85	12/31/86	Research in progress	12-28(4)
8/1/85	1/31/87	Research in progress	12-28(5)
10/1/85	9/30/88	Research in progress	12-28(6)
33 months		Contract pending	12-28(7)
24 months		Contract pending	12-28(8)
—		Postponed pending determination of scope of another project	12-28(9)
30 months		Contract pending	12-28(10)
8/26/85	11/25/87	Research in progress	12-29
21 months		In developmental stage	12-30

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWELVE (*Continued*)		
12-31	Study of Impact-Resistant Bridge Steels	—	—
12-32	Evaluation of Bridge Deck Protective Strategies	U of Washington	300,000
	AREA THIRTEEN: MAINTENANCE—EQUIPMENT		
13-1	Equipment Rental Rates	Ernst & Ernst	22,800*
	AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES		
14-1	Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements	Tallamy Assoc	205,128*
14-2	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000*
14-3	Improved Pavement-Shoulder Joint Design	Georgia Tech	100,838*
14-4	Reconditioning Heavy-Duty Freeways in Urban Areas	Texas A & M	99,665*
14-5	Maintenance Levels-of-Service Guidelines	Woodward-Clyde	204,200*
14-5(2)	Maintenance Levels-of-Service Guidelines	Woodward-Clyde	107,950*
14-6	Evaluating Deferred Maintenance Strategies	ARE Inc.	325,000
	AREA FIFTEEN: DESIGN—GENERAL DESIGN		
15-1	Guardrail Design	Cornell Aero Lab	19,723*
15-1(2)	Guardrail Performance and Design	Sw Research Inst	280,000* 100,000
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	97,300*
15-3	Rational Structural Analysis and Design of Pipe Culverts	Northwestern U	49,937*
15-4	Estimating Runoff Rates from Small Rural Watersheds	Travelers Res Cen	299,902*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Gen Mot Corp	135,000*
15-6	Development of Criteria for Safer Luminaire Supports	Texas A & M	147,254*
15-7	Flow Modifications by Storage Loss Through Flood Plain Encroachment	Dames & Moore	99,730*
15-8	Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics	U of Michigan	274,482*
15-9	Encasement of Pipelines Through Railroad and Highway Roadbeds	Byrd, Tallamy et al	30,000
15-10	Development of a Design/Graphics Interface System	Beilfuss & Assoc	500,000
	AREA SIXTEEN: DESIGN—ROADSIOE DEVELOPMENT		
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	V P I	217,300*
16-2	Evaluation of Research on Roadside Development	Western States	100,000*
16-3	Erosion Control During Highway Construction	Utah State U	179,224* 70,776*
	AREA SEVENTEEN: TRAFFIC—SAFETY		
17-1	Development of Improved Methods for Reduction of Traffic Accidents	Cornell Aero Lab	247,847*
17-2	Methods for Evaluating Highway Safety Improvements	ORI	29,973*
17-2A	Methods for Evaluating Highway Safety Improvements	Jorgensen & Assoc	98,403*
17-3	Application of Traffic Conflicts Analysis at Intersections	Midwest Res Inst	190,000*
17-4	Evaluation of Traffic Controls for Street and Highway Work Zones	BioTechnology	200,000*
17-4(2)	Evaluation of Traffic Cones and Tubes for Street and Highway Work Zones	BioTechnology	125,000*
17-5	Effectiveness of Clear Recovery Zones	Midwest Res Inst	200,000*
17-6	Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase I	BioTechnology	100,000
17-6A	Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase II	Transp Res Corp	225,000
17-7	Guidelines for Converting STOP TO YIELD Control at Intersections	Bellomo-McGee Inc	200,000

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
—		Postponed pending results of A1S1 study	12-31
36 months		Contract pending	12-32
2/1/65	1/31/66	Completed—Published as NCHRP Report 26	13-1
3/1/65	3/31/67	Completed—Published as NCHRP Report 42	14-1
10/1/70	3/31/73	Completed—Published as NCHRP Report 161	14-2
9/11/72	3/15/76	Completed—Published as NCHRP Report 202	14-3
4/15/74	3/24/76	Completed—Published as NCHRP Report 196	14-4
1/1/78	4/30/80	Completed—Published as NCHRP Report 223	14-5
9/15/81	8/31/84	Completed—Published as NCHRP Report 273	14-5(2)
6/1/82	12/31/85	Report in review stage	14-6
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	8/31/70	Completed—Published as NCHRP Reports 54, 115	15-1(2)
5/1/70	12/31/71	Completed—Published as NCHRP Reports 118, 129	15-1(2)
7/1/66	6/30/74	Completed—Ph. I rep. publ. as NCHRP Rep. 108	15-2
		Ph. II rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	15-2
10/1/67	12/31/68	Completed—Published as NCHRP Report 116	15-3
9/1/67	3/16/70	Completed—Published as NCHRP Report 136	15-4
8/15/67	1/10/69	Completed—Published as NCHRP Report 105	15-5
9/1/67	8/31/68	Completed—Published as NCHRP Report 77	15-6
5/1/80	1/31/82	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	15-7
5/1/82	5/31/84	Completed—Published as NCHRP Report 270	15-8
12 months		Contract pending	15-9
8/1/85	7/31/88	Research in progress	15-10
3/1/66	4/30/72	Completed—Published as NCHRP Reports 91 and 170	16-1
10/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
11/1/73	6/30/76	Completed—Rep. included in Phase II report	16-3
3/1/78	11/30/79	Completed—Published as NCHRP Reports 220, 221	16-3
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
1/10/72	6/20/72	Contract terminated—no report; research resumed under Project 17-2A	17-2
2/1/73	7/31/74	Completed—Published as NCHRP Report 162	17-2A
12/15/77	10/31/79	Completed—Published as NCHRP Report 219	17-3
1/2/78	6/30/79	Completed—Rep. included in NCHRP Report 236	17-4
4/23/80	9/30/81	Completed—Published as NCHRP Report 236	17-4(2)
4/1/80	4/30/82	Completed—Published as NCHRP Report 247	17-5
11/1/82	7/24/84	Completed—Research continued as Project 17-6A	17-6
10/15/84	4/15/86	Research in progress	17-6A
12/16/85	6/16/88	Research in progress	17-7

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS		
18-1	Revibration of Retarded Concrete for Continuous Bridge Decks	U of Illinois	103,895*
18-2	Use of Polymers in Highway Concrete	Lehigh U	300,000*
18-2(2)	Polymer Concrete in Highway Bridge Decks	Lehigh U	30,000*
18-2(3)	Long-Term Rehabilitation of Salt-Contaminated Bridge Decks	Lehigh U	199,900*
	AREA NINETEEN: ADMINISTRATION—FINANCE		
19-1	Budgeting for State Highway Departments	Ernst & Ernst	45,000*
19-2(1)	Develop Performance Bndgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Bndgeting System to Serve Highway Maintenance Management	Ernst & Ernst	6,000*
19-2(3)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	6,000*
19-2(4)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	220,000*
19-3	Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways	Wilbur Smith	96,728*
	AREA TWENTY: SPECIAL PROJECTS		
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy—Smith	98,760*
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	394,016* 200,540[a]
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,631* 20,000[b]
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Commnnication, and Control—Summary Reporting	Patrick J. Athol	31,116*
20-3C	Summary of the Lodge Freeway Research	Asriel Taragin	10,183*
20-3D	Summary of All Freeway Surveillance, Communication and Control Experience	Voorhees & Assoc	40,000*
20-4	Pnblic Preference for Fnture Individual Transportation	Chilton Research National Analysts	195,260* 83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	575,000[c]
20-6	Legal Problems Arising out of Highway Programs	TRB	200,000[c]
20-7	Research for AASHTO Standing Committee on Highways		
	Task 1: Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements	Texas A & M	32,837*
	Task 2: The Relation of Side Slope Design to Highway Safety	Texas A & M	104,088*
	Task 3: Development of an Effective Earth-Berm Vehicle Deflector	Texas A & M	33,973*
	Task 4: Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures	Texas A & M	112,702*
	Task 5: Effect of Curb Geometry and Location	Texas A & M	49,996*
	Task 6: Development of Impact Attenuators Utilizing Waste Materials	Texas A & M	74,852*
	Task 7: Safety at Narrow Bridge Sites	Texas A & M	100,000*
	Task 8: Energy and Transportation Systems	CalDOT	104,440*
	Task 9: Review of Highway Management Studies Co-Sponsored by AASHTO and HUFSAM	Mgmt & Trans Assoc	49,820*
	Task 10: Review of Vehicle Weight/Horsepower Ratio as Related to Passing-Lane Design Criteria	Penn State U	15,493*
	Task 11: Longitudinal Occnpancy of Freeways by Utilities	Byrd, Tallamy et al	50,000*
	Task 12: Guidelines for Citizen Participation in Transportation Planning	K. S. Hudson	15,500*
	Task 13: Guidelines for Safety Criteria for Low-Volume Roads	J. C. Glennon	33,226*
	Task 14: A Policy on Geometric Design of Highways and Streets	John F. Holman Co	98,563
	Task 15: Development of a Simplified Pavement Management System	ARE inc	103,600*
	Task 16: Regnlation of Movement of Hazardous Cargoes	D. M. Baldwin	7,341*
	Task 17: Evaluation of AASHO Road Test Satellite and Environment Studies	Texas A & M	94,402
	Task 18: Standard Specifications for Highway Bridges	Howard, Needles et al	113,000
	Task 19: Engineering Aspects of Highway Traffic Safety in an Age of Limited Resources	TRB	25,000*
	Task 20: Vehicle Acceleration and Deceleration Characteristics	U of Michigan	25,000
	Task 21: Need for Pavement Markings on Low-Volume Roads	J. C. Glennon	25,000*
	Task 22: Encasement of Pipelines Through Highway and Railroad Roadbeds	Byrd, Tallamy et al	20,000*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)		PROJECT NO.
9/1/67	12/1/69	Completed—Published as NCHRP Report 106		18-1
10/1/72	9/30/75	Completed—Published as NCHRP Report 190		18-2
1/1/78	3/15/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.		18-2(2)
5/1/80	4/29/83	Completed—Published as NCHRP Report 257		18-2(3)
9/5/67	9/4/68	Completed—Report not publ.; summarized in NCHRP Research Results Digest 20		19-1
9/2/68	10/31/68	Completed—working plan, not published		19-2(1)
9/2/68	10/31/68	Completed—working plan, not published		19-2(2)
9/2/68	10/31/68	Completed—Research continued as Project 19-2(4)		19-2(3)
2/1/69	11/30/71	Completed—Published as NCHRP Report 131		19-2(4)
9/15/70	6/14/72	Completed—Published as NCHRP Report 141		19-3
3/16/64	10/31/67	Completed—Informal publication only; service is operational		20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55		20-2
12/15/66	1/31/69	Completed—Results summarized in Project 20-3C report		20-3
1/1/67	12/31/68			20-3
11/20/68	5/31/71	Completed—Results summarized in Project 20-3C report		20-3A
1/1/69	12/31/69			20-3A
7/1/72	9/27/74	Project terminated uncompleted; no reports prepared		20-3B
11/15/75	7/15/76	Completed—Rep. uot publ.; for avail., see project writeup in latest Sum. of Prog.		20-3C
5/15/77	12/31/78	Completed—Spec. publ.; for avail., see project writeup in latest Sum. of Prog.		20-3D
5/2/67	1/21/69	Completed—Published as NCHRP Reports 49, 82		20-4
5/2/67	1/2/68	Completed—Published as NCHRP Reports 49, 82		20-4
12/15/67	[c]	Research in progress: Topic reports published as NCHRP Syntheses 1 through 117		20-5
11/1/68	[c]	Research in progress: Refer to Table III for publications		20-6
				20-7
12/2/68	3/31/72	Completed—Published as NCHRP Report 148	(Task 1)	20-7
12/2/68	1/31/74	Completed—Published as NCHRP Report 158	(Task 2)	20-7
12/2/68	3/3/71	Completed—Rep. not publ.; sum. in NCHRP Res. Results Digest 77	(Task 3)	20-7
12/2/68	7/15/71	Completed—Rep. not publ.; sum. in NCHRP Res. Results Digest 55	(Task 4)	20-7
11/1/71	10/31/72	Completed—Published as NCHRP Report 150	(Task 5)	20-7
11/1/71	1/2/74	Completed—Published as NCHRP Report 157	(Task 6)	20-7
7/2/73	6/3/75	Completed—Published as NCHRP Report 203	(Task 7)	20-7
12/1/75	10/1/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 8)	20-7
12/1/75	8/31/76	Completed—Report not publ.; available ouly to sponsors	(Task 9)	20-7
1/3/77	12/15/78	Completed—Report not publ.; available only to sponsors	(Task 10)	20-7
1/1/77	10/31/78	Completed—Report not publ.; available only to sponsors	(Task 11)	20-7
6/1/77	6/30/78	Completed—Report publ. by AASHTO	(Task 12)	20-7
7/1/77	9/30/78	Completed—Published as NCHRP Report 214	(Task 13)	20-7
4/3/78	4/30/84	Completed—Report published by AASHTO	(Task 14)	20-7
8/29/78	12/31/81	Completed—Phase I rep. publ. as NCHRP Report 215; Phase II rep. not publ., but available for loan	(Task 15)	20-7
9/4/79	5/31/80	Completed—Report not publ.; distributed to sponsors	(Task 16)	20-7
7/1/79	12/31/83	Completed—Report uot publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 17)	20-7
12/1/80	12/31/82	Completed—Report pnblished by AASHTO	(Task 18)	20-7
5/19/81	2/15/82	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 19)	20-7
—	—	Completed—Results published in NCHRP Report 270	(Task 20)	20-7
7/1/82	12/31/83	Completed—Report not publ.; for avail., see project writeup iu latest Sum. of Prog.	(Task 21)	20-7
3/1/82	11/30/82	Completed—Report uot publ.; for avail., scc project writeup in latest Sum. of Prog.	(Task 22)	20-7

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY (*Continued*)		
	Task 23: Contracting Practices and Payment Procedures	Bergstrahl-Shaw et al	80,340*
	Task 24: AASHTO Pavement Design Guide	McCullough/Finn	558,200
	Task 25: STRS Support Task	TRB	52,640
	Task 26: Research and Development Needs in Construction and Engineering Management	Bergstrahl-Shaw et al	25,000
	Task 27: Relationships Between Vehicle Configurations and Highway Design	TRB	50,000
	Task 28: AASHTO Guide for Design of Pavement Strnctures-Training Program	McCullough/Finn	100,000
20-8	Interactive Graphic Systems for Highway Design	Control Data	49,672*
20-9	Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation	RMC Res Corp	202,579*
20-10	The Benefits of Separating Pedestrians and Vehicles	Stanford Res Inst	100,000*
20-10(2)	The Benefits of Separating Pedestrians and Vehicles	SRI International	100,000*
20-11	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Poly Inst of NY	100,000*
20-11A	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Cornell U	27,212*
20-11B	Toward Environmental Benefit/Cost Analysis: Energy-Flow Analysis (Manual)	Cornell U	140,450*
20-11C	Toward Environmental Benefit/Cost Methodology: Energy-Flow Analysis (Study Design)	The Cannon Group	14,786*
20-12	Effects of Air Pollution Regulations on Highway Construction and Maintenance	Howard, Needles et al	80,446*
20-13	Beneficial Environmental Effects Associated with Freeway Construction	Penn State U	49,965*
20-14	Monitoring Carbon Monoxide Concentrations in Urban Areas	Technol Serv Corp	99,973*
20-14A	Statistical Analysis of Ozone Data for Transportation/Air Quality Planning	SRI International	193,907*
20-15	Ecological Effects of Highway Fills on Wetlands	U of Mass	152,085*
20-16	State Laws and Regulations on Truck Size, Weight, and Speed	R J Hansen Assoc	281,975*
20-17	Statewide Freight Demand Forecasting Procedures	Cambridge Syst Inc	73,151*
20-17A	Application of Statewide Freight Demand Forecasting Techniques	R. Creighton Assoc	193,500*
20-18	Evaluation of Highway Air Pollution Dispersion Models	SRI International	207,509*
20-19	Pedestrian Convenience and Safety on Suburban and Rural Highways	JHK & Assoc	160,000
20-20	SHRP Pre-Implementation Research	AASHTO	500,000
20-20(2)	SHRP Overview and Integration Planning	U of Maryland	90,000
20-20(3)	SHRP Detailed Planning for Research on Asphalt Properties	ARE Inc	100,000
20-20(5)	SHRP Detailed Planning for Research on Maintenance Effectiveness	Texas Res & Devel	80,000
20-20(6)	SHRP Detailed Planning for Research on Bridge Component Protection	David G Manning	80,000
20-20(7)	SHRP Detailed Planning for Research on Cement and Concrete	Const Tech Lab/PCA	75,000
20-20(8)	SHRP Detailed Planning for Research on Snow and Ice Removal	USA CRREL	73,781
20-21	Development of an Antomated Field Survey Data Collection System	ARE Inc/Cooper Tech	200,000
	AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION		
21-1	Instrumentation for Measurement of Moisture	Res Triangle Inst	35,027*
21-2	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	Sw Research Inst	64,976*
21-2(2)	Instrumentation for Moisture Measnrement—Bases, Subgrades, and Earth Materials (Sensor Development)	SUNY Buffalo	29,953*
21-2(3)	Instrnmentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation)	Sw Research Inst	154,452*
	AREA TWENTY-TWO: DESIGN—VEHICLE BARRIER SYSTEMS		
22-1	Concepts for Improved Traffic Barrier Systems	Walter W. White	25,000*
22-1A	Testing and Evaluation of Bridge Rail Concepts	Texas A & M	40,000*
22-2	Traffic Barrier Performance and Design	Sw Research Inst	125,000* 80,000*
22-2(2)	Multiple Service Level Highway Bridge Railings—Performance and Design Criteria	Sw Research Inst	195,000*
22-2(3)	Multiple Service Level Highway Bridge Railings—Selection Procedures	Sw Research Inst	200,000*
22-2(4)	Procedures for Testing Highway Appurtenances	Sw Research Inst	30,000*
22-3	Field Evaluation of Vehicle Barrier Systems	Calspan Corp	25,000*

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
7/26/82	4/17/84	Completed—Report not publ.; for avail., see project writeup in latest Sum. of Prog.	(Task 23) 20-7
5/15/83	8/31/85	Completed—Report to be published by AASHTO	(Task 24) 20-7
3/1/84	5/7/84	Completed—Report available only to sponsors	(Task 25) 20-7
5/20/85	2/19/86	Research in progress	(Task 26) 20-7
11/8/85	5/8/86	In developmental stage	(Task 27) 20-7
—	—	Research in progress	(Task 28) 20-7
9/1/70	7/31/71	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-8
8/1/72	12/17/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-9
8/26/74	4/30/76	Completed—Published as NCHRP Report 189	20-10
9/1/78	7/31/81	Completed—Published as NCHRP Report 240	20-10(2)
9/1/72	5/31/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-11
9/1/75	11/30/76	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-11A
1/24/77	5/4/79	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Digest 114	20-11B 20-11B
4/1/77	3/31/78	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	20-11C
4/1/74	7/31/75	Completed—Published as NCHRP Report 191	20-12
9/3/74	8/2/75	Completed—Published as NCHRP Report 193	20-13
10/1/76	3/31/78	Completed—Published as NCHRP Report 200	20-14
9/15/79	12/18/81	Completed—Published as NCHRP Report 238	20-14A
12/1/76	12/31/79	Completed—Published as NCHRP Reports 218A and 218B	20-15
10/11/76	9/1/78	Completed—Published as NCHRP Report 198	20-16
4/1/79	7/31/80	Completed—Rep. not publ.; for avail., see proj. writeup in latest Sum. of Prog.	20-17
6/1/81	1/31/84	Completed—Published as NCHRP Report 260	20-17A
3/15/79	2/28/82	Completed—Published as NCHRP Report 245	20-18
5/1/85	7/31/86	Research in progress	20-19
10/1/84	9/30/86	Research in progress	20-20
3/15/85	1/31/86	Research in progress	20-20(2)
3/15/85	1/31/86	Research in progress	20-20(3)
3/15/85	1/31/86	Research in progress	20-20(5)
3/15/85	1/31/86	Research in progress	20-20(6)
3/15/85	1/31/86	Research iu progress	20-20(7)
4/12/85	2/26/86	Research in progress	20-20(8)
1/6/86	4/5/87	Research in progress	20-21
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Completed—Report uot publ.; included in Project 21-2(3) report	21-2
4/1/72	9/30/73	Completed—Report not publ.; included in Project 21-2(3) report	21-2(2)
9/3/74	12/31/79	Completed—Report not publ.; agency rep. avail. for loan	21-2(3)
10/1/70	12/31/71	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	22-1
3/1/74	5/30/75	Completed—Rep. uot publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Dig. 81	22-1A 22-1A
1/1/72	9/30/73	Completed—Phase I and Phase II (Task 1) reports not published; for avail., see project writeup in	22-2
10/1/73	3/31/75	latest Sum. of Prog.; sum. in NCHRP Res. Results Digests 84 and 102; Task 2 rep. publ. as NCHRP Rep. 153	22-2 22-2
8/1/76	4/30/79	Completed—Agency reps. on Ph. I and Ph. II avail. for loan	22-2(2)
1/1/79	5/31/81	Completed—Published as NCHRP Report 239	22-2(3)
5/1/79	2/28/81	Completed—Published as NCHRP Report 230	22-2(4)
1/1/74	2/15/75	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Dig. 76	22-3 22-3

TABLE 5 (*Continued*)

PROJECT NO	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY-TWO (*Continued*)		
22-3A	Field Evaluation of Vehicle Barrier Systems	Arthur L. Elliott	10,000*
22-4	Performance of Longitudinal Traffic Barriers	Southwest Res Inst	500,000
22-5	Develop Performance Standards and Hardware for Low Service Level Guardrail Systems	Southwest Res Inst	200,000
22-6	Roadside Safety Design for Small Vehicles	Texas A & M	350,000
	AREA TWENTY-THREE: SOILS AND GEOLOGY—PROPERTIES		
	No Projects		
	AREA TWENTY-FOUR: SOILS AND GEOLOGY—MECHANICS AND FOUNDATIONS		
24-1	Manual on Subsurface Investigations	Haley & Aldrich	75,000
24-2	Reinforcement of Earth Slopes and Embankments	Dames & Moore	150,000
24-3	Laboratory Evaluation of Piles Installed with Vibratory Drivers	U of Houston	200,000
	AREA TWENTY-FIVE: TRANSPORTATION PLANNING—IMPACT ANALYSIS		
	This area became effective Jannary 1, 1979, and includes only those projects beginning with the FY 1981 program. Refer to Areas 7, 8, and 20 for previous projects in the realm of Impact Analysis.		
25-1	Effects of Highway Runoff on Wetlands	Rexnord, Inc	162,189*

* Final contract cost. ** Addresses: Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418; American Association of State Highway and Transportation Officials, 444 North Capitol Street NW, Washington, D.C. 20001.

* NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.

STARTING DATE	EXPECTED COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
7/1/74	12/31/74	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.; sum. in NCHRP Res. Results Dig. 76	22-3A
			22-3A
7/1/83	12/31/85	Contract to be extended by 4 months	22-4
5/1/85	1/31/87	Research in Progress	22-5
6/1/85	11/30/87	Research in Progress	22-6
4/2/79	12/31/80	Completed—Report not publ.; distributed to sponsors	24-1
8/22/83	8/31/85	Report in review stage	24-2
1/6/86	1/5/88	Contract pending	24-3
2/16/81	3/16/84	Completed—Published as NCHRP Report 264	25-1

[b] NCHRP funds obligated under the $70,000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.

[c] Continuing activity supported in FY '86 at amount shown.

TABLE 6

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '86 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS	
	NO.	%
Educational institutions	147	36
Research institutes	68	17
Industry, consultants, and trade associations	178	43
Professional societies and service organizations	8	2
State highway and transportation departments	4	>1
Special transportation and other governmental agencies	3	<1
All	408	100

ing expertise are responsible for administrative and technical surveillance of the contracts. In addition to reviewing quarterly progress reports and monthly progress schedules, and maintaining telephone contacts, each engineer visits his assigned research agencies throughout their contract periods. He discusses with each principal investigator his project's status to learn if the research is being pursued in line with the approved research plan. Finally, the engineer and cognizant project panel evaluate the completed research to determine the degree of technical compliance with the contract.

SYSTEMATIC PLANNING FOR GETTING RESEARCH RESULTS FROM NCHRP PROJECTS INTO PRACTICE

Promoting Useful Results

Previous reference has been made to the fact that many activities take place between initiation of research programs and execution of research contracts. Many additional ones take place before formal publication of the final reports is realized. At the milestones of the process network reflecting all activities, NCHRP concentrates on the opportunities to increase the odds for acquiring useful research results and to increase the probability that useful results will find their way into practice more quickly. Beyond the sponsor's first weighting of the odds by setting the goals for a program of applied research dedicated to solving pressing operational problems, the NCHRP tries to further weight the odds favorably by:

- Establishing the agency and personnel qualifications that are mandatory if the goals are to be achieved. Emphasis is placed on the importance of a record of successful past performance in endeavors similar to those to be undertaken. Further, it is also stipulated that proposals are not acceptable if they do not contain specific statements as to how the contemplated results can be used to improve practice.
- Utilizing persons who are not only experts in the particular problem area but who also have a complete understanding of the needs of the practitioners to define the research problem and its objectives in the form of a precise project statement on which fully responsive research proposals can be based. Experts drawn from the highway and transportation departments play a major role in this task.
- Exercising extreme care in the process of selecting research agencies to ensure not only that the proposed research plan is the best possible in addressing the specifics of the objectives but that it also culminates in the best promise for providing the practitioner with a product that is both usable and readily implementable.
- Establishing—on the basis of staff and project panel review of and suggested modifications to the research plan—a clear meeting of the minds as to what specifically is expected from the research and the personnel carrying it out in order to meet the needs of the practicing engineer.
- Acquiring an amplified research plan that is intended to detail comprehensively the approved research plan and to include a specific schedule of events for the major tasks. This document is used by the staff in the day-to-day surveillance of the project's progress and by the project panel as required.
- Carrying out project surveillance sufficient to keeping the research in line with the approved research plan, constantly keeping the researchers aware of the needs of the practicing engineer, and insuring that all project developments through final reporting center around these needs.
- Requiring research reports in a format that is designed specifically to first meet the needs of the busy administrator and the practicing engineer. Different treatment is given to the material that would be of interest to other researchers.

NCHRP Reporting of Research Results

In an applied research program such as the NCHRP, the sponsor rightfully expects not only results that are accurate but also findings that can be readily put into practice. This means that the final research reports must be presented in language understandable to both administrators and engineers and in such format as to permit easy assimilation. Too many of today's research reports are frequently so clouded by obscure language and format that the reader must spend precious time and effort in translating them into concise and readily usable working documents.

Research agencies for the NCHRP are required to report their results in a form that succinctly summarizes the findings for the busy administrator and likewise informs the practicing engineer of the application of the findings. These objectives are accomplished through a "Summary of Findings," and a chapter on "Interpretation, Appraisal, and Application of Results." The detailed

research techniques and analyses in which a researcher would be interested are presented in appendices and do not have to be labored through to extract the findings. The Program specifies style and organization of all reports to guide the researcher in his writing so that maximum use by the sponsors may be obtained.

Prior to publication, extraordinary measures are taken to ensure that useful research results are made immediately available to the appropriate operations personnel in the State organizations. One means consists of forwarding to them copies of the research agency drafts of final reports. According to the the urgency of the particular circumstances, these drafts may be either uncorrected or corrected on the basis of an acceptance review. Several copies of unedited drafts of the agency reports are retained until formal publication in either of the two regular NCHRP series (Reports or Syntheses of Highway Practice) and are available, on a loan basis, to others having an interest in the research. Once published in their entirety, the drafts are destroyed.

After publication in the NCHRP series, each report or synthesis is sent immediately to the chief administrative officer of each highway or transportation department. Then, through the Transportation Research Board's selective distribution system, copies go automatically to about 100 libraries, Board representatives in the State highway and transportation departments, educational institutions, liaison representatives, appropriate panels and committees of the Board, and individual members who have selected publications in the particular subject area of the report. As a further means of disseminating the research reports, announcements of their availability are made to the trade press. Each of these reports contains a staff-prepared foreword that directs the attention of the busy reader to the persons who would be most interested in the results and, also, to how the results fit into present knowledge and practice. Also, during the conduct of the work, periodic progress reports are prepared by the staff and sent to each of the highway or transportation departments as a meausre of providing a current awareness of on-going work. In addition, the Board's Technical Activities Staff personnel follow the progress of the work throughout its conduct and consequently are able to discuss application of the research results with the highway engineers during their various State highway and transportation department visits. Furthermore, AASHTO has provided the NCHRP with annual opportunities for staff and project researchers to go before the various committees of the Association to present the findings of their particular research and the usefulness of these findings to the practicing highway engineer. All research findings not published in the NCHRP series are stored on microfiche by the Academy. On an interim basis, the findings are sometimes reported in a *Research Results Digest*, described next.

The *NCHRP Research Results Digest* series—flyers published at frequent intervals—is a means for providing practicing engineers with an early awareness of the research results emanating from NCHRP projects in the NCHRP. By making results known as they are developed and prior to publication of the final reports in the regular NCHRP series, it is hoped that their early use in practice will be encouraged. For the most part, each Digest is intended to be very brief in summarizing specific findings—they do not deal with research methodology—and require the reader to expend very little time in determining how the research results may be of use to him. The basic format is couched in terms of the problem and the solution to it, the findings, and applications. Operations personnel should find them of direct assistance in serving the intermediary, or interpretive, position between research and operating personnel, for each Digest speaks directly to the vital factors of:

- Whether the research stands alone or whether it has to be combined with results from other research in order to be useful.

- Whether the results are defined explicitly enough to permit direct application to practice.

- Whether the results have to be translated into the working tools with which the practicing engineer is familiar.

- Whether the research findings have been evaluated sufficiently to make some reasonable determination of the probability of their success when applied to practice.

IMPLEMENTING RESEARCH RESULTS

Over the years there have been opportunities for the Program and various AASHTO committees to work together to structure the research findings into the best possible form for immediate use by the practicing engineer. Such joint efforts are highly desirable and represent the ultimate in the steps that the Program can take to weight the odds in favor of implementation of the findings.

Emphasis has been given in the foregoing to the devices employed to obtain solutions that are directly applicable to practice. Because the NCHRP process does not include an implementation activity, the initiatives for incorporating the solutions in practice must be taken by the States. To this end, the Program's final concentration is on the reporting of research findings in one or more of the variety of publications described earlier and, as is done herein, providing whatever details are available on the experiences of the States in using the products from NCHRP research. Because the reseach addresses critical, national problems, the assumption is that documented use and payoff to any one State should attract others to give the results a try in whatever degree they see fit. Only if the results get around and are used can it be said that AASHTO truly is capitalizing on its investment.

EXAMPLES OF UTILIZATION OF NCHRP RESEARCH RESULTS

Beyond the uses of NCHRP research results cited hereafter, there undoubtedly are many other uses that are unknown to the Program. NCHRP reports have been abstracted by numerous foreign countries, including Russia, with subsequent utilization being reported here. In the interest of all potential users, the Program will be grateful for any information on actual application of results and associated cost savings. This will be reported in the hope that widespread interest will develop in the States and that, consequently, research results will find their way more quickly into policies, practices, procedures, specifications, and standards of the highway and transportation departments.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS*

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
1-1	Reports 2, 2A	Illinois Div. of Hwys., Bur. of Res. and Devel.	In studies of existing pavements and the rehabilitated AASHTO Road Test project at Ottawa, Ill. Particular use made of recommendations for experimental designs, measurement programs, and data processing analysis.
		Conn. DOT	To design experimental pavement projects.
1-2	Report 7	N. Y. DOT	To develop a flexible pavement performance equation; in use June 1968.
		Tallamy, Byrd,—	In study of highway maintenance quality levels for Ohio Dept. of Hwys.
1-3(2)	Report 22	Conn. DOT	In evaluating flexible experimental pavements.
1-3(3)	Report 35	Conn. DOT	In evaluating flexible experimental pavements.
1-4	Report 10	Conn. DOT	In analyses of data from experimental pavements.
1-4(2)	Report 30	Conn. DOT	In evaluating flexible experimental pavements.
1-5	Report 21	Conn. DOT	In evaluating flexible experimental pavements.
1-5(2)	Report 76	N. Dak. SHD	Major equipment purchase based on successful use of similar equipment in conduct of project.
		Conn. DOT	In evaluating flexible experimental pavements.
1-7	Report 37	Nat'l. Hwy. Safety Bur.	In preparation of a *Highway Safety Program Manual* for issuance to the States.
		92nd Cong., 1 Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
		Conn. DOT	As justification to establish skid test program in Connecticut.
1-8	Agency final report	Consult. for USN and USAF	Development of new approach to pavement design for heavy aircraft loadings; used for redesign of Salt Lake City runway to accommodate B747 aircraft and in design of runway, taxiways, and aprons at Air Force Plant No. 42 near Palmdale, Calif., where design load is 500 tons (gross) from B2707 (SST) configuration.
1-9	Report 61	Calif. Div. of Hwys.	In evaluation of proposed State legislation regarding use of studded tires.
		Conn. DOT	In providing documentation for studded tire legislation.
1-10	Agency final report	Consult. for USN and USAF	See Project 1-8.
1-11	Agency report	U.S. Forest Serv.	In preparation of an Engineering Technical Report evaluating several commonly accepted pavement design methods, as to their applicability for design of pavement systems for Forest Service roads.
		AASHTO	Partly published as *Interim Guide for Design of Pavement Structures, 1972*
1-12	--	92nd Congress, 1st Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
	Report 154	Conn. DOT	As background information on skid-testing program.
1-12(2)	—	92nd Cong., 1 Sess.	See Project 1-12.
	Report 151	Conn. DOT	As background information on skid-testing program.
		N. Y. DOT	Leans heavily on the suggestions presented when purchasing or altering skid trailers and when modifying operational procedures.
		ASTM	As basis for updating ASTM Method E274.
1-12(3)	—	92nd Cong., 1 Sess.	See Project 1-12.
1-14	Agency final report	Va. DOT	Safety Committee reviewed agency recommendations for improvements at high accident site, with resulting request for FHWA approval as an Interstate Safety Project.
1-17	Report 224	Washington DOT	In the design of pavement rehabilitation programs.
		Japan Road Contractors Association	Translated in Japanese.
1-18	Report 228	World Bank	Basis for designing an international calibration exercise for road meters.
1-19	Agency interim report	FHWA	As input to FHWA-AASHTO Long-Term Pavement Monitoring Program documents.
		Illinois DOT	As reference for identifying concrete pavement distress.

* Project titles, as well as project status, are given in Table 5. Publication titles are given in Tables 7 and 8.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
1-21	Agency draft guide, "Specs. for Joint Repair"	FHWA	As input to internal publication titled, "Construction Handbook on PCC Pavement Rehabilitation."
		Penn. DOT	As a guide for developing policies and repair techniques.
2-5	Reports 13, 111	One State (unkn.)	To replace outdated material in AASHTO book, *Urban Freeway Design.*
2-5A	Report 111	AASHTO	In draft of proposed AASHTO publication, *A Policy on Arterial Highways in Urban Areas.*
		W. W. Rankin, I.T.E.	In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant, W. G. Ireson	In textbook, *Principles of Engineering Economy.*
2-11	Report 122	World Bank	For teaching purposes by the Economic Development Institute of the International Bank for Reconstruction and Development.
2-12	Agency rep. and Rep. 111	Federal Supply Serv., Gen. Serv. Adm.	Vehicle operating cost data applied in review of Govt. employee automobile costs.
	Agency report	J. Leisch & Assoc.	As an aid in conducting a planning-design course for the South Carolina SHD in coordination with the Governor's Safety Program.
		AASHTO	Published by AASHTO as *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements.*
		Colorado SHD	As a partial basis for development of the State's "Benefit/Cost Analysis Manual."
3-2	Reports 9, 29	Illinois Div. of Hwys., Bur. of Traffic	In a FAI 80 Motorist Communication project. Also, more emphasis being placed on influence of pedestrians on signal timing, because signals in small cities are almost always in the CBD where there are many pedestrians.
3-4	Reports 6, 40	Calif. Div. of Hwys.	Source of background information for highway and law enforcement officials facing problem decisions on location of disabled or stopped vehicles.
3-5	Reports 3, 32, 73, 124	D.C. Dept. of Hwys. and Traffic	Incremental travel cost technique applied to a comprehensive determination of existing effectiveness of operation in D.C. traffic signal system. Annual incremental travel costs in D.C. system were estimated and used in benefit/cost analysis of traffic signal system improvement alternatives.
		Minn. DOH	Steps taken toward implementation of the delay difference offset technique in an existing signal network.
		Calif. Div. of Hwys.	Source of information to supplement and improve the effectiveness with which the Division can carry out its program of reducing delay to the motorist. Also of value in designing innovative signals; in fact, the Division engaged the principal investigator on a consulting basis to help simulate different levels of traffic for a project under design in Riverside County.
	Agency final report	Goodell, Grivas and Assoc.	Obtained contract to use model described in report on a network in Detroit.
3-7	Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ.	Demand for the tape has been large, and loan copies have been circulated widely. Although the principal use of the tape has been educational in nature, one County Board of Education was so impressed with the noise differential between open and closed window situations that consideration was given to installation of air conditioning and storm windows for school buildings adjacent to freeways.
		Georgia SHD	Noise design guide used in design of urban freeway system.
		Minnesota Legislature	For demonstration purposes in hearings by House "Transportation" Committee, and Senate "Highways" and "Natural Resources and Environment" Committees. Both Senate committees took favorable action on a Truck Noise Control bill patterned after the California law.
		Virginia DOH	To evaluate noise for several proposed highways and to make subsequent explanations to the public on the impact of the noise on the community. One instance involved I-195, a six-lane depressed highway in a residential area of Richmond. Using the computer program from *Report 78,* peak-hour traffic was used to project the noise levels; comparisons were made with actual readings taken in the area. Another case involved projecting noise levels on I-66 in the vicinity of Washington, D.C., to determine if they would be within an acceptable limit. Revisions were made in the cross sections where estimates exceed the acceptable limit. The Department estimates that almost $18,000 was saved by doing the evaluation work in-house, rather than contracting it. Annual savings of $50,000 to $75,000 have been forecast in the instance of standard evaluations of major projects.
		Arizona cons. firm	In design and location of a 4.5-mi segment of I-10 (Papago Freeway) traversing a high-density area of downtown Phoenix. Recommendations made are expected to substantially reduce noise levels in areas adjacent to the Freeway.
		Natl. Assn. of Home-builders	In development of a *Builders' Acoustical Manual* that includes guidelines for prediction of site noise due to traffic.
		Missouri SH Comm.	Highway traffic noise simulation program used to establish noise projections on new project designs.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		FHWA	In developing highway noise level standards PPM 90-2, "Interim Noise Standards and Procedures for Implementing Section 109(I) 23 U.S.C."
		Louisiana DOH	As primary texts in a "noise school" for parish (county) engineers.
		AASHTO	As source documents for new (1974) publication, "Guide on Evaluation and Attenuation of Traffic Noise."
	Report 117	Howard, Needles, et al.	Model for predicting highway traffic noise validated under contract to a state highway department.
		Express Hwy. Res. Fdn. (Japan)	Abridgment (8 pp.) published in April 1972 issue of *Expressways and Automobiles* (in Japanese).
		Colorado DOH	Projected noise study based on a U.S. DOT program developed directly from this report, considered to represent the best study procedure from available empirical and theoretical research on highway noise.
		Minnesota DOH	Predictions for use in design of I-35W noise barrier in S. Minneapolis.
	Agency final rep. draft	Envir. Protection Agency	In evaluating alternatives for truck noise emission regulations.
	Agency final rep.	Nat. Bur. Stand.	Published a form of the Noise Prediction Nomogram adapted to an "L-equivalent" measure.
		Md.-Natl. Cap. Park and Plan. Comm.	Found to be useful and quite accurate as a tool in preparation of land-use plans.
	Rep. 78, 117, 144	Conn. DOT	As a basis for noise analyses.
3-8	Report 50	Orange Co. (Calif.) Traf. Eng. Council	Extensive use as best available source of information for preparation of warrants for installation of protective devices at rail-grade crossings.
		Illinois Div. of Hwys., Bur. of Design	In a continuing program toward grade crossing safety, with particular use seen for portion dealing with crossings where flashing light signals—with or without gates—are not warranted.
		Conn. DOT	Source reference for Railroad-Highway Safety Grade Crossing Program.
3-9	Report 84	Calif. Div. of Hwys.	Recommendations used on Freeway Surveillance and Control Project (Los Angeles), involving expenditure of about $8 million in three years.
3-12	Report 123	Transp. Syst. Center	Information on fixed highway signing principles particularly helpful in providing control signals to pilots at Kennedy International Airport (New York).
	Agency report	Street Name Signing Comm., ITE	As background information in review of street name signing applications to meet motorists' needs.
3-12(2)	Agency final report	AAA Found. for Traffic Safety	As the primary reference for preparation of the pamphlet, "Improving Road Guide Signs . . . What Can You Do About It?"
3-13	Report 93	City of Waco, Tex.	Plans to incorporate in subdivision and zoning regulations many of the controls recommended as a means of protecting facility capacity and safety.
3-14	Film, "Relief for Tired Streets"	New York DOT	To encourage municipalities in State to apply traffic engineering solutions to their congestion problems.
3-15	Agency report	Consultant	Using nomographs and incorporating the research findings into some current projects.
3-16	Agency report	FHWA	As support material in resolving an operations problem.
3-18(1)	Agency interim report	City of Lincoln, Nebr.	In design of digital computer-controlled traffic control system to supervise 250-300 signalized intersections.
	Agency report	New Zealand Ministry of Works	To reduce hardware costs by applying greater software capabilities to computer-controlled traffic signal operations.
		New York DOT	As background and design evaluation for a centralized computer traffic surveillance and control system in the Northern Long Island Corridor.
3-18(2)	Agency report	Dade Cty., Fla.	As basis for operational changes at selected locations.
3-18(3)	Agency interim report	FHWA	A summary report presenting results of a survey of traffic signal system design and operation practices was used in development of a FHWA training program for traffic engineering personnel.
	Agency report	Texas SDH and Pub. Transp.	Report selected as a textbook for a course for city and state traffic engineers in traffic signal system design.
3-19	Agency report	Utah DOT	In highway analysis.
3-20	Agency report	FHWA	To develop interest in warrant improvement within Signals Subcommittee of National Advisory Committee on Uniform Traffic Devices.
3-21	Agency report	N.J. Tpk. Auth.	In conjunction with research project studying visual effects of variable-message signs.
3-22A	Report 232	Texas SDHPT	Text material for the "Freeway Management Operations Workshop." Participants included SDHPT district personnel, state and city traffic engineers, and state and city police.
3-23	Agency report	AMV Australia	In developing a manual for design of signalized intersections for Road Safety and Traffic Authority, Victoria, Australia.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		FHWA	To amend Sections 4B-8, 4B-10, 4B-11, and 4B-12 of the *Manual on Uniform Traffic Control Devices.*
3-25	Agency final report	Consultant	To determine the safety impacts of lower design standards related to construction and maintenance activities in the context of energy conservation.
3-26	Agency interim report	City of Edmonton, Alberta, Can.	In designing noise-barrier walls.
	Agency final report	County of Sacramento Plng. & Commun. Dev. Dept.	As a supplement to the FHWA Highway Noise Prediction Model used to conduct environmental analyses of proposed highway projects.
3-27	Report 233	Fuel Efficient Traffic Signal Mgmt. Program	In their Bulletin, readers were referred to various Report figures that would aid in determining timing parameters for traffic-actuated controllers.
3-28	Unpublished by NCHRP. TRB Circular 212	Polytechnic Inst. of N.Y.	Highway capacity workshop materials.
4-3	Reports 12, 15, 65, 66	ASTM	Basis for development of C671, "Tentative Method of Test for Critical Dilation of Concrete Specimens Subject to Freezing," and C682, "Resistance of Aggregates to Freezing."
4-6	Reports 74, 74A, 74B	Conn. DOT	As backup in developing paint systems for highway bridges.
4-7	Report 164	AASHTO	Recommendations for consideration of fatigue of reinforcement in concrete highway bridges incorporated in 1975 as provisions in AASHTO "Standard Specifications for Highway Bridges."
4-8(3)	Agency final report	Arizona DOT	To revise Department's asphalt paving mix design criteria
4-11	Agency interim report	Fed. Aviation Admin.	Tentative guidelines for selection and installation of plastic pipe were used to reduce time and funds required for a research project on plastic pipe for airport drainage.
		State Hwy. and Transp. Materials Engrs.	On basis of advisory panel member comments that information in report would be useful to practicing engineers, report was distributed to members of AASHTO Operating Sub-Committee on Materials.
		U.S. Forest Serv.	Distributed to each regional office on basis of headquarters office determination that it will prove of use to engineers involved in design of road and sanitary sewer projects.
		Albuquerque, N.M.	In deciding on use of certain materials for city sewers.
		Illinois DOT	In preparing specifications and purchase of plastic pipe.
	Report 225	Soil Conservation Service, USDA	As a guide in developing a technical release on plastic piping materials for use by field personnel in planning and design of plastic pipe systems.
		AASHTO	In developing materials' specifications.
5-4	Report 20	AASHTO Stdg. Comm. on Engrg. and Opers.	Input (with Report 77, Proj. 15-6) to the March 1969 publication, *Informational Guide to Roadway Lighting.*
5-5A, B	Agency report	DeLeuw Cather	Findings incorporated in research study.
5-7	Report 130	Ohio DOH	Reference source of current and complete information on individual delineation techniques.
		Org. for Econ. Coop. and Devel. Res. Group C-8	In preparing report on Visual Effectiveness and Durability of Road Markings, Reflectors, and Delineators.
		FHWA	In a report of two FHWA Delineation Conferences, summarized in four parts for group presentations, NCHRP Project 5-7 is described as the most comprehensive delineation research in recent years and its report as giving the best available description of the guidance function of delineation.
6-1	Report 19	California Div. of Hwys.	Source material and bibliography simplified literature search and saved much valuable time. Results incorporated in planning and design of new projects.
		Conn. DOT	In developing deicing chemical policy.
6-2	Report 4	Calif. Div. of Hwys.	See Project 6-1.
		Conn. DOT	In developing snow and ice policies.
6-3	Report 16	Calif. Div. of Hwys.	See Project 6-1.
		Natl. Flaxseed Processors Assn.	Advertising (*Civil Eng.*, Feb. 1966) highlighting research results in stating "... considering both the economy and performance, the best results by far were obtained by vegetable oil, and particularly linseed oil solutions."
		Conn. DOT	In developing treatments to prevent deterioration of PCC bridge decks.
6-4	Report 23	Iowa SH Conn.	Constructed bridge with galvanized reinforcing bars in one-half of deck. This follows recommendations to the effect that more field evaluation is required of zinc, nickel, and asphalt-epoxy coatings.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
6-5	Report 27	Calif. Div. of Hwys.	See Project 6-1.
6-8	Report 1	Calif. Div. of Hwys.	See Project 6-1.
		U.S. Park Serv.	Techniques used by consulting engineering firm for deck repair of Memorial Bridge, Washington, D.C., depended heavily on reported results.
6-10	Agency reports	Calif. Div. of Hwys.	In preparation of plans for two sections of US 50 from Riverton to the Nevada State line. Design consideration given to those factors considered vital to increased safety and reduced maintenance at interchanges under the adverse conditions of snow and ice.
	Report 127	Conn. DOT	As source reference for snow and ice policy.
	Report 127 and 35-mm slides	New York DOT	Region 5 duplicated a loan set of 35-mm slides illustrating Appendix J for showing at Region meetings. They have proven helpful for both design and maintenance activities.
7-4	Report 89	Illinois DOT, Bur. Planning	Findings have been found useful, and practice has been modified to conform with them.
7-7	Report 64	Ohio DOH	Implemented several recommendations pertaining to rest areas with maps and other information of interest to motorists, signing conformity, service patrols, patrol aircraft, and medicopter service.
7-8	Report 133	Conn. DOT	As a basis for noise analyses.
		Dept. of Eng., Univ. of Wisconsin	As a reference text for an extension course entitled "Data Collection and Evaluation Techniques for Transportation Systems Management."
7-10	Agency interim report	Oregon County Transit Dist.	In preparation of an energy contingency plan.
	Agency report	U.S. Environmental Protection Agency	To brief members of Senate Public Works Committee on the state of the art of transportation controls.
	Report 169	N.Y. State DOT	As examples of how to develop possible air quality packages for seminars to state and metropolitan planning organization transportation planners.
		Hawaii DOT	As a basic guide for the State's TSM plan.
7-10(2)	Agency final report	N.Y. State DOT	Same as Project 7-10
7-11	Report 263	FHWA	Material for transportation planning methods course.
8-3	Agency report	Arizona HD	Source material for decisions based on consumer sensitivity to the various factors considered in trip making.
8-4	Report 96	Dept. of Eng., Univ. of Wisconsin	As a text in short course on Urban Transportation Planning.
8-5	Report 121	Dept. of Eng., Univ. of Wisconsin	As a text in Traffic Engineering Seminar.
8-5A	Report 121	G. E. Pidcock Co.	To forecast volume of traffic generated by proposed subdivisions and developments.
8-8(3)	Agency interim report	Iowa SH Comm.	In development of an action plan in conformance with FHWA PPM 90-4.
		Delaware DOH & T	In development of an action plan in conformance with FHWA PPM 90-4.
	Agency report	N.Y. DOT, Transp. Planning Div.	In preparation of a synthesis report giving background to regional personnel responsible for citizen participation. Also useful in development of N.Y. State Action Plan.
		FHWA	Assisted in development of PPM 90-4.
		Michigan DOT	Assisted in preparation of the state's Action Plan.
	Report 156	Nat'l. Inst. for Road Res., S. Africa	In developing similar procedures in South Africa.
		Conn. DOT	In preparing environmental impact statements.
8-10	Report 155	Harvard Professor	In preparing a textbook.
8-11	Agency report	Illinois DOT	Portions incorporated into a manual on assessment of ecological impacts from highways for distribution to district engineers and others doing work for the department.
8-12	Agency report	FHWA	By regional transportation planners to provide technical support to the states.
		Princeton Univ.	In graduate courses.
8-12A	Agency final report and User's Guide	NYS DOT	User's Guide distributed to all regional planning offices to provide a quick-response capability for estimating travel demand.
		Consultant to Nat'l. Inst. for Transport and Road Res., S. Africa	To develop guidelines for undertaking urban transportation studies.
	Reports 186 and 187	Harvard Univ.	As course material.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Univ. of Wisconsin Extension	As course material in conjunction with the NCHRP training material.
		FHWA, Urban Planning Div.	Practical applications by state and local agencies were documented in a report entitled "Application of Quick Response Travel Estimation Procedures." Site impact, corridor, and system analyses were included.
	Report 187, Training Materials, and microcomputer applications	FHWA, National Hwy. Inst., State/Local Agencies, & Numerous Universities	As the basic training aid for short courses. More than 1,000 state and local officials have participated in 35 courses sponsored by FHWA's Urban Planning Div. in cooperation with MHI. Six additional courses are planned for next year.
8-16	Agency final report Appendix, "Transportation	Am. Public Transit Assoc.	Testimony on proposed DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
	Services for the Transportation Disadvantaged"	U.S. Congress	Evaluation of DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
8-16	Report 208	Division of Mass Transp., Caltrans	For determining alternatives for service implementation.
	Report 209	Division of Mass Transp., Caltrans	In development of transportation services for the transportation disadvantaged.
	Report 210	Division of Mass Transp., Caltrans	As a resource document for over-all planning activities.
	Report 211	Division of Mass Transp., Caltrans	To restructure and reorient marketing efforts.
8-20	Preliminary Draft Rpt.	Nat'l Inst. for Transport & Road Res., S. Africa	To design traffic counting program for four provinces of South Africa
8-23	Agency report	North Central Texas Council of Govts.	In quarterly report on DOE contract, the projected automotive operating costs of gasoline and non-gasoline engines.
8-25	Agency report	Montana Dept. of Commerce	To redesign approach of an analysis of intercity buses.
8-27	Report 262	New York MTA	To develop handicapped ridership for rail system.
8-3	Report 38	Ford Motor Co.	Saved countless hours of search and survey by state-of-the-art section on highways joint and crack sealing materials and methods. Useful in further understanding various design, construction, and maintenance problems, in analyzing specific failures, and in adapting future developments in highways to their industrial and other roadway problems.
10-1	Report 17	North Dakota State Univ.	Basic text for a course in statistical quality control taught to both undergraduates and a sizable number of engineers, the majority of the latter being highway department employees.
		Illinois Div. H, Bur. Materials	In conjunction with FHWA sigma bank, and data developed by our field testing, to develop special provisions covering statistical acceptance of bituminous concrete pavement.
		Conn. DOT.	As reference by Specifications Division.
10-2	Report 34	Illinois Div. H, Bur. Materials	In conjunction with supplementary materials, as a basis for recommending and/or limiting stockpiling methods to be included in the policy being developed for aggregate inspection and acceptance.
10-2A	Report 69	Conn. DOT	In developing statistical specifications.
10-5	Reports 14, 13	Conn. DOT	In establishing nuclear density and moisture tests in soils.
10-6	Report 52	Illinois Div. H, Bur. R&D	Considering a trial of recommendation for use of nuclear pellet technique for measuring pavement thickness.
10-8	Agency final report	Penn. DOT	The Ohio State ultrasonic gauge, several eddy current proximity gauges, and additional pachometers used with the new statistically based acceptance specifications to reduce over-all construction costs.
10-9	Res. Results Digest 48	U. Minn. and Minnesota DOH	In seminars conducted throughout Minnesota to train city and county personnel in use of the pavement surface condition rating system.
10-10	Report 201	FHWA	As a basis to prohibit use of electroslag welding in main structural tension members on federal-aid projects and to institute a program of rigorous inspection in existing structures welded by the electroslag process.
10-18	Report 258	Concrete Construction Magazine	A condensed version of this report appeared in the August 1984 issue. The magazine is distributed nationally to engineers and contractors by a number of State ready-mixed-concrete associations.
10-21	Synthesis 86	Delaware River Joint Toll Bridge Comm.	Information of direct relevance in decision regarding replacement of bridge deck on a major bridge.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
11-1(6)	Report 92	N. Mex. SH Comm.	In settling negotiations for purchase of an airport.
11-3	Report 56	Indiana SH Comm.	Rated as "excellent" by Land Acquisition Division, which requested extra copies for use in development of new work in area of responsibility.
		Illinois Div. H, Bur. Rt.-of-Way	Most of the principles set forth have been in practice. Land Economic Study unit conducted a study according to the report recommendation for one method of analysis of the value of scenic easements.
12-2	Report 83	California Div. of Hwys.	Own research project on "Analysis, Design and Behavior of Highway Bridges" used both basic knowledge and example of a well-devised rational approach to further simplify the proposed formulas and criteria recommended as revisions to the AASHTO Specifications, and to consolidate and authenticate the proposed criteria by further model and prototype verification of analytically obtained values.
12-5	Report 90	California Div. of Hwys.	Confirmed the Division's present practices, gave reassurance that its long-term investment in prestressed concrete structures is sound, and answered the question as to practicability of protective coatings.
12-7	Report 102	Naval Ship Res. and Devel. Lab.	Limited portions used in a technical report entitled "Some Observations on the Fatigue Behavior of Specimens and Structures."
		Illinois DOT, Bur. Design	Findings have been found useful, and practice has been modified to conform with them.
		Conn. DOT	To change bridge design parameters in order to reduce fatigue cracking.
	Report 147	AASHTO	Fatigue specification recommendations adopted in total in 1974 Interim AASHTO "Standard Specifications for Highway Bridges."
		Conn. DOT.	To accomplish bridge design modifications intended to reduce fatigue cracking.
		Am. Rwy. Eng. Assn.	To develop modifications to fatigue provisions in AREA Specifications (1975).
12-8	Report 86	Canadian Stds. Assn.	Committee on Design of Highway Bridges used results in updating standards for bridge railing loads.
		Conn. DOT	To provide backup information for current bridge-rail design.
12-11	Report 165	Minnesota DOT	In selecting waterproof membrane systems for field evaluation.
12-15(3)	Report 227	Wisc. DOT Iowa DOT Ill. DOT Kans. DOT Pa. DOT Conn. DOT	To retrofit fatigue-susceptible structural details in welded steel highway bridges.
12-19A	Report 244	Kansas DOT	As reference for guidance in selecting concrete sealers.
		Commercial product manufacturers	As a standard for establishing their own specifications on specific products.
		Industrywide	Results of study have caused many states and industry to be more concerned with technical support on claims made for the performance of concrete sealers. Test procedures in report have become an unofficial standard.
13-1	Report 26	Delaware SHD	In a study of highway maintenance management, Advanced Management Planning, Inc., recommended use as a guide in establishing equipment rental rates.
14-1	Report 42	Minnesota DOH	Of considerable assistance to the investigators in the Maintenance Program Budget Pilot Study, which includes a determination of the sets of road characteristics to which quality and quantity standards codes should be assigned.
		Washington State SH Comm.	In development of a unit maintenance expenditure index for the State.
		Ohio Dept. of Hwys.	In a study to develop a forecast of maintenance needs for the 1970-80 decade and compare it with the trends in highway maintenance needs for the U.S. as a whole and for the Northeast region in particular.
		Conn. DOT	In establishing Maintenance Management System.
14-5	Report 223	Penn. DOT	To determine tradeoffs between various maintnenace activities for resource allocation. Allowing gross to grow 6 in. higher before cutting saves $600,000 a year that may be used to reduce edge-drop-off.
15-1	Report 36	Commercial firm	In formulating a design for a new fiberglass guardrail system.
15-1(2)	Report 54	Federal and State agencies	In planning, design, construction, maintenance, replacement of guardrails and median barriers.
		American Iron and Steel Inst.	Recommendations on standardization of guardrail hardware by the Highway Task Force of the Institute's Sheet Committee to include use of the flat washer illustrated on page 29 of *Report 54*.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Illinois Div. of Hwys.	Included in highway design policies and standards by Bur. of Design. New Bur. of Maintenance standards for guardrail and median barriers adapted from report. Bur. of Traffic comments highlight *Design Manual* or *Highway Standards* areas that could be improved by the findings; the warranting of trial installations of various types of median barriers, for reasons of both safety and economy; and the value of certain information as a tool to determine whether to remove or upgrade existing installations.
		Nevada DOH	In evaluating acceptability of the Department's design criteria and standards.
	Report 115	Illinois DOT, Bur. Design	Findings have been found useful, and practice has been modified to conform with them.
		Conn. DOT	As a basis of guardrail systems currently used in Connecticut.
	Report 118	New York DOT	As a vital supplement to a recently prepared design manual covering policies, procedures, and standards. Design guide refers to report for further information.
15-2	Report 108	Connecticut DOT	On trial basis, used the design technique developed for channels lined with riprap. Major relocation of a stream and tributaries having a design flood discharge of 3,900 cfs from a drainage area of 7.3 sq mi was involved. Saving from use of riprap instead of paving was estimated to be more than $90,000. Evaluation of the effectiveness of the treatment is continuing, especially observation of behavior during and after any significant storms.
		Wisconsin DOT	Channel design procedure applied to ditches along the Lake Wissota—Cadott Road in Chippewa County, previously subject to erosion, but none has occurred since use of riprap according to the procedure.
		Kansas SH Comm.	As basis for publication, "Design of Stable Roadside Channels."
		Minnesota DOH	To design riprap for a stream relocation at Moose Lake. Riprap erosion protection functioned as planned during rainstorms providing discharges approximating the design value of 275 cfs.
		Colorado DOH	Method to size riprap protection included in Ch. 8 of Design Manual.
		Soil Conserv. Serv., U.S. Dept. of Agr.	Recommendations used in preparation of *SCS Tech. Release No. 59*, "Hydraulic Design of Riprap Gradient Control Structures."
	Report 108 and agency draft	Hydr. Br., Bridge Div., FHWA	As source documents for "Stable Channel Designs"; design procedures for riprap linings developed principally from Report 108.
	Report 108 and agency report	Consultant, Madrid, Spain	Riprap design procedure applied to channels along motorways in Spain.
15-4	Report 136	Indiana SH Comm.	Used National Small Streams Data Inventory compiled during project as an additional check on flood flow estimates.
15-6	Report 77	AASHTO Stdg. Comm. on Hwys.	Input (with Report 20, Proj. 5-4) to March 1969 publication, *Informational Guide to Roadway Lighting*.
		California Div. of Hwys.	Instrumental in setting the standards for California and aiding in developing the most satisfactory breakaway base. The California research, without that done under NCHRP, reportedly would have cost well over $100,000 to develop or affirm preliminary designs of this type.
		Conn. DOT	As a basis for breakaway luminaires for highway lighting.
15-7	Agency final report and User's Manual	Wyoming Hwy. Dept.	As reference for guidance in determining flow modifications caused by storage losses on encroached flood plains.
16-1	Report 91	California Div. of Hwys.	Appendix D ("Effects of Salts on Plant Biota") is the most complete dissertation on soil salinity and salt-tolerant plants in the Division's reference files.
		U.S. Government	As a primary reference in formulating the National Environmental Policy Act of 1969 and Executive Order 11514 on "Protection and Enhancement of Environmental Quality."
		Conn. DOT	In preparation of environmental impact statements.
16-3	Agency report	Iowa DOT	In a training program on erosion control for state personnel.
	Report 221	Hittman Assoc. Inc.	Information and illustrations used in a field manual for the Office of Surface Mining, U.S. Dept. of Interior.
	Reports 220 and 221	Utah DOT Park City, Utah	To develop a manual. Developers are required by city ordinance to comply with provisions set forth in the reports.
17-1	Report 79	Robley Winfrey	In development of college textbook, *Economic Analysis for Highways*.
		Calspan	As starting point for a Tri-Level Accident Research Program for NHTSA and the Motor Vehicle Mfrs. Assn.
		Min. of Transp., Brazil	Translated into Portuguese.
17-2A	Agency report	S. Dak. DOT., Div. of Hwys.	To assist in evaluating safety improvements accomplished under an ongoing safety program.
	Report 162	Northwestern Univ.	As a reference and teaching aid in a graduate course in highway safety programming.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Office of Highway Safety, FHWA	By staff serving as instructors for a series of regional seminars on evaluation of safety improvements.
17-3	Report 219	FHWA Office of Traffic Operation	As source document for FHWA's Positive Guidance series on planning and collection of field data.
		The Israel Nat'l Council for Prevention of Accidents	The final report and a training film prepared to this research were used in a pilot project to study conflicting traffic movements at intersections.
18-2(3)	Report 257	Penn. DOT	To develop a field trial for the deep polymer impregnation of a bridge deck with the "deep grooving technique."
19-2(4)	Report 131	Off. of R&D, FHWA	As a primary reference in training courses on managing highway maintenance.
19-3	Report 141	Nat'l. Inst. for Road Res., S. Africa	As source document in investigating certain aspects of vehicle sizes and weights on South African highways.
20-1	(HRIS)	Many diverse agencies	The Highway Research Information Service is known to be used widely by a number of organizations in addition to state highway departments. Recognition has been given to the periodic issues of *Highway Research in Progress* as being very useful and of great value to many other government agencies.
20-2	Report 55	Illinois Div. H. Bur. R&D	A committee within the Illinois Highway Research Council, having the assignment of developing a system of establishing research priorities for the Division's program, uses the method outlined for structuring research programs.
20-3	—	California Div. of Hwys.	Although not yet published, results from the second year of research are being used as background for installing surveillance and control systems and in planning alternative methods of improving operations on the Los Angeles Area freeway system.
20-5	Synthesis 1	Conn. DOT	As a basis for current signing patterns from Maintenance.
	Synthesis 2	Lab. de Eng., Angola	Translated into Portuguese.
	Synthesis 4	California Div. of Hwys.	As a basic document in the continuing development of Division practices and procedures to cope with the bridge deck deterioration problem. Also used as a guide for those lines of research that will yield the highest return.
		U.S. DOT	In preparation of *Instructional Memorandum 40-2-70.*
		N. Mex. SHD	In revising the Department's *Bridge Construction Manual.*
	Synthesis 5	Ctr. for PW Studies and Exper. (Spain)	Translated into Spanish as an "Information Bulletin" of the Transport and Soil Mechanics Laboratory.
		Louisiana DOH	As procedural guide to emergency measures to contain and/or control scour at bridge sites.
	Synthesis 6	Conn. DOT	In project scheduling.
	Synthesis 7	92nd Cong., 1 Sess.	See Project 1-12.
		Conn. DOT	Provided justification for motorist aid call-box system.
	Synthesis 10	Conn. DOT	By Maintenance in training personnel for equipment responsibilities.
	Synthesis 11	AASHTO	As a text in Highway Management Course (conducted by the Highway Management Institute at the Univ. of Mississippi).
	Synthesis 12	Conn. DOT	As a basis for Maintenance Telecommunication System.
	Synthesis 14	Texas Hwy. Dept.	Recommended to District offices as a reference to answer skid-resistance questions from both Departmental and non-Departmental personnel.
		Conn. DOT	To provide guidelines for skid-resistance program.
	Synthesis 16	Conn. DOT	Reference source for design of CRC pavements.
	Synthesis 18	Texas HD and Tex. Div., FHWA	As background information in plan preparation and review; construction supervision and inspection; maintenance activity.
	Synthesis 24	Conn. DOT	As input into snow and ice policy.
	Synthesis 32	Conn. DOT	As backup for studded-tire legislation.
	Synthesis 37	Upper Plains States Innovation Group	Used in stabilization handbook for local governments.
	Syntheses 56 and 60	Texas SDH and Public Transp.	For review by district offices prior to Pavement Rehabilitation Conference.
	Synthesis 81	Texas SDH and Public Transp.	Text material for Corridor Management Team Conference. Participants included city and state personnel from 12 largest urban areas within Texas. Also used as text for Urban Traffic Operations and Management Seminar.
		FHWA	As source material in short courses on Organization and Management of Ridesharing.
	Syntheses 81 and 93	Univ. of Calif.—Berkeley	As reference material for course work.
20-6	Res. Dig. 11	Md. Rds. Comm.	In a case before September 1969 term, State Court of Appeals.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	Syntheses 96 and 99	FHWA	As a supplement to the training sessions on drainage and overlay designs in a "Pavement Design Training Course."
	Res. Dig. 11 and others	Colorado DOH	Used on several occasions involving condemnation cases and other legal matters. Digests noted as being extremely helpful in view of their discussions of current problems and consequent saving of legal staff time.
	Res. Results Digest 3	Sec. of Transp.	Included *in toto* in 1970 Annual Report to the Congress in respect to progress made in administration of the highway relocation assistance program as enacted under the Federal-Aid Highway Act of 1968.
	Res. Results Digests	Virginia Atty. Genl. Office	As an aid to maintaining a current awareness of legal research of an original nature, as a basis for further research by personnel of the Office, and as a point of departure for reviews of settled law.
	Res. Dig. 25	U. Wis., Dept. Eng.	As a text in short course on Urban Transportation Planning.
20-7	—	92nd Congress, 1st Sess.	Task 4, "Laternal Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relating to Available Pavement Skid-Resistant Measures." See Project 1-12.
	Report 157	Conn. DOT	In developing the scrap tire attenuation system.
	Res. Dig. 98	FHWA	To analyze Oklahoma DOT structure upgrading program.
	Agency final report (Task 8)	New York DOT	As primary source of information on energy used in construction and maintenance of transportation facilities for estimation of energy savings by Transportation System Management (TSM) actions. TSM actions are estimated to save 37.1 million gal of gasoline in the State of N.Y. during the 1978 calendar year.
		FHWA	As the primary source document for preparing the Workshop Notes for Energy Requirements for Transportation Systems.
	Agency final report (Task 12)	AASHTO	Published by AASHTO as *Guidelines on Citizen Participation in Transportation Planning.*
	Agency final report (Task 16)	North Central Council of Governments	As an aid in the validation of a survey regarding hazardous materials shipments.
20-12	Agency report	FHWA	In preparation of handbook on "Air Pollution Control for Construction and Maintenance."
20-13	Report 193	Metro. Expy. Public Corp. Tokyo, Japan	Translated into Japanese and distributed within the Corporation.
20-15	Report 218	Florida Dept. of Environ. Regs.	To write rules related to wetland protection.
20-16	Report 198	AASHTO	Findings used in testimony before U.S. Senate.
22-2	Res. Results Dig. 84, 102, 124	State highway agencies	Breakaway cable terminal (BCT) installed as a guardrail end treatment in at least 40 states since 1973.
		Federal Aviation Administration	To install breakaway cable terminals as part of a demonstration project on the Dulles Airport Access Highway.
	Report 153	AASHTO	Referenced in Section 1.1.9A(2), Loadings and Geometrics, of the 1975 "Interim Bridge Specifications."
	Res. Results Dig. 84, 102	Australian state hwy. agencies	Breakaway cable terminal (BCT) installed as a guardrail and treatment in at least two Australian states.
25-1	Agency draft final report	U.S. Army Corps of Engineers Waterways Experiment Station	As a resource document.

AWARD-WINNING RESEARCH UNDER NCHRP

Several projects have been honored to date as outstanding contributions to the field of highway safety and have received Metropolitan Life Awards for Research in Accident Prevention from the National Safety Council. They are:

- NCHRP Project 1-7, "Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces." In 1968 this project, reported as *NCHRP Report 37,* "Tentative Skid-Resistance Requirements for Main Rural Highways," received the Award of Merit ($500).

- NCHRP Project 3-8, "Factors Influencing Safety at Highway-Rail Grade Crossings." In 1969, this project, reported as *NCHRP Report 50,* "Factors Influencing Safety at Highway-Rail Grade Crossings," received top honors—the Award of Honor ($1,000).

- NCHRP Project 2-3, "Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements." Also in 1969, this project, reported as *NCHRP Report 47,* "Accident Rates as Related to Design Elements of Rural Highways," placed second and received the Award of Merit ($500).

Other projects prominent in various other classes of awards are:

- NCHRP Project 20-7, Task 2, "The Relation of Side Slope Design to Highway Safety." In 1977, Eugene D. Marquis and Graeme D. Weaver shared the 1977 Arthur M. Wellington Prize of the American Society of civil Engineers for their paper, "Roadside Slope Design for Safety," which was based on the research reported in *NCHRP Report 158,* "Selection of Safe Roadside Cross Sections."

- NCHRP Project 20-3, "Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control." In 1969, a paper based on this project received Honorable Mention under the Past President's Award, Institute of Traffic Engineers.

- NCHRP Project 9-1, "Asphalt Durability and Its Relation to Pavement Performance." In 1969, a paper based on this project, reported in *NCHRP Report 67,* "Relation of Asphalt Rheological Properties to Pavement Durability," received the W. J. Emmons Annual Award of the Association of Asphalt Paving Technologists as the best paper at the annual meeting.

- NCHRP Project 5-8, "Warrants for Highway Lighting." In 1973, a paper based on this project, reported in *NCHRP Report 152,* "Warrants for Highway Lighting," received the Highway Research Board Award as the most outstanding paper presented at the Board's Annual Meeting.

- NCHRP Project 12-7, "Effects of Weldments on Fatigue Strength of Steel Beams." In 1977, the Principal Investigator, Professor John W. Fisher, received the T. R. Higgins Award from the American Institute of Steel Construction as author of *NCHRP Report 147,* "Fatigue Strength of Steel Beams with Welded Stiffeners."

- NCHRP Project 12-12, "Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings." In 1979, the Principal Investigators, Karl H. Klippstein and Charles G. Schilling, were co-recipients of the Arthur M. Wellington Prize from the American Society of Civil Engineers for their paper, "Fatigue of Steel Beams by Simulated Bridge Traffic," published in the *Journal of the Structural Division,* August 1977. The paper was based on Project 12-12.

- NCHRP Project 20-9, "Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation." The Principal Investigator, Mr. Jon E. Burkhardt, received the 1980 Pyke Johnson Award from the Transportation Research Board as author of the paper "Residential Dislocation: Costs and Consequences."

- NCHRP Project 1-17, "Guidelines for Recycling Pavement Materials." In 1981, a paper based on this project, reported in *NCHRP Report 224,* "Guidelines for Recycling Pavement Materials," received the W. J. Emmons award for the best technical paper at the annual meeting of the Association of Asphalt Paving Technologists.

PERSONNEL

Effective February 1, 1985, Dr. Robert J. Reilly assumed the directorship of the Cooperative Research Programs following the retirement of Krieger W. Henderson. Dr. Reilly came to the Transportation Research Board in 1972 from the University of Maryland where he was assistant professor of civil engineering. He is a graduate of Manhattan College and received M.S. and Ph.D. degrees from the University of Maryland. He has also completed several courses at the Catholic University School of Law. At the University of Maryland, Reilly taught undergraduate and graduate courses in the areas of structural engineering, applied mathematics, engineering materials, computer methods, and solid and fluid mechanics.

Dr. Reilly worked on highway bridge research projects sponsored by the Maryland Department of Transportation, and has held positions as materials engineer, structural designer, and construction engineer. In recent years, NCHRP's sponsors have shown a strong interest in research on the structural evaluation, repair, and rehabilitation of existing bridges. Reilly has been responsible for technical administration of research in this area, which during the past 4 years has included an average load of more than 20 projects annually with total funding of about $4 million. The success of many of these projects has been evidenced by the acceptance and use of the findings by the AASHTO Bridge Committee.

Dr. Reilly has lectured in programs sponsored by AISC, AASHTO, and AISI, and has published papers in the ASCE *Structural Division Journal* and the *International Journal of Computers and Structures.* He is a past director of the Maryland section of ASCE and a Registered Professional Engineer.

On July 1, 1985, Robert E. Spicher will be appointed to the position of Deputy Director of the Cooperative Research Programs. Formerly a Projects Engineer on the CRP staff, Mr. Spicher will now be responsible for assisting Dr. Robert J. Reilly, Director, CRP, in all administrative and technical matters arising from day-to-day CRP management and will also continue his project-related activities in the traffic and safety areas.

Mr. Spicher, formerly a transportation planner with the Comsis Corporation in Washington, D.C., joined the staff of the National Cooperative Highway Research Program on March 1, 1975, as a Projects Engineer.

A native of Pennsylvania, Mr. Spicher spent three years with the Maryland State Roads Commission, four years with the District of Columbia Department of Highways and Traffic, and five years with the Highway Users Federation before joining Comsis in 1973. In these positions he was active in many planning studies, including the Baltimore Metropolitan Area Transportation Study and the 1972 National Transportation Study conducted by the U.S. Department of Transportation.

While at Comsis Corporation, Mr. Spicher provided assistance to the States of Maryland and Delaware in conducting their portion of the 1974 National Transportation Study and took part in the preparation of the national summary report for this study. He was also the principal investigator on a study for the Federal Highway Administration to develop improved procedures for determining highway needs.

Mr. Spicher is a graduate of Drexel Institute of Technology and the Yale Bureau of Highway Traffic and, prior to joining the staff, chaired the Transportation Research Board's Committee on Planning, Programming, and Evaluation. He has long been active in the Institute of Traffic Engineers and is past president of its Washington, D.C. section.

Ian M. Friedland joined the National Cooperative Highway Research Program on May 23, 1985, as a Projects Engineer. Mr. Friedland will be working on the administration and supervision of a number of research projects in the areas of "bridge design" and "specifications, procedures, and practices" for construction and materials.

Mr. Friedland received his Bachelor of Science degree from Cornell University and his Master of Science degree from the University of Maryland. Both degrees were in Civil/Structural engineering. While at the University of Maryland, he was actively engaged in bridge-fatigue research and has authored several papers on weathering-steel fatigue that were published in the *American Society of Civil Engineers Structural Division Journal.*

Prior to joining TRB, Mr. Friedland worked for Stone and Webster Engineering Corporation in Cherry Hill, N.J., and for Bechtel Power Corporation. In both positions he was a staff engineer, designing power-plant structures and facilities being built and retrofitted around the country. He is a registered Professional Engineer in New Jersey and Pennsylvania.

TABLE 7

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
• 1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
• 2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
• 2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
• 3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
• 4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
• 5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
• 6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p., $3.20
• 7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80.
• 8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
• 9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
• 10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
• 11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
• 12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
• 13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
• 14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
• 15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
• 16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
• 17	Development of Gnidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
• 18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
• 19	Economical and Effective Deicing Agents for Use on Highway Strnctures (Proj. 6-1), 19 p., $1.20
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
• 21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
• 22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
• 23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
• 24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
• 25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
• 26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
• 27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
• 30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
• 31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
• 32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
• 33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
• 34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
• 35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
• 36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
• 38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
• 39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
• 41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60
42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
• 43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
• 44	Traffic Attraction of Rural Ontdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
• 47	Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
• 49	National Survey of Transportation Attitudes and Be-

* Highway Research Board Special Report 80.

NOTE: Out-of-print publications marked with a bullet (•) are available only in microfiche form from the Transportation Research Board. See final page of this document for ordering information.

TABLE 7 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
	havior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20
• 50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
• 52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80
• 53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20
• 54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
• 55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
• 56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
• 57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20
• 58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60
• 59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20
• 60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2), 148 p., $6.00
• 61	Evaluation of Studded Tire—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00
• 62	Urban Travel Patterns for Hospitals, Universities, Office Buildings and Capitols (Proj. 7-1), 144 p., $5.60
• 63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00
64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60
65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40
66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80
• 67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20
• 68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00
• 69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80
• 70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00
• 71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80
72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20
• 73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5), 55 p., $2.80
74	Protective Coatings for Highway Strnctural Steel (Proj. 4-6), 64 p., $2.80
• 74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
• 74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
• 75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60
76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2), 37 p., $2.00
• 77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
• 78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Prof. 3-7), 78 p., $3.20
79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
• 80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
• 81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
• 82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
• 83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80
86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20
87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00
88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00
89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20
90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00
91	Effects of Deicing Salts on Water Quality and Biota—Literatnre Review and Recommended Research (Proj. 16-1), 70 p., $3.20
92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60
93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20
• 94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80
• 95	Highway Fog (Proj. 5-6), 48 p., $2.40
• 96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40
97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60
• 98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p., $5.00
• 99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
• 101	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60

TABLE 7 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40
• 103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
104	Rules of Compensability and Valuation Evidence for Highway Land Acqnisition (Proj. 11-1), 77 p., $4.40
• 105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
• 106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
• 108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
• 109	Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
• 110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40
• 111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
• 112	Jnnkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
• 114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
• 115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
• 116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
• 118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
• 119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
• 120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
• 121	Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
• 122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., $9.60
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., $4.80
125	Optimization of Density and Moistnre Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., $4.40
• 126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., $3.00
127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., $5.20
• 128	Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., $5.60
• 129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., $4.80
130	Roadway Delineation Systems (Proj. 5-7), 349 p., $14.00
131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., $8.40
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TABLE 7 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
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177	Freight Data Requirements for Statewide Transportation Systems Planning—Research Report (Proj. 8-17), 196 p., $8.80
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TABLE 7 (*Continued*)

REPORT NO.	TITLE, PROJECT, PAGES, PRICE
209	Market Opportunity Analysis for Short-Range Public Transportation Planning—Transportation Services for the Transportation Disadvantaged (Proj. 8-16), 52 p., $6.00
210	Market Opportunity Analysis for Short-Range Public Transportation Planning—Economic, Energy, and Environmental Impacts (Proj. 8-16), 45 p., $6.00
211	Market Opportunity Analysis for Short-Range Public Transportation Planning—Goals and Policy Development, Institutional Constraints, and Alternative Organizational Arrangements (Proj. 8-16), 161 p., $9.20
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213	Bayesian Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress (Proj. 9-4A), 52 p., $6.00
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215	Pavement Management System Development (Proj. 20-7, Task 15), 32 p., $5.20
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* Special publication.

TABLE 7 (*Continued*)

REPORT

NO.	TITLE, PROJECT, PAGES, PRICE
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259	Design of Emulsified Asphalt Paving Mixtures (Proj. 9-5), 97 p., $8.80
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262	Planning Transportation Services for Handicapped Persons—User's Guide (Proj. 8-27), 74 p., $8.00
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279	Intersection Channelization Design Guide (Proj. 3-30), 153 p., $16.00
280	Guidelines for Evaluation and Repair of Damaged Prestressed Concrete Bridge Members (Proj. 12-21(1)), (In press)
281	Joint Repair Methods for Portland Cement Concrete Pavements—Design and Construction Guidelines (Proj. 1-21), (In press)

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TABLE 7 (*Continued*)

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• 27	PCC Pavements for Low-Volume Roads and City Streets (Proj. 20-5, Topic 5-06), 31 p., $3.60
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TABLE 7 (*Continued*)

SYNTHESIS OF HIGHWAY PRACTICE

NO.	TITLE, PAGES, PRICE
81	Experiences in Transportation System Management (Proj. 20-5, Topic 11-14), 88 p., $8.40
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83	Bus Transit Accessibility for the Handicapped in Urban Areas (Proj. 20-5, Topic 11-13), 73 p., $7.60
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88	Underwater Inspection and Repairs of Bridge Substructures (Proj. 20-5, Topic 10-08), 77 p., $7.60
89	Geotechnical Instrumentation for Monitoring Field Performance (Proj. 20-5, Topic 11-06), 46 p., $6.80
90	New-Product Evaluation Procedures (Proj. 20-5, Topic 12-12), 34 pp., $6.80
91	Highway Accident Analysis Systems (Proj. 20-5, Topic 12-03), 69 pp., $7.60
92	Minimizing Reflection Cracking of Pavement Overlays (Proj. 20-5, Topic 11-04), 38 pp., $6.80
93	Coordination of Transportation System Management and Land Use Management (Proj. 20-5, Topic 12-08), 38 pp. $6.80
94	Photologging (Proj. 20-5, Topic 8-10), 38 p., $6.80
95	Statewide Transportation Planning (Proj. 20-5, Topic 13-05), 54 p., $7.20
96	Pavement Subsurface Drainage Systems (Proj. 20-5, Topic 11-07), 38 p., $6.80
97	Transit Ownership/Operation Options for Small Urban and Rural Areas (Proj. 20-5, Topic 13-06), 28 p., $6.40
98	Resealing Joints and Cracks in Rigid and Flexible Pavements (Proj. 20-5, Topic 12-04), 62 p., $7.20
99	Resurfacing with Portland Cement Concrete (Proj. 20-5, Topic 13-04), 90 p., $8.40
100	Managing State Highway Finance (Proj. 20-5, Topic 13-03), 23 p., $6.40
101	Historic Bridges: Criteria for Decision Making (Proj. 20-5, Topic 13-11), 84 p., $8.00
102	Material Certification and Material-Certification Effectiveness (Proj. 20-5, Topic 14-05), 24 p., $6.00
103	Risk Assessment Process for Hazardons Materials Transportation (Proj. 20-5, Topic 13-10), 36 p., $6.40
104	Criteria for Use of Asphalt Friction Surfaces (Proj. 20-5, Topic 14-08), 41 p., $6.80
105	Construction Contract Claims: Causes and Methods of Settlement (Proj. 20-5, Topic 13-01), 58 p., $7.20
106	Practical Gnidelines for Minimizing Tort Liability (Proj. 20-5, Topic 14-01), 40 p., $6.80
107	Shallow Foundations for Highway Structures (Proj. 20-5, Topic 12-06), 38 p., $6.80
108	Bridge Weight Limit Posting Practice (Proj. 20-5, Topic 13-08), 30 p., $6.40
109	Highway Users of Epoxy with Concrete (Proj. 20-5, Topic 14-12), 68 p., $8.80
110	Maintenance Management Systems (Proj. 20-5, Topic 14-06), 49 p., $8.00
111	Distribution of Wheel Loads on Highway Bridges (Proj. 20-5, Topic 14-22), 21 p., $7.20
112	Cost Effectiveness of Hot-Dip Galvanizing for Exposed Steel (Proj. 20-5, Topic 15-19), 28 p., $7.20
113	Administration of Research, Development, and Implementation Activities in Highway Agencies (Proj. 20-5, Topic 14-11), 49 p., $8.00
114	Management of Traffic Signal Maintenance (Proj. 20-5, Topic 14-02), 133 p., $10.80
115	Reducing Construction Conflicts Between Highways and Utilities (Proj. 20-5, Topic 14-03), 72 p., $8.80
116	Asphalt Overlay Design Procedures (Proj. 20-5, Topic 14-04), 66 p., $8.40
117	Toll Highway Financing (Proj. 20-5, Topic 15-01), 29 p., $7.20
118	Detecting Defects and Deterioration in Highway Structures (Proj. 20-5, Topic 15-03), 75 p., $8.80
119	Prefabricated Bridge Elements and Systems (Proj. 20-5, Topic 15-10), 75 p., $8.80
120	Professional Resource Management and Forecasting (Proj. 20-5, Topic 15-08), (In press)
121	Energy Conservation in Transportation (Proj. 20-5, Topic 14-09), (In press).
122	Life-Cycle Cost Analysis of Pavements (Proj. 20-5, Topic 15-07), (In press)
123	Bridge Designs to Reduce and Facilitate Maintenance Repairs (Proj. 20-5, Topic 12-11), (In press)

TABLE 8
NCHRP RESEARCH RESULTS DIGESTS[a]

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
3	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act 18 p. $1.00
6	20-6	Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administrative Discretion in Route Location of Federal-Aid Highways 9 p. $1.00
11	20-6	Valuation Changes Resulting from Influence of Public Improvements 25 p. $1.00
14	12-3	Waterproof Expansion Joints for Bridges 3 p. $1.00
19	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968 21 p. $1.00
20	19-1	Budgeting for State Highway Departments 4 p. $1.00
22	20-6	Valuation in Eminent Domain as Affected by Zoning 19 p. $1.00
25	20-6	Federal Environmental Legislation and Regulations as Affecting Highways 35 p. $1.00
31	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way 12 p. $1.00
32	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 13 p. $1.00
39	20-6	Legal Effect of Representations as to Subsurface Conditions 17 p. $1.00
40	20-6	Appeal Bodies for Highway Relocation Assistance 16 p. $1.00
41	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases 24 p. $1.00
42	20-6	Supplemental Condemnation: A Discussion of the Principles of excess and Substitute Condemnation 20 p. $1.00
45	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned 24 p. $1.00
47	20-6	Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation 13 p. $1.00
48	10-9	Surface Condition Rating System for Bituminous Pavements 24 p. $1.50
54	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation 31 p. $1.00
55	20-7	Side-Friction Factors in the Design of Highway Curves (Task 4) 9 p. $1.00
67	15-2	Field Evaluation of Tentative Design Procedure for Riprap-Lined Channels 4 p. $1.00
68	20-6	The Meaning of Highway Purpose 15 p. $1.00
76	22-3, 3A	Field Evaluation of Vehicle Barrier System 3 p. $1.00
77	20-7	Earth-Berm Vehicle Deflector (Task 3) 3 p. $1.00
78	3-20	Traffic Signal Warrants—A Bibliography 42 p. $1.00
79	20-6	Personal Liability of State Highway Department Officers and Employees 22 p. $3.00
80	20-6	Liability of State Highway Departments for Design, Construction, and Maintenance Defects 49 p. $3.00
81	22-1A	Crash Testing and Evaluation of Attenuating Bridge Railing System 10 p. $1.00
82	1-15	Design of Continuously Reinforced Concrete Pavements for Highways 12 p. $1.00
83	20-6	Liability of State and Local Governments for Snow and Ice Control 16 p. $3.00
84	22-2	Breakaway Cable Terminals for Guardrails and Median Barriers 18 p. $1.00
85	12-16	Bridge Deck Repairs 22 p. $1.00
87	3-24	Current Practices in Use of Retroreflective Signing Materials 6 p. $1.00
89	1-12(3)	Guidelines for Skid-Resistant Highway Pavement Surfaces 12 p. $1.00
91	3-21	Motorist Response to Guide Signing 9 p. $1.00
95	20-6	Legal Implications of Regulations Aimed at Reducing Wet-Weather Skidding Accidents on Highways 31 p. $3.00
97	3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations 8 p. $1.00
99	20-6	Liability of the State for Highway Traffic Noise 14 p. $3.00
100	20-5	Safe Conduct of Traffic Through Highway Construction and Maintenance Zones 5 p. $1.00
102	22-2	Modified Breakaway Cable Terminals for Guardrails and Median Barriers 13 p. $1.00
103	20-6	Payment of Attorney Fees in Eminent Domain and Environmental Litigation 24 p. $3.00
105	3-26	Selected Acoustical Parameters of Highway Noise Barriers 8 p. $100
106	20-5	Use of Waste Materials in Highway Construction and Maintenance 2 p. $1.00
108	20-6	Trial Strategy and Techniques in Highway Contract Litigation 31 p. $3.00
109	20-6	Control of Conflicts of Interest in Highway Construction Contract Administration 56 p. $3.00
110	20-6	Liability of State and Local Governments for Negligence Arising out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings 14 p. $3.00
111	20-6	Trial Aids in Highway Condemnation Cases 11 p. $3.00
112	20-6	Legal Implications of Control of Access to Uncontrolled-Access Highways 22 p. $3.00
113	20-6	Right to Compensation in Eminent Domain for Abrogation of Restrictive Covenants 12 p. $3.00
114	20-11B	Energy Analysis Methodology for Assessing Environmental Impacts 7 p. $1.00
115	Var.	NCHRP Research on the Durability of Reinforced Concrete Bridge Components 6 p. $1.00
116	20-6	Payments to Public Utilities for Relocation of Facilities in Highway Rights-of-Way 35 p. $3.00
119	20-6	Recovery of Condemnation Blight Under Inverse Law 11 p. $3.00
120[b]	20-9	Residential Dislocation—Costs and Consequences 3 p. $1.00
121	21-2(3)	Development and Field Evaluation of Prototype Soil Moisture Sensors. 3 p. $1.00
122	3-26	Noise Barrier Acoustical Parameters—Experimental Results 5 p. $1.00
123[b]	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems 7 p. $1.00
124[b]	22-2(3)	A Modified Foundation for Breakaway Cable terminals 7 p. $1.00
126	3-18(4)	Performance Evaluation of Signalized Network Control Strategies 4 p. $100
127	8-19	The Vehicle-Miles of Travel—Urban Highway Supply Relationship 7 p. $1.00
128[b]	20-6	Continuing Project on Highway Right-of-Way and Legal Problems 7 p. $1.00

TABLE 8 (*Continued*)

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
129	20-6	Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines 17 p. $3.00
133	1-16	Evaluation of Winter-Driving Traction Aids 7 p. $1.00
134	20-6	Procedural Aspects of Inverse Condemnation—Title on Interest Acquired by Transportation and Other Public Agencies 13 pp. $3.00
135	20-6	Liability of the State for Injury-Producing Defects in Highway Surface 14 p. $3.00
136	20-6	State Highway Programs Versus the Spending Powers of Congress 18 p. $3.00
137	20-6	The Effects of Federal and State Public Information Acts on Highway and Transportation Department Activities 23 pp. $3.00
138	20-6	Legal Aspects of Historic Preservation in Highway Programs 27 p. $3.00
140[b]	3-28(B)	Development of a New Highway Capacity Manual—Status Report 5 p. $1.00
141	**20-6**	**Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges 20 pp. $3.00**
143[b]	Var.	NCHRP Research on Bridge Engineering 8 pp. $1.00
144[b]	20-5	Continuing Project to Synthesize Information on Highway Problems 8 p. $1.00
145	20-6	First Amendment Aspects of Control of Outdoor Advertising 31 p. $5.00
146	20-6	Minority and Disadvantaged Business Enterprise Requirements in Public Contracting 31 pp. $5.00
147	20-6	Mineral Rights in Rights-of-Way: Acquisition, Valuations, and Disposition 15 pp. $5.00

[a] See Table 5 for project titles. All items listed are final publications except where noted. Numbers missing from the series have been superseded by a late publication. See final page of this document for ordering information.

[b] Subsequent publication anticipated.

PROGRESS BY PROJECT

AREA 1: PAVEMENTS

Project 1-1(1) FY'63

Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements

Research Agency: Highway Research Board
Principal Invest: Dr. Paul E. Irick
Effective Date: March 1, 1963
Completion Dote: February 29, 1964
Funds: $42,800

Guidelines were established for the study of existing and new experimental pavements in the satellite research program. Definitions were provided for pavement units and behavior, traffic factors, and environmental factors. Recommendations were made for experimental designs and requirements for collecting adequate data.

The final report has been published in two volumes as:

NCHRP Report 2. "An Introduction to Guidelines for Satellite Studies of Pavement Performance";

NCHRP Report 2A, "Guidelines for Satellite Studies of Pavement Performance."

Report 2 contains a brief presentation of the essentials of the research, whereas Report 2A contains the details.

Project 1-1(2) Fy '64

Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase

Research Agency: Highway Research Board
Principal Invest: Dr. Paul E. Irick
Effective Date: March 1, 1964
Completion Date: August 31, 1965
Funds: $11,356

In follow-up to the development of NCHRP Report 2A, the intent of this continuation was to establish means for advising and assisting the various satellite programs in the use of the guidelines, techniques, and standards for data acquisition, procedures for data processing, and methods for updating the original guidelines in light of the findings of other research in Area One.

Inasmuch as the Bureau of Public Roads undertook implementation of the guidelines, rather than doing this through the Highway Rcsearch Board, the project was closed out.

Project 1-2 FY '63

Comparison of Different Methods for Evaluating Pavement Conditions

Research Agency: Purdue University
Principal Invest.: Prof. E. J. Yoder
Prof. B. E. Quinn
Effective Date: February 15, 1963
Completion Date: February 28, 1965
Funds: $29,957

This project was authorized to evaluate the effectiveness of various objective measurement techniques for obtaining data on road surface properties for use in the prediction of pavement serviceability ratings. Initially, a comparison was made between existing types of "road-roughness" measuring equipment. Such devices as the BPR roughometer, the AASHO slope profilometer, and the CHLOE profilometer were involved in the comparison study.

Research has been completed, and the project report published as:

NCHRP Report 7, "Comparison of Different Methods of Measuring Pavement Condition."

Because the initial reseach resulted in sufficient data to permit calculation of elevation power spectra, the work was extended to consider specifically the problems associated with using these spectra as criteria of pavement condition. The report on the power spectra work was not published in the regular NCHRP series, but a copy of the agency's final report is available on microfiche (see final page of this section for ordering information).

A paper on this work was also published in *Highway Research Record No. 189.*

Project 1-3(1) FY '63 and FY '64

Factors Influencing Pavement Performance—Regional

Research Agency: Purdue University
Principal Invest.: Prof. K. B. Woods
Prof. E. J. Yoder
Prof. R. D. Miles
Dr. C. W. Lovell, Jr.
Effective Date: February 15, 1963
Completion Date: September 30, 1967
Funds: $45,982

The degree of influence of various factors commonly assumed to affect pavement performance has not been suitably evaluated to allow translation of test results from one geographic area to another. The objectives of this project were to identify factors that influence pavement performance, to determine the relative effect of each factor, and to correlate pavement design and performance

with factors common to a number of regions of the United States.

A regional classification system, using 97 physiographic units and covering the 48 contiguous states, was adapted from the system originally developed by K. B. Woods and C. W. Lovell, Jr., and published in the *Highway Engineering Handbook,* McGraw-Hill, New York (1960). The highway factors analyzed by physiographic unit were: (1) availability of aggregates, (2) soil origin and texture, (3) high-volume-change soils, (4) potentially poor subgrade support conditions, and (5) frost-susceptible soils.

The Research has been completed, and the project report has been published as:

NCHRP Report 132, "Relationships Between Physiographic Units and Highway Design Factors."

Project 1-3(2) FY '63

Factors Influencing Pavement Performance—Local

Research Agency: Northwestern University
Principal Invest.: Dr. R. L. Kondner
Effective Date: September 1, 1963
Completion Date: September 30, 1964
Funds: $19,850

In contrast with other research concerned with organizing regions into like groupings of sufficient size to permit the applications of the principles of meteorology, pedology, and geology to the identification of significant factors influencing pavement performance, this study was directed to the establishment of significant trends between flexible pavement response and various factors such as axle load, number of load applications, and thickness of pavement components. Performance data from the AASHO Road Test and other similar experiments were examined, and observed behavioral trends were expressed mathematically for consideration of the possibility of incorporating performance, expressed in terms of the present serviceability index (PSI), in flexible pavement design procedures.

This research has been completed, and the results have been published as:

NCHRP Report 22, "Factors Influencing Flexible Pavement Performance."

Project 1-3(3) FY '64

Factors Influencing Pavement Performance

Research Agency: University of California
Principal Invest.: Dr. H. B. Seed
Prof. C. L. Monismith
Effective Date: April 1, 1964
Completion Date: October 31, 1965
Funds: $19,800

The reported analyses of AASHO Road Test data describe to a limited degree the independent reactions of the various components of the pavement structure to the imposed test conditions. The analyses treat very conclusively the reaction of the entire pavement sections to these test conditions. The degree of influence of various factors commonly assumed to affect pavement performance has not been suitably evaluated, however, to allow trauslation of performance test results from one area to another. It is desirable that all of these factors be studied and evaluated in an attempt to determiue order of importance and relative effect on pavement design.

As experience has demonstrated that heavy-duty asphalt pavements experience fatigue cracking under repetitions of heavy load, this research was initiated to develop procedures for predicting pavement deflections on the basis of the results from controlled repeated-load tests on materials comprising the pavement sections and within the framework of existing layered system theory.

Research has been completed, and the results have been published as:

NCHRP Report 35, "Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests."

Project 1-4(1) FY '63

Extension of Road Test Performance Concepts

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. A. S. Vesic
Leonard Domaschuk
Effective Date: October 1, 1963
Completion Date: September 30, 1964
Funds: $10,000

This research involved a critical review of existing hypotheses and the development of new hypotheses of flexible pavement performance as related to fundamental principles of engineering mechanics and material science. New hypotheses of flexible pavement performance as related to design were sought and tested with available data from the AASHO Road Test and elsewhere.

Research has been completed, and the results have been published as:

NCHRP Report 10, "Theoretical Analysis of Structural Behavior of Road Test Flexible Pavemeuts."

Project 1-4(1)A FY '64

Extension of Road Test Performance Concepts

Research Agency: Duke University
Principal Invest.: Dr. A. S. Vesic
Effective Date: February 1, 1965
Completion Date: September 30, 1966
Funds: $19,924

This research was concerned with existing theories of structural behavior of rigid pavements. Available data on deflections, stresses, and observed structural failures of rigid pavements during the AASHO Road Test were collected and critically reviewed. Rational correlations were developed for existing theories of mechanical behavior of rigid pavements.

The project report has been published as:

NCHRP Report 97, "Analysis of Structural Behavior of AASHO Road Test Rigid Pavements."

Project 1-4(2) FY '64

Extension of Road Test Performance Concepts

Research Agency: Purdue University
Principal Invest.: Dr. M. E. Harr
Effective Date: February 1, 1964
Completion Date: January 31, 1966
Funds: $12,243

There exist in the literature many theories that attempt to describe, from a mechanistic point of view, the action and reaction of pavements subjected to various loading. In general, they represent solutions to particular problems which, because of the high cost of performance testing, have never been thoroughly evaluated. In the light of the findings of the AASHO Road Test, a comprehensive overview of all theories is needed to determine relationships which are necessary and sufficient for a broad and adequate description of pavement performance. To pursue this problem, this research study was authorized to examine existing hypotheses and to develop new hypotheses of pavement performance as related to fundamental principles of engineering mechanics and materials science and, alternately, to test these hypotheses with data from any other available source.

This research has been completed, and the project report has been published as:

NCHRP Report 30, "Extension of AASHO Road Test Performance Concepts."

Project 1-5 FY '64

Detecting Variations in Load-Carrying Capacity of Flexible Pavements

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: Dr. N. M. Isada
Effective Date: January 15, 1964
Completion Date: July 15, 1965
Funds: $49,011

A need exists for an accurate method which will indicate the relative load-carrying capacity of pavements when compared with capacities during fall or other seasons so that restrictions in load limits can be more objectively applied. It is desirable that such a method be rapid and simple in operation and nondestructive to the pavement.

This research approached the objectives in terms of investigating the displacement response of flexible pavements to impulsive loadings as a measure of the seasonal changes in the elastic properties. The findings have been published as:

NCHRP Report 21, "Detecting Variations in Load-Carrying Capacity of Flexible Pavements."

Project 1-5(2) Fy '67

Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements

Research Agency: Texas A & M University Research Foundation
Principal Invest.: F. H. Scrivner
W. M. Moore
Effective Date: September 1, 1966
Completion Date: June 30, 1968
Funds: $49,428

Frost, temperature, moisture, and other environmental factors influence the seasonal changes in strength of flexible pavements, particularly during the spring thaw periods in the northern areas of the country. A simple, rapid, and nondestructive procedure is needed for determining the relative load-carrying capabilities of pavements during all seasons of the year. The objectives of this study were to evaluate methods of meeting this need and to develop techniques and guidelines for field use of the most promising procedure. As a result of the evaluation, the Lane-Wells Dynaflect equipment was selected for field evaluation and recommended for field operation.

Research has been completed, and the project report has been published as:

NCHRP Report 76, "Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements."

Project 1-6 FY '64

Standard Measurements for Satellite Program—Measurement Team

Research Agency: Texas A & M University Research Foundation
Principal Invest.: F. H. Scrivner
Effective Date: March 31, 1964
Completion Date: January 31, 1967
Funds: $61,353

This research related to establishing measurement teams equipped, staffed, and trained to make common denominator measurements on the projects in any proposed satellite research program and to insure continuity of these measurements during the life of such a program.

The measurement program considered minimal for a nationwide coordinated satellite program was outlined in the guidelines prepared under NCHRP Project 1-1, but

the guidelines did not specify actual items of test equipment nor describe team personnel requirements or procedures in detail. In addition, it did not attempt to define the testing program for the measurement teams in terms of frequency of visits to individual projects or schedules of measurements within projects.

Research has been completed, and the project report has been published as:

NCHRP Report 59, "Standard Measurements for Satellite Road Test Program."

Project 1-7 FY '65

Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces

Research Agency: The Pennsylvania State University
Principal Invest.: Prof. W. E. Meyer
Effective Date: June 15, 1965
Completion Date: December 15, 1966
Funds: $24,815

This study was conducted to satisfy an immediate need for determining minimum service values of skid resistance. These values are interim in nature, as much additional research on the skid problem is needed. The high speeds and rapid accelerations and decelerations of modern vehicles result in pavement surfaces which were once considered skid resistant but are now deficient in this respect. The problem lies not only in providing surfaces which are adequately skid resistant but also in the development of standard measurement equipment and procedure. The specific objectives of this research were to (1) develop a state-of-knowledge report on skid measurement techniques and coefficients for highway pavements, (2) recommend interim design values and minimum service values for skid resistance of wet pavements in terms of safety and economy for different methods of measurements, and (3) outline a long-range program to provide verification or refinement of the recommended values.

Research has been completed, and the project report has been published as:

NCHRP Report 37, "Tentative Skid-Resistance Requirements for Main Rural Highways."

Project 1-8 FY '65

Factors Involved in the Design of Asphalt Pavement Surfaces

Research Agency: Materials Research & Development
Principal Invest.: F. N. Finn
Effective Date: January 1, 1965
Completion Date: February 28, 1966
Funds: $23,255

Research is needed to improve the methods currently being used to design both asphalt concrete mixtures and thicknesses for flexible pavement surfaces. It is necessary that design methods take into consideration the many factors that affect surface-course performance and the function of the surface course in performance of the total structure of the pavement. A knowledge of all these interrelationships is necessary to the achievement of optimum performance, durability, and economy of the pavement. This research was authorized to identify the factors fundamental to comprehensive design of asphalt surface courses; to appraise the state of knowledge concerning both the recognition of and accounting for these factors in design; and to recommend areas in which new test methods and research are needed if currently used test methods are inadequate to provide the necessary information concerning the fundamental factors.

Research has been completed, and the project report has been published as:

NCHRP Report 39, "Factors Involved in the Design of Asphaltic Pavement Surfaces."

Project 1-9 FY '67

Evaluation of Studded Tires

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: F. R. Haselton
Effective Date: October 1, 1966
Completion Date: June 30, 1967
Funds: $24,998

This was essentially a state-of-the-art study in which currently available data on the performance of studded tires were evaluated and correlated. Correlations of published and unpublished information on both the effectiveness of studded tires and the wear resulting from their use were provided. Some recommendations were made for measuring pavement wear caused by studded tires and for a controlled systematic means for investigating the pavement wear on a nationwide basis.

Research has been completed, and the project report has been published as:

NCHRP Report 61, "Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement."

Project 1-10 FY '67 and FY '69

Translating AASHO Road Test Findings—Basic Properties of Pavement Components

Research Agency: Materials Research and Development
Principal Invest.: B. A. Vallerga
F. N. Finn
Dr. W. R. Hudson
Dr. Keshavan Nair

Effective Dates:	Sept. 12, 1966	Dec. 1, 1968
Completion Dates:	Mar. 11, 1968	Dec. 31, 1970
Funds:	$99,803	$103,291

A wealth of useful and performance information resulted from the AASHO Road Test; however, means do not now exist for reliably translating this information to other localities throughout the United States. This research concentrated on improving the understanding of the significant basic properties of pavement systems and components and their relationships to design and performance, with due regard to locality and environment. The specific objectives of the research were (1) development of descriptions of significant basic properties of materials used in road structures, (2) development of procedures for measuring these properties in a manner applicable to pavement design and evaluation, and (3) development of procedures for pavement design, utilizing the measured values of the basic properties, which would be applicable to all locations, environments, and traffic loadings.

Project efforts were divided into two major subdivisions: (1) characterization of materials in terms of stress/strain relationships representative of loading and environmental conditions, and (2) formulation of an operational pavement system model that organizes the over-all influencing factors, such as materials characterization, maintenance requirements, user costs, and economics, within a suitable framework for flexible pavement design and management.

Research has been completed, and project reports covering the subdivisions have been published as:

NCHRP Report 139, "Flexible Pavement Design and Management—Systems Formulation" and

NCHRP Report 140, "Flexible Pavement Design and Management—Materials Characterization."

Project 1-10A FY '72

Systems Approach to Pavement Design—Implementation Phase

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	R. L. Lytton W. F. McFarland
Effective Date:	March 1, 1972
Completion Date:	December 31, 1973
Funds:	$100,000

Pavements are extremely complex physical systems involving the interaction of numerous variables. Their performance is influenced by such factors as material properties, environment, traffic loading, construction practices, and maintenance activities. The pavement design process must consider all of these influencing factors, plus other constraints imposed by management.

Methods are needed for considering the effect of the interaction of the numerous variables during the over-all pavement design process. An operational pavement systems model (SAMP5), including a computer program using up to 100 input variables, developed during work on NCHRP Project 1-10, appears to be one approach to meeting this need. For the method to be fully implementable, detailed descriptions for user guides, input forms, and data feedback storage systems are needed.

The primary objective of this project was the further development of the SAMP5 program to field application stage and its pilot testing in one or more state highway departments.

The research has been completed and the objective accomplished. The systems model (now designated as SAMP6) has been modified to include full roadbed cross sections, variable unit costs with quantity and time, stochastic variability of some values, environmental roughness, and a modified structural subsystem. Trial implementation of the SAMP6 program was undertaken in the States of Florida, Kansas, and Louisiana. An evaluation of the pilot studies indicates that SAMP6 is an operational computer program that can be a useful tool in the pavement design and management process.

The project report has been published as:

NCHRP Report 160, "Flexible Pavement Design and Management—Systems Approach Implementation."

Project 1-10B FY '73

Development of Pavement Structural Subsystems

Research Agency:	Materials Redevelopment
Principal Invest.:	F. N. Finn Dr. C. L. Saraf Dr. W. S. Smith
Effective Date:	February 1, 1974
Completion Date:	July 31, 1982
Funds:	$450,000

Pavements are extremely complex physical systems involving the interaction of numerous variables. Their performance is influenced by such factors as material properties, environment, traffic loading, construction practices, and maintenance activities. The pavement design process must consider all of these influencing factors, plus other constraints imposed by management.

Methods have been developed and are being implemented for considering the effect of the interaction of the numerous variables during the over-all pavement design and management process. One example of an operational pavement design and management system has been developed under NCHRP Projects 1-10 and 1-10A. To be most useful, a pavement management system should contain mechanistic structural subsystems that utilize measured values of the significant basic or fundamental properties of the pavement components and have the capability to predict certain distress modes that can be related to the performance of the pavement.

The primary objective of this project is to develop, modularize, and demonstrate implementability of flexible-

type pavement structural subsystems utilizing implementable mechanistic techniques to analyze specific distress modes in pavement structures for various environmental, traffic, and construction conditions and having the capability of being used to evaluate both new pavement structures and overlays. The analysis techniques are based on available information from previous and current research. They are expected to be applicable to all flexible-type pavements, including those with treated base and subbase courses and full-depth bituminous structures. Specific distress modes that were considered are:

(a) Cracking from repetitive traffic loading.
(b) Permanent deformation from repetitive traffic loading.
(c) Thermal cracking.

The initial phase of the research has been completed with the development of two computer programs, one referred to as PDMAP (Probabilistic Distress Models for Asphalt Pavements) for fatigue cracking and permanent deformation, and the second referred to as COLD (Computation of Low-Temperature Damage) for low-temperature cracking. The programs are capable of predicting the occurrence of pavement distress based on material properties, traffic loading, and environmental input data. They can be used in pavement management systems, diagnostic investigations, formulation of design criteria, and preparation of material and construction specifications.

The essential findings from the initial phase of the project have been published in a paper, "Mechanistic Structural Subsystems for Asphalt Concrete Pavement Design and Management," in *Transportation Research Record 602* and in the *Proceedings of the Fourth International Conference on Structural Design of Pavements.*

Phase II of the project had the objective of assisting the state highway agencies in Florida and Utah during calibration and implementation of the PDMAP and COLD programs. These efforts were intended to use materials characterization data previously developed by the participating states. However, it was determined that the existing data would be suitable for only a demonstration of the programs rather than actual implementation. The cooperating state highway agencies have conducted materials testing to generate new data, and some correlation testing between them and other laboratories was also conducted.

Research has been completed, and the preliminary draft final report for Phase II is in the review stage.

Project 1-11 FY '68

Evaluation of AASHO Interim Guides for Design of Pavement Structures

Research Agency:	Materials Research and Development	
Principal Invest.:	C. J. Van Til B. F. McCullough	
Effective Dates:	Oct. 23, 1967	Aug. 1, 1970
Completion Dates:	June 30, 1970	Apr. 30, 1971
Funds:	$63,720	$20,205

In the AASHO Interim Guides for the Design of Flexible and Rigid Pavement Structures distributed in 1962, it was emphasized that the guides were ". . . interim in nature and subject to adjustment based on experience and additional research." Since that time, no evaluation has been made of the experience accumulated by the State highway departments as reflected by current design procedures. An immediate need existed for a review and evaluation of these procedures for the purpose of updating the guides. Accordingly, the specific objectives of this research were (1) to collect, review, and summarize current State highway department pavement design procedures, and (2) to develop proposed revisions to the AASHO Interim Guides for the Design of Pavement Structures based on an evaluation of the results of the first objective.

To achieve the objectives, information on current pavement design procedures was collected from 50 state highway departments, the District of Columbia, and Puerto Rico. This was analyzed along with the original AASHO Road Test data and the findings of other research work in the problem area. For the purpose of providing State highway departments with maximum benefits from the project, a continuation contract was executed with the agency with the objective of drafting revised Guides based on suggested revisions contained in the project report.

Research has been completed, and the project reports have been published as:

NCHRP Report 128, "Evaluation of AASHO Interim Guides for Design of Pavement Structures" and

"AASHO Interim Guide for Design of Pavement Structures," published by the American Association of State Highway and Transportation Officials, 444 North Capitol St., N.W., Suite 225, Washington, D. C. 20001.

Project 1-12 FY '70

Determination of Pavement Friction Coefficients Required for Driving Tasks

Research Agency:	The Franklin Institute
Principal Invest.:	Eugene Farber
Effective Date:	August 25, 1969
Completion Date:	June 8, 1973
Funds:	$309,244

Increases in traffic density, vehicle speed, and engine horsepower contribute to the rise in number and the severity of highway accidents resulting in thousands of deaths and billions of dollars in property damage each year. It is recognized that the highway accident problem is very complex, involving relationships between the high-

way, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all of the varions aspects of this problem.

The ultimate objectives of research in this problem area, dealing with the frictional coupling of the vehicle tire and the pavement surface, were to (1) determine pavement skid resistance requirements, (2) improve the reliability of skid resistance measurements, and (3) improve the ability to build and maintain highly skid resistant pavements. The specific objective of this project was the development of procedures for determining pavement skid resistance requirements for various classes of highways, taking into consideration such factors as driver and vehicle characteristics, traffic, weather, and highway geometry.

Research has been completed and a procedure developed for determining skid resistance requirements for intersections and other roadway sites where braking occurs. Further research is necessary to develop procedures for determining minimnm skid resistauce requirements for highway curves and other sites subjected to cornering maneuvers.

The project report has been published as:

NCHRP Report 154, "Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites."

Project 1-12A FY '74

Wet-Weather Skidding Accident Reduction at Intersections

Research Agency: Ohio Department of Transportation
Principal Invest.: R. D. Paddock
Effective Date: July 1, 1975
Completion Date: July 1, 1978
Funds: $199,955

Research conducted under NCHRP Project 1-12 indicated that longitudinal accelerations can be used to predict the relative traffic demand for tire-pavement interface friction at braking sites. Refinement and field validation of longitudinal acceleration assessment was needed to provide highway agencies with additional tools for determining types of corrective actions needed at high or potentially high accident sites.

This project was directed toward examination of methods developed under NCHRP Project 1-12 for determining vehicnlar longitudinal acceleration forces and to relate these forces to the incidence of vehicle skidding through loss of traction at the tire-pavement interface. The overall objective was to provide highway agencies with practical methods needed for determining where longitudinal acceleration demand exceeds available tire-pavement interface friction.

Research has been completed. It was found that vehicle deceleration profiles were strongly related to wet-weather accident rates at intersection sites and approach speed data could be used in place of the more difficult to obtain acceleration data for modeling wet-weather accident rates. The Ohio DOT is implementing on a trial basis the procedures for predicting accident rates developed during this project.

Copies of the agency report were distributed to program sponsors and will not be published in the regular NCHRP report series. Loan copies are available or microfiche of the report may be pnrchased (see final page of this section for ordering information).

Project 1-12(2) FY '71

Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques

Research Agency: The Pennsylvania State University
Principal Invest.: Prof. W. E. Meyer
R. R. Hegmon
Effective Date: September 16, 1970
Completion Date: May 15, 1973
Funds: $319,000

Increases in traffic density, vehicle speed, and engine horsepower contribute to the rise in the number and severity of highway accidents, resulting in thousands of deaths and billions of dollars in property damage each year. It is recognized that the highway accident problem is very complex, involving relationships among the highway, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all of the various aspects of this problem.

Implementation of the results of Project 1-12, dealing with pavement skid resistance requirements, depends on the ability to measure the skid resistance of pavement surfaces with a reasonable degree of reliability. The specific objective of this project was the development and verification of methods for improving the ability to measure pavement skid resistance with skid testers in general conformance with ASTM Method E-274.

The project report has been published as:

NCHRP Report 151, "Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques."

Project 1-12(3) FY '72

Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces

Research Agency: Materials Research & Development
Principal Invest.: C. J. Van Til
Effective Date: November 1, 1971
Completion Date: September 30, 1975
Funds: $261,955

Traffic density and the use of winter traction aids contribute to accelerated polishing and wear of highway pave-

ment surfaces. The resulting loss of surface texture reduces tire-pavement friction. Channelized traffic can also produce wheelpath depressions or ruts that may be detrimental to vehicle control and permit pondering of water with adverse safety effects, such as splashing, ice formation, and increased potential for hydroplaning.

In the interest of highway safety, it is essential that economical and effective procedures be provided for correcting polished or worn surfaces and that new pavement surfaces be designed and constructed to retain acceptable levels of resistance to wear and polishing.

The objectives of this project were to (1) identify and evaluate currently available pavement surfaces, construction procedures, and treatments for improving wear resistance and skid resistance of roadways and (2) conduct an experimental program to evaluate promising innovative procedures for providing highly wear- and skid-resistant pavement surfaces.

The research has been completed. The essential findings have been published as NCHRP Research Results Digest 89. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis upon written request to the NCHRP. Microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-13 FY '72

Effects of Studded Tires on Highway Safety

Research Agency: Calspan Corporation
Principal Invest.: Kenneth Perchonok
Effective Date: April 19, 1971
Completion Date: August 20, 1974
Funds: $208,898

The use of studded tires has been encouraged by claims for greater highway safety. Many highway and transportation departments, aware of accelerated pavement damage caused by studded tires, have conducted studies designed to measure the damage and evaluate the associated costs. The specific objective of this project was to measure, by study of accidents, accident records, accident investigations, or other appropriate means, the effect of studded tire use on the incidence and severity of accidents occurring under winter driving conditions. Analysis included consideration of exposure of vehicles with and without studded tires to accident occurrence.

Accident data and driver exposure data from Minnesota and Michigan were analyzed to measure the effect of banning studded tires. The Minnesota analyses involved a comparison of accident and injury data before and after studded tires were banned in the State. The Michigan analyses included a comparison of accident rate and injury occurrence for autos having studded tires with autos having snow tires. Various procedures were employed to control and measure driver effects associated with the type of tire used. Although all relationships that were developed did not prove to be statistically significant (at the 95 percent level) a slight safety advantage was indicated for studded tires.

The project report has been published as:

NCHRP Report 183, "Studded Tires and Accident Safety—An Accident Analysis."

Project 1-13(2) FY '72

Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions

Research Agency: University of Michigan
Principal Invest.: J. A. Green, J. S. Creswell, D. F. Dunlap
Effective Date: February 15, 1972
Completion Date: May 31, 1973
Funds: $39,450

Pavement wear by studded tires has been suspected of causing an unnatural placement of vehicles in traffic lanes by drivers attempting to avoid worn channels, of increasing the hydroplaning potential by water entrapment in the ruts, of reducing skid resistance, and of having an adverse effect on steering. Studded tires are known to cause premature loss of pavement markings. Quantitative information is needed on these, and other, stud-related influences on highway safety that should be considered in reaching rational decisions regarding the over-all value of studded tires. This project was a first step in obtaining the needed data.

The objectives of this study were to synthesize current knowledge about studded tires related to their non-winter driving safety effects and to use this synthesis to formulate a plan for determining the magnitude of these non-winter safety effects where this information cannot be derived with assurance from existing data.

Project work has beeu completed and has offered some insight into the magnitude of the further investigational work required to quantify the many stud-related influences on highway safety.

The project report has been published as:

NCHRP Report 176, "Studded Tires and Highway Safety—Feasibility of Determining Indirect Benefits."

Project 1-14 FY '73

Influence of Combined Highway Grade and Horizontal Alignment on Skidding

Research Agency: University of Michigan
Principal Invest.: Paul Fancher
Effective Date: October 15, 1972
Completion Date: January 14, 1974
Funds: $69,968

A variety of factors have contributed to the rise in number and severity of highway accidents with attendant loss of life, injury, and property damage. It is recognized

that the highway accident problem is an extremely complex one involving all aspects of the system. Thus, continuing research is needed on all facets of the problem.

At present, "A Policy on Geometric Design of Rural Highways" (AASHO, 1965) treats combinations of vertical and horizontal alignment in a general and relatively nonspecific manner. Although a detailed treatment is afforded to horizontal alignment alone and a similar treatment is given vertical alignment alone, a significant information gap exists on combined alignments. Because the combined alignment condition is common, and because certain combinations of alignments have been identified as a probable causative factor in skidding accidents, the study of these combinations is most appropriate.

The objective of the research was to develop tentative guidelines for highway geometrics and pavement surface characteristics to ensure adequate vehicle control during anticipated maneuvers on highway sections containing the combination of horizontal alignment and upgrade and downgrade vertical alignment.

Research has been completed with the finding that the AASHTO design procedures—as described in *A Policy on Geometric Design of Rural Highways, 1965* and *A Policy on Design of Urban Highways and Arterial Streets, 1973*—provide a practical method for arriving at reasonable geometric designs for sites with combined horizontal curvature and vertical grade, provided (1) the selected values of superelevation are large enough to result in adequate pavement surface drainage and (2) the pavement skid resistance is sufficient for anticipated vehicle maneuvering. However, misinterpretation of the AASHTO design procedures has resnlted in design and construction of long-radius curves with inadequate superelevation for surface drainage that contributes to an extraordinary wet-weather accident rate at this type of site.

The project report has been published as:

NCHRP Report 184, "Influence of Combined Highway Grade and Horizontal Alignment on Skidding."

Project 1-15 FY '73

Design of Continuously Reinforced Concrete Pavements for Highways

Research Agency:	University of Texas at Austin
Principal Invest.:	Dr. B. F. McCnllough
	Dr. W. R. Hudson
Effective Date:	August 1, 1972
Completion Date:	August 31, 1975
Funds:	$151,870

Most of the thonsands of miles of CRCP that have been built have been performing adequately. Failures have been sufficiently numerous, however, to suggest a need for defining more quantitatively the relationships that exist between the design variables that affect performance. These problems generally have appeared to be associated with irregular crack spacing, erratic crack patterns, excessive crack widths, and excessive deflections. They have manifested themselves as isolated areas of premature distress in the forms of (1) steel failure at transverse cracks, (2) edge pumping, (3) spalling transverse cracks, and (4) failure of the concrete. To overcome these problems and to realize the total potential from CRCP, design procedures more precise than the current procedures based on limited and incomplete performance data are needed.

Project work included general condition surveys of CRCP performance in a large group of states and diagnostic studies in several; laboratory studies of the behavior of model CRCP slabs under repetitive loading; and theoretical analysis of CRCP behavior. The research produced well-defined guidelines for a new CRCP design procedure; recommendations for certain of the required design criteria and for approaches to the establishment of others; and suggestions for improving the construction process.

Research has been completed. The essential findings of the study have been published as NCHRP Research Results Digest 82. The agency report has been distribnted to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-16 FY '74

Evaluation of Winter-Driving Traction Aids

Research Agency:	The Pennsylvania State University
Principal Invest.:	Prof. W. E. Meyer
	Dr. J. J. Henry
Effective Date:	June 3, 1974
Completion Date:	October 31, 1981
Funds:	$304,863

The all-weather movement of traffic is vital to today's economy and a matter of public demand. In addition to transporting the work force, it is essential to maintain emergency transportation services. In response to these needs, highway agencies spend large sums of money on winter maintenance activities. To aid in the efficient movement of people and materials during the winter season, industry has developed various winter-driving traction aids such as tire chains, snow tires, studded tires, the limited-slip differential, nonlocking brakes, the four-wheel drive, polyethylene chains, and improved rubber compounds. These aids do not appear to be equally effective on snow-and ice-covered roads. In addition, some of these aids are quite damaging to pavement surfaces. Standard procedures are needed for evaluating the relative performance and pavement wear effects of winter-driving traction aids. There is also a need for a comprehensive investigation of currently available devices for improving vehicle performance on ice- and snow-covered roads.

Research has been completed, with partial accomplish-

ment of project objectives. A set of vehicle performance test procedures has been selected for evaluating winter-driving traction aids. An experimental program to evaluate the performance of available winter-driving traction aid types on ice surfaces was conducted on an indoor ice rink. Testing on snow surfaces was not completed due to lack of snow and difficulties characterizing snow surfaces. A cost-effectiveness model for evaluating winter-driving traction aids has been developed and illustrative examples prepared. Although an over-all ranking of winter-driving traction aids could not be made due to the limited amount of data available, standardized test procedures are described for comparing the performance of traction aids of a similar type.

The essential findings of the study have been published as NCHRP Research Digest 133. Copies of the revised agency report have been distributed to the Program sponsors and will not be published in the regular NCHRP report series. Loan copies are available from the NCHRP upon written request or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 1-17 FY '77

Guidelines for Recycling Pavement Materials

Research Agency: Texas A&M University Research Foundation
Principal Invest.: Dr. Jon A. Epps
Effective Date: November 1, 1976
Completion Date: September 30, 1979
Funds: $199,470

State and local agencies responsible for the construction, rehabilitation, and maintenance of transportation facilities are faced with inflation, reductions in available funds, reductions of material supplies, and curtailment of energy use. Because of these, an urgent need exists to examine the use of materials, energy, and funds in order to further optimize their utilization. One approach toward meeting this need is to reuse or recycle existing pavement materials for reconstruction and rehabilitation of portland cement concrete and bituminous pavements.

The over-all objective of this project was the development of realistic guidelines for the recycling of pavement materials for the rehabilitation and reconstruction of existing pavements. The objective has been accomplished and the project report published as:

NCHRP Report 224, "Guidelines for Recycling Pavement Materials."

Project 1-18 FY '77

Calibration and Correlation of Response-Type Road Roughness Measuring Systems

Research Agency: University of Michigan
Principol Invest.: Dr. T. D. Gillespie
Effective Date: October 1, 1977
Completion Date: September 30, 1980
Funds: $250,000

Response-type road roughness measuring systems are used by many state highway and transportation agencies to perform road roughness surveys. Although several different types of systems are used, most are of the type that accumulate the displacement measurement between the rear axle housing and the body of the measuring automobile. The main advantages of these response-type systems are their relatively low cost, simplicity of operation, and high measuring speed. One of their disadvantages is the difficulty in correlation between similar and dissimilar systems; another is their susceptibility to changes that affect their time stability. Most users attempt to minimize the effect of these changes by periodic calibration.

Presently used calibration procedures normally consist of driving the measuring system over roads that have previously been accepted as reference surfaces. The measurements obtained are then compared to the roughness values of the reference surfaces. Based on these comparisons, a relationship is obtained which can be applied to measurements on other roads. There are two problems with this calibration method: (1) the roughness values of the reference surfaces are difficult to determine, and (2) once determined, the values change with season, age, and use.

The objective of this project was the development and verification of relatively rapid and inexpensive methods for the calibration and correlation of response-type road roughness measuring systems. Research has been completed. Road roughness measuring systems were investigated to determine their performance characteristics and the necessary conditions for calibration. Primary and secondary calibration methods were developed and evaluated during a limited correlation program.

The project report has been published as:

NCHRP Report 228, "Calibration of Response-Type Road Roughness Measuring Systems."

Project 1-19 FY '78 and FY '80

Development of a System for Nationwide Evaluation of Portland Cement Concrete Pavements

Research Agency: University of Illinois
Principal Invest.: Dr. M. I. Darter
Effective Date: January 23, 1978
Completion Date: October 31, 1983
Funds: $225,000

Although the great majority of portland cement concrete (PCC) pavements in the United States are providing satisfactory performance, there is sufficient mileage of prematurely distressed pavement to necessitate a systematic approach to defining the causes and remedies of this

distress. It is believed that in many respects the pavements presently in service constitute a dependable source of information on which to base future improvements in design and construction.

A general evaluation of the performance of existing PCC pavements should provide guidance for design and construction in the future and develop information useful in planning rehabilitation of these pavements.

Recognizing that a nationwide survey and evaluation of the performance of all existing PCC pavements, or of those on the Interstate System alone, would be beyond the realistic scope of an NCHRP project, the objectives of this project were (a) the development of a system for collection and analysis of information relevant to the performance of PCC pavements and the evaluation of the nature, extent, and cause of distress in such pavements and (b) demonstration of the system. The system could be used in conjunction with pavement management systems for continued collection and analysis of information and identification of methods for further improvements in the performance of PCC pavements.

Research is complete. A Concrete Pavements Evaluation System (COPES) has been developed and applied to several States (Illinois, Georgia, California, Utah, Minnesota, and Louisiana). COPES provides the format and procedures for collecting data from historical records and field observations and measurements on PCC concrete pavement projects. COPES will interface with selected, standard computer packages for data management and statistical analyses. Uses of COPES for design, construction, materials evaluation, maintenance and rehabilitation purposes have been demonstrated within states and among states.

A final report has been published as:

NCHRP Report 277, "Portland Cement Concrete Pavement Evaluation System (COPES)." This report contains an analysis of data among states for purposes of demonstrating the system and a nser's manual for implementing COPES.

An agency report titled, "Concrete Pavement Evaluation Systems (COPES), Research Report," is also available for loan or purchase (see final page of this section for ordering information). This agency report contains analyses of data per each of the participating states. Again, these analyses were meant to demonstrate potential uses of COPES; however, significant insight into the performance of concrete pavements can be gained.

Project 1-20 FY '79

Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance

Research Agency: Texas A&M University
Principal Invest.: B. M. Gallaway
J. W. Button
Dr. J. A. Epps
Effective Date: May 1, 1979
Completion Date: February 29, 1984
Funds: $200,000

Based on an AASHTO survey and other information, there appears to be an increase in the occurrence of problems such as placement difficulties, excessive displacement under traffic, thermal cracking, raveling, and stripping of asphaltic concrete pavements placed in recent years. This situation could result in higher maintenance costs, shorter service life, and criticism by the public. One of the causes of these problems is believed to be variations in the temperature susceptibility of asphalt cements.

The overall objectives of research on this problem were:

1. To determine the range or extent of variability in temperature susceptibility of asphalt cements currently being used in road construction.
2. To evaluate the effects of the identified variability, in relation to other factors and over the full range of service temperatures, on pavement construction operations and short-term performance of pavements.
3. To identify the limits of variability in temperature susceptibility that can be accommodated through application of known asphalt technology by changes in asphaltic concrete construction procedures and mix design considerations.
4. To determine procedures for accommodating or controlling that variability in temperature susceptibility of asphalt cements that cannot be accommodated by known asphalt technology.

Research has been completed. On the basis of a thorough analysis of available data from other studies during the past 40 years on asphalt cement characteristics, plus a limited amount of laboratory testing on recently obtained asphalt samples, it was determined that, in general, the range of values of temperature susceptibility and other physical properties has not changed appreciably over the years; however, there appears to be an increase in the short-term variability of these properties for asphalt cements from a given producer or source of supply. It is further recognized that the asphalt cement and its variability is only one of the number of factors, such as aggregates. construction equipment, structural design, traffic, and environment, that influence the performance of asphaltic concrete pavements. Variability exists in each of these factors. The utilization of available materials, including their variability, to produce pavements that will perform satisfactorily under predicted traffic loadings and environmental conditions requires careful consideration of all factors during the design and construction activities. To help alleviate variability problems, the use of additives to alter properties of asphalt cements used in paving mixtures may become more widespread in the future.

The project report has been published in 2 volumes as:

NCHRP Report 268, "Influence of Asphalt Temperature Snsceptibility in Pavement Construction and Per-

formance," and NCHRP Report 269, "Paving with Asphalt Cements Produced in the 1980."

Project 1-21 FY '80

Repair of Joint-Related Distress in Portland Cement Concrete Pavements

Research Agency: University of Illinois
Principal Invests.: Dr. M. I. Darter
Dr. E. J. Barenberg
Mr. W. G. Yrjanson
Effective Date: May 15, 1980
Completion Date: March 31, 1985
Funds: $300,000

A significant portiou of the nation's highway system consists of jointed portland cement concrete (PCC) pavements of numerous designs. These pavements have been in service for various lengths of time and have been exposed to different climatic conditions as well as different levels of traffic loading and varying standards of maintenance. Various forms of distress have occurred in some of these pavements and some of the rehabilitation procedures can be very costly. Effective and advantageous means to retard or arrest developing distress and to repair already damaged pavement in order to restore serviceability or in preparation for an overlay are needed.

The objective of this research was to develop guidelines and criteria for making cost-effective decisions for correcting failures related to joints (or cracks acting as joints) of jointed PCC pavements. The types of failures to be considered included faulting, D-cracking, restraint cracking, corner cracking, and load transfer. The techniques of overlay and recycling were not considered as part of this research.

Research by the agency and its subcontractor, the American Concrete Pavement Association (ACPA), is essentially complete. Procedures for project evaluation and selection of cost effective repair and preventive techniques were developed. Detailed "Design and Construction Guidelines" and "Guide Specifications" were prepared for seven different techniques for repairing and preventing the deterioration of joints and cracks. These techniques inclnde: (1) full-depth repair of deteriorated joints, cracks, and shattered slabs; (2) partial depth patching of joint spalls; (3) subsealing to fill voids and restore support; (4) restoration of load transfer of joints and cracks; (5) diamond grinding; (6) resealing of joints and cracks; and (7) improved slab edge support. The procedures were tested and partially verified through a series of field demonstrations. A void detection procedure was developed that ntilizes nondestructive deflection testing procedures to locate areas requiring subsealing.

The final report has been published as:

NCHRP Report 281, "Joint Repair Methods for Portland Cement Concrete Pavements—Design and Construction Guidelines." This report documents the research effort in general and contains the guidelines and guide specifications for the various repair and preventive techniques. Agency copies of Appendix B, "Field Demonstration Projects of Joint/Crack Repairs," and Appendix C, "Void Detection Procedures," are also available for loan or pnrchase (see final page of this section for ordering information).

Project 1-22 FY '81

Shoulder Geometrics and Use Guidelines

Research Agency: Hugh Downs—RK & K
Principal Invest.: H. G. Downs, Jr.
Effective Date: September 8, 1981
Completion Date: December 7, 1982
Funds: $100,000

Historically, the design of shoulders has been compatible with the AASHTO definition of shoulders as ". . . the portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use and for lateral support of surface courses." However, their use has broadeued considerably beyond that described in the definition. Examples of other uses are: (1) mail and other deliveries, (2) "off-tracking" recovery areas, (3) intermittent travel lane for slow-moving vehicles, (4) intersection use for right-turn and passing maneuvers, (5) emergency vehicle travel, (6) construction and maintenance activities, (7) unauthorized parking (8) snow storage, (9) pedestrian and bicycles use, and (10) improved pavement performance.

In order to accommodate this variety of uses, highway agencies have developed different solutions by varying the geometric and structural design of shoulders which in many instances have increased the utility of highway facilities. In some cases these solutions have resulted in nonuniformity, which may violate driver expectancy and create other problems when the intended shoulder use is not clear.

Because these problems are common, ranging from local roads to urban freeways, research is necessary to develop geometric and structural guidelines for shoulder design commensurate with operational requirements.

This project will concentrate on the geometric design and operational aspects of the problem.

The objective of the research was to determine optimum use of highway shoulders considering such factors as safety, economics, traffic operations, roadway fnnctional classification, and traffic volume. Research has been completed, resulting in a set of shoulder geometric design and use guidelines that will encourage greater uniformity.

The project report has been published as:

NCHRP Reprt 254, "Shoulder Geometrics and Use Guidelines."

Project 1-23 FY '82

Pavement Roughness and Rideability

Research Agency: KETRON, Inc.
Principal Invest.: M. S. Janoff
Effective Date: January 4, 1982
Completion Date: March 31, 1984
Funds: $249,990

During the AASHO Road Test, serviceability was defined as the ability of a pavement to serve the travelling public. The most commonly used objective measure of serviceability, the Present Serviceability Index (PSI), is derived from measurements made with response-type road roughness measuring systems (RTRRMS). However, this PSI only approximates the original panel rating concept and is recognized as having shortcomings. Whether the public's perception of serviceability is the same today as it was 20 years ago is questionable; vehicles, highway characteristics, and travel speeds have changed, and serviceability, as previously defined, is not exclusively a measure of pavement rideability, but is confounded by the inclusion of factors for surface defects.

For management of pavement inventory, it would be better to have separate measures of rideability and surface defects. Therefore, there is a need to develop a new pavement rating scale to ensure that objective pavement evaluations are directly and reasonably related to the public's perception of rideability. Rideability is defined as the subjective evaluation of pavement roughness. Roughness is defined as "the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, and dynamic pavement loads."

The objectives of this research were to (1) develop a scale that accurately reflects the public's perception of pavement roughness, (2) develop transforms that relate pavement profiles to the scale developed in objective 1, and (3) show how roughness statistics produced by various RTRRMS relate to the scale developed in objective 1.

Research has been completed with accomplishment of the objectives. Subjective ratings of pavement rideability were determined for various pavement types in Florida, Ohio, and Pennsylvania using a scale of 0 to 5, similar to that developed at the AASHO Road Test. Transforms were developed for relating the 0.125 to 0.630 cycles per foot portion of pavement profiles to mean panel ratings (subjective) thus producing an objective measure of pavement rideability referred to as ride number (RN). The roughness numbers produced by response type road roughness measuring systems such as Mays Meters on asphalt pavements are highly correlated with subjective ratings and the RN developed during this project but the correlation between roughness numbers from portland cement concrete, composite, or resurfaced pavements and the subjective ratings is only fair to poor.

The project report has been published as: NCHRP Report 275, "Pavement Roughness and Rideability."

Project 1-23(2) FY '87

Pavement Roughness and Rideability—Field Evaluation

Research Agency: JMJ Research
Principal Invest.: M. S. Janoff
Effective Date: January 6, 1986
Completion Date: October 5, 1987
Funds: $200,000

Research conducted under Project 1-23 has resulted in the development of a method for determining the serviceability of pavements in terms of rideability or ride number (RN) from measured pavement profiles. This project is intended to provide regional verification of the method and determine its suitability for adoption by AASHTO as a universal method for determining pavement rideability. The objective of the project is to conduct a field evaluation of the method developed under Project 1-23 for determining the rideability (RN) of pavements from measured pavement profiles. The field evaluation will result in verification or modification of the Project 1-23 models. It is anticipated that conduct of the field evaluation will involve collection and analysis of subjective (panel ratings of rideability) and objective (measured profiles) data for selected pavements in four states in different regions of the country to investigate (1) a range of vehicle sizes, (2) panel regionality, (3) effect of profile measurements from one wheelpath and two wheelpaths, and (4) comparison of alternate models.

Research is being accelerated by an advance of available funds from Project 20-7 as recommended by the AASHTO Standing Committee on Highways.

Project 1-26 FY '87

Mechanistic-Empirical Pavement Design Methods

Research Agency:
Principal Invest.:
Effective Date: In development stage
Completion Date:
Funds: $250,000

During the initial phases of the development of the revised AASHTO Guide for the Structural Design of Pavements, the AASHTO Joint Task Force on Pavements decided that the new guide would incorporate the original AASHTO Road Test algorithms with those modifications and improvements deemed appropriate as a result of experience and research subsequent to the Road Test. Furthermore, the Task Force decided that the new guide should present a framework for mechanistic-empirical pavement design methods as a window into the future. The draft guide as developed incorporates these concepts.

The objective of this project is to develop to implementable form mechanistic-empirical pavement design methods based on previous research and experience. These methods should be suitable for use in future versions of the AASHTO pavement design guides after field calibration. It is intended that the field calibration be accomplished as part of the Long Term Pavement Performance activity of SHRP.

Research is being accelerated by an advance of available funds from Project 20-7 as recommended by the AASHTO Standing Committee on Highways.

AREA 2: ECONOMICS

Project 2-1 FY '63 and FY '64

Criteria for Highway Benefit Analysis

Research Agency: University of Washington
Principal Invest.: Prof. R. G. Hennes
Effective Date: June 1, 1963
Completion Date: November 30, 1967
Funds: $101,948

This project provided estimates of the relevance of different types of benefit and cost data to decisions in highway location. Basic guides for priorities, guidelines for data collection, and basic information related to taxation were developed.

An interdisciplinary approach to the problem was undertaken by the Departments of Civil Engineering, Political Science, Business Administration, Economics, and Sociology of the University of Washington.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 2-2 FY '63

Guidelines for the Determination of Community Consequences

Research Agency: University of Washington
Principal Invest.: Prof. Edgar M. Horwood
Effective Date: July 1, 1963
Completion Date: August 31, 1964
Funds: $48,873

This project was concerned with identifying and predicting community consequences arising from highway improvements. It was designed to seek out both favorable and unfavorable consequences and involved evaluation of existing economic impact studies, developing of guidelines for highway agencies to follow in these studies, and the outlining of urgent aspects of this problem needing detailed researched.

The Urban Planning and Civil Engineering Departments combined their talents and analyzed more than 600 research reports and other writings. The final report presented an analysis of bypasses, circumferentials, and radial freeway impact effects. The utility of these studies, as well as expressed gaps in knowledge, was also discussed.

This research has been completed, and the results have been published as:

NCHRP Report 18, "Community Consequences of Highway Improvement."

Project 2-3 FY '63 and FY '64

Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: Dr. J. K. Kihlberg
Effective Date: Jnne 1, 1963
Completion Date: August 31, 1966
Funds: $155,972

The objective of the study was to determine the relationship of motor vehicle accidents to highway design elements. The study consisted of two phases: Phase 1 was a one-year study to determine accident and severity rates for various highway types; Phase 2 was a two-year study to extend these rates to various geometric elements of the highway.

Phase 1 was accomplished with highway and accident data from California, Louisiana, and Ohio. The highway data were the highway networks divided into a multitude of short segments, each of known length, each with a known ADT, and each homogeneous with respect to nnmber of lanes, access control, and median. Data of the accidents that had occurred on a particular highway segment were affixed to that segment. By grouping the highway data according to highway type and ADT, the various accident and severity rates could be computed.

Phase 2 used highway and accident data from Ohio, Connecticut, and Florida. The highway network of each State was subdivided into segments, each 0.3 mile long, each with known ADT, each homogeneous with respect to number of lanes, access control, and median, and each containing known geometric elements (curvature, gradient, intersections, and structures). As in Phase 1, accidents were affixed to the highway segments at the site of occurrence. Proper grouping allowed calcnlation of accident and severity rates (within each State) for the various geometric elements.

The project report has been published as:

NCHRP Report 47, "Accident Rates as Related to Design Elements of Rural Highways."

Project 2-4 FY '63 and FY '64

The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed

Research Agency: Texas A&M University Research Foundation

Principal Invest.: Dr. W. G. Adkins
Effective Date: June 1, 1963
Completion Date: August 31, 1966
Funds: $77,100

Various methods that have been proposed to evaluate time savings accruing to highway vehicles are reviewed in this report, and two selected models were used to analyze Interstate Commerce Commission data on commercial highway carriage for the year 1962. Values of time saving in dollars per hour were derived for nine geographical regions as designated by the Interstate Commerce Commission for cargo vehicles and for intercity buses. Detailed methodology of the cost-savings model is presented so that other researchers can make similar estimates under known local conditions. Also, an updating technique has been developed, and the 1962 costs were projected to 1965 utilizing equipment costs and driver wags and benefit indexes to develop multipliers. The assumptions of this technique and the limitations of applying the derived reuslts are discussed.

The final report for this project has been published as:

NCHRP Report 33, "Values of Time Savings of Commercial Vehicles."

Project 2-5 FY '63 and FY '64

Running Cost of Motor Vehicles as Affected by Highway Design and Traffic

Research Agency:	The Catholic University of America	
Principal Invest:	Dr. Paul J. Claffey	
Effective Date:	June 1, 1963	June 1, 1965
Completion Date:	Aug. 31, 1964	Dec. 31, 1966
Funds:	$49,998	$51,265

In this project, the motor vehicle running costs were developed for use in evaluating user costs related to proposed highway improvements and traffic regulations. These costs were determined from actual vehicle field tests as well as from the available literature.

A research report presenting the results of the first year's work was received and has been published as:

NCHRP Report 13, "Running Cost of Motor Vehicles as Affected by Highway Design."

This report relates the fuel consumption cost of a typical passenger vehicle to various roadway geometrics and operating characteristics as measured by more than 4,000 test runs in the field. It describes the development of a precise fuel meter used to collect the data. Brief studies are reported on oil consumption, maintenance, tire wear, and depreciation costs as they are affected by highway and traffic conditions.

During the second phase of research, fuel and time consumption data were collected for a second passenger vehicle, a transit bus, a tractor semitrailer, a single-unit truck, and a diesel truck. A special fuel meter for measuring the fuel consumption of diesel trucks was developed.

The results of this project have been combined with the results of Projects 2-5A and 2-7. The findings of the combined research effort have been published as:

NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-5A FY '65 and FY '67

Running Cost of Motor Vehicles as Affected by Highway Design and Traffic

Research Agency:	Paul J. Claffey and Associates	
Principal Invest.:	Dr. Paul J. Claffey	
Effective Date:	July 1, 1967	Aug. 11, 1969
Completion Date:	Dec. 31, 1968	Aug. 10, 1970
Funds:	$35,000	$30,665

The original 2-5 project was continued with the principal investigator as the contracting agency to obtain more detailed data on running costs of motor vehicles in order to eliminate certain gaps that exist in the information available on this subject. The results of the earlier work on Project 2-5 and Project 2-7 have been combined with the additional results of this phase of the project into a single comprehensive final report. The effects that variations in gradient, road surface, speed-change frequency, and traffic volumes have on the running costs of passenger cars, pickup trucks, two-axle six-tire trucks, and tractor-trailer combinations are included in the final report, and information is provided on the operating expenditures of fuel and oil consumption, maintenance and depreciation, tire wear, and accidents. Condensed graphs of the findings of the fuel consumption and tire wear studies are presented. Each is designed to provide fuel and tire wear cost for various combinations of road design elements and speed-change conditions for a given running speed. Also included are families of curves of fuel consumption and tire wear for the eleven test vehicles used in the study and data on the maintenance costs of passenger cars and trucks relative to travel distance, together with average oil consumption rates for operation on dust-free pavements in free-flowing traffic, on dustry roads, in free-flowing traffic, and on high-type pavements under restrictive traffic conditions. Several appendices detail a comparative analysis of fuel consumption of diesel and gasoline trucks, determination of the excess fuel consumed by passenger car passing maneuvers, an investigation of devices for the measurement of tire wear, development of equipment for the measurement of vehicle fuel consumption, and an annotated bibliography on highway motor vehicle operating costs.

The final report for this project has been combined with those from Projects 2-5 and 2-7 and published as:

NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-6 FY '63 and FY '64

Warranted Levels of Improvement for Local Rural Roads

Research Agency: Stanford University
Principal Invest.: Prof. C. H. Oglesby
Effective Date: June 1, 1963
Completion Date: September 30, 1966
Funds: $40,000

This project was concerned with the setting of economic standards for the construction and maintenance of local rural roads. Prevailing rural design standards and practices were examined in depth, and user benefits were weighed against cost. Economic and social consequences to local residents, businesses, and communities were studied also and related to the proposed rural road improvements. Operating costs on two-lane roads of various widths were analyzed.

Data were assembled or developed on construction and maintenance costs, on vehicle operations and their associated costs, and on accident expectancies and their costs. These costs were related to various roadbed widths and surface types for straight roads with unimpaired sight distance and traffic volumes of 400 vehicles per day or less.

The research has been completed, and the results have been published as:

NCHRP Report 63, "Economics of Design Standards for Low-Volume Rural Roads."

Project 2-7 FY '64 and FY '65

Road User Costs in Urban Areas

Research Agency: The Catholic University of America
Principal Invest.: Dr. Paul J. Claffey
Effective Date: February 1, 1964
Completion Date: May 31, 1966
Funds: $99,376

The purpose of this research was to provide data on road-user costs as classified by arterial type, operating speed, traffic composition, and delay factors. Basic tables applicable for planning and for selecting arterial street and highway systems from the various alternates in urban areas were developed.

The final report contains information on fuel and time consumption rates of a passenger vehicle, two trucks, and a bus operating on various types of urban facilities under various levels of service. Some study was devoted to determining motor vehicle accident costs and oil and maintenance costs which can be attributed to urban driving conditions. Tire wear data were collected for freeway aud urban arterial comparisons.

The results presented in the project report have beeu combined with the results of Projects 2-5 and 2-5A and published as:

NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-8 FY '64

Estimation and Evaluation of Diverted and Generated (Induced) Traffic

Research Agency: Northwestern University
Principal Invest.: Prof. W. L. Garrison
Effective Date: May 1, 1964
Completion Date: August 31, 1966
Funds: $40,000

Traffic volumes on new or improved highway facilities are found to increase more than can be attributed to normal growth of existing traffic. This extraordinary traffic increase is composed of two components, diverted and generated. In making analyses of highway improvement consequences, snch diverted and generated traffic must be taken into account. At the present time, sufficient information is not available concerning characteristics of this type of traffic.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 2-9 FY '66

Effect of Highway Landscape Development on Nearby Property

Research Agency: The Franklin Institute
Principal Invest.: Joel N. Bloom
Effective Date: November 8, 1965
Completion Date: January 31, 1968
Funds: $149,103

The intent of this research is to study how highway landscape development affects nearby property on a nationwide basis. This study determines the comparative effects of different basic types of landscape treatments in regard to property values, land use compatibility, and general acceptability. Factors relative to the problem include geometric design as well as plantings, fencing, slope blending, and screening applications.

A pilot study was conducted in the Philadelphia area to test the research techniques. Measurements of headlight annoyance, noise, vibration, air pollution, and concealment were made and correlated to the highway design and landscape treatment, property valuation, and attitude data obtained from household interviews. Field studies were continued in New York, Connecticut, Pennsylvania, Maryland, Ohio, and California. Statistical tests were conducted to determine if an economic effect could be determined. Regression analyses were made to illustrate the effects that landscapes and landforms have on noise level reduction. Correlation analyses were made to show the relations among landform, landscape, disturbance, inter-

view data, and the value of properties adjacent to highways.

The report will assist highway engineers and landscape architects in developing designs that will reduce highway noise levels to an acceptable range for adjacent residents. The research results have been published as:

NCHRP Report 75, "Effect of Highway Landscape Development on Nearby Property."

Project 2-10 FY '67

Future Needs for Oversize-Overweight Permit Operation on State Highways

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	Ralph D. Johnson
Effective Date:	November 1, 1966
Completion Date:	April 30, 1968
Funds:	$99,655

The purpose of this study was to evaluate the extent of current and future activities of oversize-overweight vehicles in relation to the highway transport situation. Because of the physical and economic aspects of oversize-overweight vehicles with respect to present and future highway needs, it is timely that basic information be developed.

A survey was conducted in each State to determine the location of permit files and the magnitude of these records. A 3 percent sample of all the permit records for 1966 in all the contiguous States was coded and punched into cards for statistical analyses. This amounted to a sample of 60,139 permits, which represents an estimated 2,160,000 permits issued in 1966.

Data were also collected from the Heavy-Specialized Carriers and the Oil Field Haulers through the American Trucking Association concerning movements made during the summer of 1967. The Mobile Home Manufacturers' Association provided statistics on shipments, and the Defense Department contributed data on their special movements.

Detailed analysis was conducted using automatic data processing statistical programs. Future trends in industries reliant upon permits for movements of certain commodities were projected to 1975. The research results have been published as:

NCHRP Report 80, "Oversize-Overweight Permit Operation on State Highways."

Project 2-11 FY '67

Summary and Evaluation of Economic Consequences of Highway Improvements

Research Agency:	Highway Research Board
Principal Invest.:	Robley Winfrey
Effective Date:	January 1, 1967
Completion Date:	July 31, 1970
Funds:	$110,000

This project reviewed the reports submitted on economics in NCHRP, as well as information from other sources, and prepared the results in a form that may be nsed directly by engineers, economists, and others who wish to make highway economic studies.

The research was conducted in four phases: (a) to present the background and principles of engineering economy and economic analysis; (b) to present the findings of Projects 2-1 to 2-9, together with supplementary data from other sources, in an organized form for use in benefit-cost studies and other economic analyses; (c) to identify gaps in the information available and needed research to fill these gaps; and (d) to make an introductory study of probable future trends in the technology of economic analysis.

The project report has been published as:

NCHRP Report 122, "Summary and Evaluation of Economic Consequences of Highway Improvements."

Project 2-12 FY '73 and FY '77

Highway User Economic Analysis

Research Agency:	Stanford Research Institute	
Principal Invest.:	D. G. Andersen	
Effective Date:	Apr. 1, 1974	Oct. 11, 1976
Completion Date:	Oct. 31, 1975	May 31, 1977
Funds:	$90,074	$9,995

The 1960 AASHO "Informational Report by Committee on Planning and Design Policies on Road User Benefit Analyses for Highway Improvements" (updated revision of the original 1952 report) was written to provide a simple, easy-to-use method for carrying out economic analyses on highway alternatives by those having only basic knowledge of principles of economics. The objective of this research was to employ, to the best possible extent, current empirical data on highway user benefits and costs (such as from NCHRP Report 122 and other research) to provide a revised and updated version of the 1960 AASHO publication. The revised version includes an analysis methodology based on sound economic theory and is suitable for immediate, direct application. The methodology provides a means of evaluating public transit operating on public highways. This evaluation allows comparisons between transit operation and additional highway improvements. Further, procedures are included that provide the user with a means for periodic updating of the numerical factors and cost coefficients through utilization of commonly available economic data. Although it was recognized that environmental and social factors are significant items of inpnt to the decision-making process, this research was limited to road user benefits and costs only.

The final report, "A Manual on User Benefit Analysis of Highway and Bus Transit Improvements," has been published by AASHTO and can be obtained by writing to: American Association of State Highway and Trans-

portation Officials, 444 North Capitol St., N.W., Suite 225, Washington, D.C. 20001

Project 2-13 FY '83

Multilane Design Alternatives for Improving Suburban Highways

Research Agency: Midwest Research Institute
Principal Invest.: Douglas W. Harwood
Effective Date: July 18, 1983
Completion Date: March 31, 1985
Funds: $100,000

Because of the limited funds available for highway improvements, transportation agencies must search for the most cost-effective means to provide the additional highway capacity needed to accommodate the increasing traffic demand within urban fringe areas. In the selection of a capacity improvement, the designer must evaluate safety, operational characteristics, and access to adjacent properties while taking right-of-way and other costs into consideration. The existence of developed properties adjacent to the in-place roadway is a major problem in suburban areas because substantial cost increases are incurred if additional right-of-way width is needed.

The objective of this research is to investigate and compare the safety, operational, and cost characteristics of selected multilane design alternatives for use in suburban areas. Operational characteristics include capacity, level of service, and accessibility. Alternatives to be investigated include:

- Three-lane with two-way left-turn lane.
- Four-lane divided with one-way left-turn lanes in the median.
- Four-lane undivided.
- Five-lane undivided, including a center two-way left-turn lane.

Each alternative was investigated under both a no-shoulder condition and a full shoulder condition. Of particular concern were highways with traffic volumes over 7,000 vehicles per day and speeds between 35 and 50 mph (i.e., these conditions usually indicate that a 2-lane highway can no longer handle the traffic demand).

A set of critical factors was identified that should be considered in making meaningful comparisons of the various highway types. The following factors were considered: median presence; shoulder width; accessibility to roadside developments; right-of-way requirements; capacity; operational characteristics; and accident experience. Accident data were obtained from California and Michigan and operational data were developed by the University of Nebraska using a computer simulation model.

The relative merits of each highway design alternative were described in terms of operations, safety, and costs. Primary advantages, disadvantages, and limitations of each alternative were delineated. An example was developed to illnstrate how all of the identified factors would typically be considered by state or local authorities in the selection of a particular design. This example demonstrates the general approach, rather than a rigid methodology, to the selection process.

The final report is expected to be published as NCHRP Report 282.

Project 2-14 FY '86

Public/Private Partnerships for Financing Highway Improvements

Research Agency: Kumley-Horn and Associates
Principal Invest.: Laurence J. Meisner
Effective Date: January 1, 1986
Completion Date: July 31, 1987
Funds: $125,000

In recent years, needs for highway construction and maintenance have risen much faster than available revenues. It is estimated that highways and streets on the Federal-aid highway systems require more than $20 billion a year for improvements. Although the Surface Transportation Assistance Act of 1982 makes available about $12 billion a year through Fiscal Year 1986, state and local financing responsibilities constitute a significant and indispensable component. However, many state and local governments lack snfficient funds to make improvements needed in state and local highway systems. This shortfall and the future needs for new construction require consideration of different approaches in financing highway improvements.

Greater private participation in financing highway and road improvements is being explored today, in both public and private sectors of the economy, as a supplement to public funding. Such participation may be especially appropriate for improvements made to accommodate increased traffic generated by major new private developments such as shopping centers, employment centers, and residential projects. Activities include road widening, maintenance, intersection improvements, and occasionally construction of new facilities. However, there are few systematic and organized ways to facilitate public/private partnerships. Research is needed to define the possible nature of such partnerships, the overlying decision processes, and the necessary legislation and model ordinances.

The objective of this research is to provide guidance to state and local highway officials and private developers on existing and potential public/private partnership mechanisms, including present state and local statutes and ordinances related to private (e.g., developer) participation in financing highway improvements. The project will identify constraints on private participation in financing highway and road improvements, will identify potential opportunities and appropriate processes to implement public/private partnerships, and will develop

model state and local legislation enabling and encouraging such partnerships. Guidelines will be developed for application at the state and local levels to facilitate this form of highway financing.

This research project consists of three phases of which only the first two phases are funded. The following tasks are being performed for Phase I which will cost no more than $50,000 and will be completed within six months from the start of contract.

Task 1. Examine existing and potential public/private partnership mechanisms. This examination will include mechanisms such as bargaining/negotiation, exactions, and voluntary contributions. Special consideration will be given to mechauisms that are not currently in practice but have the potential to facilitate public/private partnerships in financing highway improvements.

Task 2. Examine the characteristics of successful public/private partnerships as well as the barriers or constraints that inhibit successful implementation.

Task 3. Review state and local legislation and relevant court decisions. It is expected that state and local legislation significantly affects the opportunities for public/private partnerships. This task will include review of legislation and court decisions that facilitate or constrain public/private partnerships in highway financing and related areas.

Task 4. Prepare an overview of potential case studies. This overview will include a brief description of a sufficient number of case studies to illustrate the implementation of public/private partnerships in different situations and for different mechanisms.

Task 5. Prepare an interim report. The interim report will document the results of Tasks 1 through 4. Of particular interest are analysis of evolving patterns and the reasons for recommending the case studies. On the basis of this report, approximately five case studies for in-depth analysis will be selected.

The following tasks are suggested for Phase II, which will require the balance of funds available.

Task 6. Conduct in-depth case studies. The case studies will include an analysis of the institutional and legal factors that contributed (or could contribute) to successful public/private partnerships.

Task 7. Develop and annotate model legislation. This task will include a section-by-section analysis and case citations.

Task 8. Develop guidelines to facilitate the successful implementation of public/private partnerships in highway financing through the measures identified in previous tasks.

Task 9. Prepare the final report including a "Summary" limited to 6 to 8 pages.

Phase III, for which funds are not presently available, is expected to provide for widespread dissemination of research findings consisting of publications, and possible seminars.

Project 2-15 FY '86

Identifying Measuring, and Evaluating the Benefits of Safety Roadside Rest Areas

Research Agency:	KLD Associates, Inc.
Principal Invest.:	Gerhart F. King
Effective Date:	
Completion Date:	24 months
Funds:	$220,000

There is no known reliable and generally accepted method for measuring and evaluating the benefits of safety roadside rest areas. Most states have not yet completed the originally planned rest area system and now also face the necessity of major reconstruction of many older rest areas.

Rest areas are very popular with the traveling public. Recent sharp increases have occurred in both construction and operation costs of rest areas, and competition for funding with other highway construction and maintenance programs has become difficult. Therefore, the need is extremely great for a reliable and accepted method of comparing rest area benefits with costs. A study is necessary to identify (1) how state highway agencies benefit from rest areas, (2) users and nonusers and how they benefit, and (3) the value of these benefits and related costs.

A new profile of rest area users and their needs is necessary to properly evaluate existing facilities, and to plan and design new and reconstructed rest areas.

The makeup of rest area users today has changed since rest areas were first built. Driving habits are different, motorists' attitudes toward mobility have changed, and there is an increasingly more mobile public, e.g., senior citizens, handicapped, and young families. Furthermore, traffic speeds and conditions have changed, along with vehicle types and sizes.

While rest area benefits are viewed in a variety of ways, safety is typically near the top of the list. Investigation of experience in managing and operating highway systems with rest areas, including those with commercial facilities, and those systems without rest areas may provide useful data on driver fatigue, behavior, and accident patterns.

The objective of this research is to develop a method for measuring and evaluating the benefits of roadside rest areas to result in more cost-effective designs and operations. This research will address both the benefits and disbenefits associated with rest area facilities.

The research will include the following tasks:

Task 1—Review relevant domestic and foreign publications and research findings.

Task 2—Determine present practice and experience among the states and other appropriate sources in cost and benefit analyses relative to the planning and management of roadside rest area programs.

Task 3—Develop a profile of rest area users and their needs. The user profile should reflect the current mix of

rest area users as well as forecasted trend changes over the anticipated 20-year service life of the facilities.

Task 4—On the basis of an evaluation of the methods identified in Tasks 1 and 2 and the profile developed in Task 3, develop a preliminary cost/benefit analysis method for general application. This method will identify:

- How state highway agencies benefit from rest areas.
- How users benefit and who they are.
- How nonusers benefit and who they are.
- The value of these benefits and related costs.

The method should be comprehensive and cover (1) rest area user needs, (2) functional attributes of rest areas (e.g., safety, comfort, information, security, maintainability, aesthetics), (3) resultant economic benefits or disbenefits to the user, community, tourism, local business, state economy, etc., and (4) the capital and operating costs. The method should consider the type of users (e.g., trucking, recreational), type of highway, location (rural/urban), vehicle mix, cooperation with adjoining states, speed limit, and it should be applicable to both new projects and rehabilitation of existing rest areas. Who pays and who benefits should be specifically addressed, as well as innovative funding approaches including private funding, joint use, etc.

Safety is considered to be a primary factor in the decision to provide rest areas. This research will identify and quantify, to the extent possible, the safety elements provided by rest areas. Practical operating problems such as seasonal fluctuations in demand, personnel turnover, and the like, are also of interest.

Although quantification of benefits and disbenefits is desired, many factors are too subjective to develop precise quantitative values. Therefore, the method should provide some means, such as a subjective ranking scheme, to address these factors. For example, the priority or emphasis a particular state or area places on the desire to promote tourism could be factored into the analysis.

In relating benefits to costs, the method should include a level-of-service concept. In effect, the benefits of a basic rest area (only parking and restrooms) should be assessed in relation to its cost, as well as incremental additions (e.g., picnic areas, information facilities, sanitary dumping facilities).

Task 5—Prepare an interim report that discusses the preliminary method developed in Task 4.

Task 6—Design a process to conduct a rest area cost/benefit analysis incorporating the method developed in Task 4, and apply this process to an actual case study.

The process should (1) reflect the public's perception of what a rest area should be, (2) have wide application, (3) lead to more cost-effective programs and facility designs, and (4) be clear, easily applied, reasonable, and acceptable to highway agencies and the public.

Task 7—Prepare a final research report as well as a handbook to assist managers in applying rest area cost/benefit analysis. The handbook will include the case study to illustrate how the process is applied.

Research should be initiated in early 1986.

AREA 3: OPERATIONS AND CONTROL

Project 3-1 FY '63 and FY '64

Development of Criteria for Evaluating Traffic Operations

Research Agency:	Cornell Aeronautical Laboratory	
Principal Invest.:	Jaime F. Torres	
Effective Date:	Feb. 15, 1963	July 2, 1964
Completion Date:	Feb. 29, 1964	Feb. 28, 1966
Funds:	$78,965	$79,913

This research project provided an investigation into the application of criteria based on travel time, driver comfort, safety, and vehicle running costs. The linear combination of these factors weighted by an appropriate set of cost coefficients quantified the operational performance. A procedure was studied which would provide estimates of the four components based on measurements of traffic volume and an inventory of roadway characteristics. Travel time, volume, and roadway inventory data were collected from several cities and analyzed. Estimating relationships were derived for many classes of urban arterials, whereby travel time can be obtained from the measurement of volume and a knowledge of the street characteristics. A survey vehicle was equipped to monitor skin resistance, heart pulse, and respiration of two subjects in traffic while steering, brake, throttle, and speed were being recorded to study driver comfort. Accident data in the Buffalo area were analyzed and related to the safety factor, and vehicle running costs were estimated through the use of speed distributions for a sample of streets.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-2 FY '63 and FY '64

Surveillance Methods and Ways and Means of Communicating with Drivers

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Morton I. Weinberg
Effective Date:	February 15, 1963
Completion Date:	April 30, 1966
Funds:	$246,756

This project, which was concerned with the development, practice, and evaluation of various methods of surveillance and means of communicating with drivers, took advantage of the several surveillance systems available in the United States to further its research.

The report of the first phase of research described a predictive model to provide warning of impending congestion, study of a ramp advisory signal, and use of an airborne observer for traffic control. It has been published as:

NCHRP Report 9, "Traffic Surveillance and Means of Communicating with Drivers."

In the second phase of the project, the researchers developed the mathematical logic to predict the effects from unexpected blockages on a freeway and validated the model on the John C. Lodge Freeway in Detroit. Also included was an evaluation of an airborne surveillance and control system. The results of this phase have been published as:

NCHRP Report 28, "Surveillance Methods and Ways and Means of Communicating with Drivers."

In the third phase of the project, a computer-controlled signal system for a typical urban complex was synthesized, including control logic and equipment requirements. The results of this phase have been published as:

NCHRP Report 29, "Digital-Computer-Controlled Traffic Signal System for a Small City."

Project 3-3 FY '63 and FY '64

Sensing and Communication Between Vehicles

Research Agency:	The Ohio State University
Principal Invest.:	Dr. Thomas H. Rockwell
	Dr. Joseph Treiterer
Effective Date:	February 15, 1963
Completion Date:	November 30, 1965
Funds:	$163,190

This project involved establishment of the operating requirements of a communication system designed to enable better communications between vehicles on expressway-type facilities.

Evaluation and comparative examinations of four intervehicular commnnication systems were completed. These involved both night and day study of car-following for no signal display, for the conventional brake light, for the tri-light system denoting brake and accelerator action and an acceleration information display of horizontal rows of green and red lights to indicate the magnitude of the vehicle's acceleration or deceleration. Studies of lane changing decisions were also made. Taxonomies of functional groupings of conceptual rear-end visual display components were studied for the various signal systems previously tested. A prototype infrared sensing system was developed and tested to indicate distance and relative velocities between vehicles. Field studies of traffic dynamics were analyzed to determine the data which should be transferred by the sensing and communication system to increase traffic volume and improve safety and speed of traffic flow. Model development studies were made to quantitatively evaluate possible improvements which may be obtained through improved communication between vehicles.

The final report has been published as:

NCHRP Report 51, "Sensing and Communication Between Vehicles."

Project 3-4 FY '63, FY '64, and FY '66

Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location

Research Agency:	Airborne Instruments Laboratory	
Principal Invest.:	Fred Pogust	
Effective Date:	March 1, 1963	July 1, 1965
Completion Date:	March 31, 1965	Dec. 15, 1966
Funds:	$78,517	$49,474

This study was directed toward evaluating the nature and extent of the problem and describing the need for communication as well as the benefits of locating disabled vehicles. An additional task was researching the ways that information about disabled or stopped vehicles may be used.

An interim report has been published as:

NCHRP Report 6, "Means of Locating and Communicating with Disabled Vehicles."

Following the comprehensive review of the nature, extent, and characteristics of the stopped-vehicle problem conducted during the first year of research, the researchers continued to investigate the feasibility of a detector system. A roadside vehicle detector system was developed using a silicon photo-voltair diode as the roadside receiving unit, and signalling was performed by a vehicle-mounted relay-type interrupting device which modulates infrared-emitting diodes. A prototype system was built, tested, and demonstrated to the project panel.

The final report has been published as:

NCHRP Report 40, "Means of Locating Disabled or Stopped Vehicles."

Project 3-5 FY '63, FY '64, FY '66, and FY '69

Improved Criteria for Designing and Timing Traffic Signal Systems

Research Agency:	Planning Research Corp.		
Principal Invest.:	F. A. Wagner, Jr.		
Effective Date:	3/1/63	7/1/66	8/1/68
Completion Date:	12/31/65	7/31/67	12/31/69
Funds:	$123,030	$48,155	$93,717

The over-all objective of the research was to determine the most efficient method of timing traffic signals for isolated intersections, arterial highways, and grid networks of city streets. The research was accomplished in three phases.

The results of the first phase of research, involving methods of signal timing for the isolated intersection, have been published as:

NCHRP Report 3, "Improved Criteria for Traffic Signals at Individual Intersections—Interim Report," and

NCHRP Report 32, "Improved Criteria for Traffic Signals at Individual Intersections."

The second phase involved development and comprehensive, closely controlled, scientific testing of several advanced concepts for operating traffic-signal systems on urban arterial streets. The results indicate that a significant degree of improvement in traffic operation is possible through application of advanced control methods. This phase final report has been published as:

NCHRP Report 73, "Improved Criteria for Designing and Timing Traffic Signal Systems—Urban Arterials."

The objective of the third phase was to simulate and field test promising signal-control logic that will produce improved signal timings for a grid network of traffic signals. With the assistance of cooperating agencies, test networks were located in Los Angeles and San Jose. The San Jose computerized traffic signal network contained 46 signalized intersections, and the Los Angeles network contained 26 signalized intersections. The following signal-timing methods wee evaluated using simulation techniques and through actual field tests: (1) existing control; (2) Delay-Difference Method, Preferred Arterials Plan; (3) Delay-Difference Method, Volume Priority Plan; (4) Delay-Difference Method, Mixed Cycle Plan; (5) SIGOP Plan; (6) Combination Method Plan.

The final report has been published as:

NCHRP Report 124, "Improved Criteria for Traffic Signal Systems in Urban Networks."

Project 3-6 FY '63, FY '64, and FY '66

Effect of Regulatory Devices on Intersectional Capacity and Operation

Research Agency:	De Leuw, Cather & Company
Principal Invest.:	Ronald Pfefer
Effective Date:	April 1, 1963
Completion Date:	August 15, 1966
Funds:	$153,175

The purpose of this research was to identify the effect of specified traffic regulatory devices on intersection capacity and operations and on systems of traffic facilities. The effects of stop and yield signs were investigated as they apply to capacity, traffic operations, safety, driver acceptance, and the traffic operations of the area of influence.

The initial phase of research has been published as:

NCHRP Report 11, "Effect of Control Devices on Traffic Operation."

The report examines efficient methods of intersection study and derives some preliminary relationships concerning the operations of intersections with YIELD and two-way STOP control and their street system effects.

During the second phase of research, field data were collected at STOP- and YIELD-sign locations in the areas of Chicago, San Francisco, New York, and Toronto. Analyses were made to select criteria for intersection controls and develop a method for applying them. Programs and procedures were developed to integrate and analyze the field data collected during the first phase. Detailed traffic-control-devices questionnaires were analyzed from States, cities, and counties throughout the country.

The final report has been published as:

NCHRP Report 41, "Effect of Control Devices on Traffic Operations."

Project 3-7 FY '64, '65, '67, '71, and '73

Establishment of Standards for Highway Noise Levels

Research Agency:	Bolt Beranek and Newman			
Principal Invest.:	Andrew Kugler			
Effective Date:	2/1/64	10/14/68	4/1/71	9/1/72
Completion Date:	4/30/67	1/15/70	6/30/72	11/30/74
Funds:	$144,920	$69,930	$49,927	$307,486

This project was concerned with the evaluation of noise levels of the various classes of highways and the effectiveness of controlling highway noise through highway design features as well as the reduction of noise production by means of legislation and vehicle regulation. Questions relating to highway noise levels and their effect on adjacent land users frequently arise in urban highway planning and design.

The Phase I research involved the selection of the most appropriate means and units for measuring and evaluating highway noise. Its results have been published as:

NCHRP Report 78, "Highway Noise-Measurement, Simulation, and Mixed Reactions."

The Phase II research objective was to prepare a highway design noise manual for the practicing highway engineer. In addition, a magnetic tape recording was produced to demonstrate basic elements of highway noise and to present examples illustrating changes in traffic noise. Loan copies of the tape recording are available on request to the TRB Audio-Visual Library (see final page of this section for ordering information).

The results of the Phase II research have been published as:

NCHRP Report 117, "Highway Noise—A Design Guide for Highway Engineers."

The objective of the Phase III research was to conduct a thorough measurement program on various noise reduction treatments under a variety of traffic and environmental conditions. This research developed a tie between field data and analytic approaches so that the performance of noise reduction treatments may be more accurately predicted.

The results of the Phase III research have been published as:

NCHRP Report 144, "Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures."

The Phase IV research started on September 1, 1972, with the following objectives: to summarize the present state-of-the-art for controlling the noise-producing properties of the individual mechanical components of motor vehicles that lead to the composite noise produced by motor vehicles on highways; to assess the technological and economic feasibility of reduction of traffic noise that will enable highway officials to seek federal and local legislation that might redistribute the burden of noise control; and to improve procedures for highway noise control that will allow the designer to more realistically assess the highway noise problem.

The research has been completed. Final report materials include a computer program for use with the design guide and a 17-min color film entitled "Quiet Highway Design." The film is available on a loan basis from the TRB Audio-Visual Library (see final page of this section for ordering information), and copies of the computer program can be supplied upon written request to the NCHRP. The final report on the concluding phase of this research has been published in two volumes:

NCHRP Report 173, "Highway Noise—Generation and Control," and

NCHRP Report 174, "Highway Noise—A Design Guide for Prediction and Control."

A report on a study task on time-varying highway noise criteria was not published, but microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-8 FY '64 and FY '65

Factors Influencing Safety at Highway-Rail Grade Crossings

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	David W. Schoppert	
	Dan W. Hoyt	
Effective Date:	Dec. 1, 1963	Apr. 1, 1965
Completion Date:	Dec. 31, 1964	Jan. 6, 1967
Funds:	$17,171	$74,250

This study was directed toward the interpretation and analysis of currently available highway-rail grade-crossing data in the United States.

The initial research reviewed previous work in this area and developed a mathematical model for predicting accidents, and this was tested with accident data obtained from Minnesota, Oregon, and Virginia. A warrant was developed based on the cost of providing protective devices and the cost of possible accident savings.

Later work involved the development and testing of improved grade-crossing protective devices, and several experimental devices were studied by the agency. A human factors study was completed. Several important sources of data were found that facilitated the research associated with the development of the accident predictive model as well as refinement of the proposed criteria for grade-crossing protection. Data acquired from Stanford University included 18 years of data at 617 crossings, and data acquired from the Ohio Department of Highways included all accidents occurring at 1,000 rural grade crossings. From the Interstate Commerce Commission, the investigators obtained more than 15,000 grade-crossing accident reports spanning a five-year period.

The project report has been published as:

NCHRP Report 50, "Factors Influencing Safety at Highway Rail Grade Crossings."

Project 3-9 FY '66

Analysis and Projection of Research on Traffic Surveillance, Communication, and Control

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	Karl Moskowitz
Effective Date:	October 15, 1966
Completion Date:	January 14, 1968
Funds:	$23,760

The purpose of this study was to review the results of NCHRP Projects 3-2, 3-3, and 3-4, together with the accomplishments of other recently completed research in this area in the United States and abroad, and to determine the state of the art and set forth guidelines regarding the proposed future research efforts to be conducted in this area.

The investigators visited other researchers to collect progress reports and unpublished information. On-site observations were made on the major freeway surveillance and control facilities currently in operation.

The project report has been published as:

NCHRP Report 84, "Analysis and Projection of Research on Traffic Surveillance, Communication, and Control."

Project 3-10 FY '66

Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Morton I. Weinberg
	Dr. Kenneth J. Tharp
Effective Date:	January 1, 1966
Completion Date:	March 10, 1967
Funds:	$41,520

This research was directed at identifying the motor vehicle characteristics that are related to highway geometric design and traffic control operations. The objective was to determine the relationships between the vehicle and its operating environment. Vehicle characteristics were reviewed; where appropriate, highway design criteria were suggested.

Elements of geometric design and traffic operations presented in the basic design and policy manuals were analyzed to determine how vehicle characteristics are being utilized. A rational approach was made to determine, expand, or modify the existing criteria. The results of the review revealed those vehicle characteristics which should be known and used in designing and operating streets and highways. For vehicle characteristics which are presently unknown or where information is outdated, methods of obtaining data and methods of using this information in geometric design and traffic operations were recommended.

The final report has been published as:

NCHRP Report 68, "Application of Vehicle Operating Characteristics to Geometric Design and Traffic Conditions."

Project 3-11 FY '67

Optimizing Street Operations Through Traffic Regulations and Control

Research Agency:	Peat, Marwick, Mitchell & Co.
Principal Invest.:	James H. Kell
Effective Date:	September 1, 1966
Completion Date:	September 30, 1968
Funds:	$258,331

This research was directed to applying the best traffic regulation and control techniques to an area of typical urban streets and evaluating results. Innovations that may be expected to improve operational efficiency were explored. The cities of Sunnyvale and Redwood, Calif., were selected as the cooperating demonstration test cities. The research emphasis was placed on a quantified evaluation of the effect of traffic regulation and control techniques on the central business districts of these cities.

A base-condition traffic operations profile was established for each city and used for subsequent comparisons as changes in traffic regulations and control were implemented and evaluated through a series of test stages. Operational techniques ranging from relatively simple, but effective, signal timing to extensive left-turn prohibitions and one-way operations, were evaluated. Angle parking, no-stopping towaway, and unbalanced traffic flow were also evaluated throughout an area of urban streets. Average speeds, stops, delays, and a variety of other measures were used to determine the relative magnitude of operational efficieucy on an areawide basis. Business performance, public acceptance, and driver observance were also measured for each combination of traffic improvement techniques.

As this research study iucluded the significant areas of business performance and public opinion, greater insight was gained into the political feasibility of a proposed traffic change. The study findings substautiated the theory that no major traffic improvement plan can be implemented, regardless of the extent to which it may serve the public interest, unless it meets with the support of the general public, especially that of the business community.

The final report has been published as:

NCHRP Report 110, "Optimizing Street Operations Through Traffic Regulations and Control."

Project 3-12 FY '67, FY '68, and FY '71

Development of Information Requirements and Transmission Techniques for Highway Users

Research Agency:	Airborne Instruments Laboratory		
Principal Invest.:	M. A. Warskow	G. F. King	G. F. King
Effective Date:	10/1/66	3/29/71	4/1/68
Completion Date:	12/31/67	12/1/69	12/11/72
Funds:	$198,655	$100,500	$99,821

The objective of the over-all research problem was the development of a well-defined information system for the highway user. The system represents all conditions with which the driver is routinely, occasionally, and rarely confronted.

Analysis of the driving task disclosed that the operations performed by a driver can be characterized in terms of a hierarchy. It was found that a demanding priority (primacy) exists in satisfying information needs, and it was concluded that satisfying the primary of information needs is basic to the design of a highway information system. A procedure was developed for the systematic application of these principles to actual highway situations in accordance with basic information system requirements. In addition, current sign use was investigated, particularly the night legibility problem, to determine problem areas in sign application criteria. Mathematical analyses were presented on the probability of sign blockage by trucks and the effect of lateral displacement of signs. A sign design procedure to incorporate the findings with regard to sign use was outlined. The test site for the project was located in North Carolina.

The first- and second-phase research has been completed, and the project report has been published as:

NCHRP Report 123, "Information Requirements and Transmission Techniques for Highway Users."

Although engineers have certain established concepts and standards regarding highway guide signing, additional research, identified as Phase III of this project, was conducted to determine whether or not these present standards provide the information required to guide motorists properly on their journeys. This research involved critical highway signiug in and around urban areas and included inner-city signing, beltway signing, and junction signing for arterial routes and freeways.

The final report was not published in the NCHRP report series; however, microfiche of the report may be

purchase (see final page of this section for ordering information).

Project 3-13 FY '68

Guidelines for Medial and Marginal Access Control of Major Roadways

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Dr. Vergil G. Stover
Effective Date:	September 1, 1967
Completion Date:	November 30, 1969
Funds:	$149,293

A need existed for guides in selecting the degree of access control for a specific project and for selecting the type, location, and width of median and median openings and the design and frequency of entrances to be associated with the degree of access control.

Factors considered in this research were: accident frequency and severity; cost of physical construction and right-of-way to accomplish access control; legal considerations; traffic patterns; service to the highway user; motor vehicle operating costs; travel time and costs; land use; convenience of access to abutting property; property values; and provision for future needs for access control and for changing traffic characteristics, user requirements, or land use.

The project report has been published as:

NCHRP Report 93, "Guidelines for Medial and Marginal Access Control on Major Roadways."

Project 3-14 FY '68

Optimizing Flow on Existing Street Networks

Research Agency:	Edwards & Kelcey
Principal Invest.:	Walter E. Pontier
Effective Date:	October 1, 1967
Completion Date:	January 10, 1970
Funds:	$990,000

This project investigated the benefits to traffic flow in downtown areas which can be achieved by application of traffic engineering measures. Experimentation to quantify the effect of road improvements was carried on in two study areas—the downtown portions of Louisville, Ky., and Newark, N.J. Data developed for control and analysis of these experiments were subjected to statistical evaluation to describe those controlling conditions which influence measurements in the downtown area and to develop meaningful relationships which describe the quality of traffic flow, attaining a level of service definition for downtown streets. Methods were developed for application of the results of this research to streets of other areas.

Thirty-seven experiments were conducted to quantify the effect of traffic engineering measures. These experiments can be grouped into six major categories, as follows: directional control and lane use, curb lane controls, channelization, signal controls, inclement weather effects, and bus operation.

Consideration of the limitations of a direct capacity-volume approach to analysis of downtown traffic flows led to investigations of developing other means for quantifying and describing traffic flow of a downtown area. These included studies of acceleration noise, mean velocity gradient, and travel time, together with several elements related to travel time such as delay time, average speed, running speed, number of stops, and the number of saturated cycles at signalized intersections. These analyses indicated that a comprehensive analysis of travel time was the best medium for understanding and classifying traffic flow in the downtown area. Using the voluminous travel time and intersection study data accumulated on the project, regression analyses were performed to demonstrate the relationships which exist between various elements of travel time. It was also demonstrated that these relationships are fairly constant for arterial streets of the two study areas, in spite of their widely differing characteristics. The delay ratio—the ratio of delay time to total travel time—was developed and used in a level-of-service definition for arterial roadways of the downtown area.

A statistical evaluation of flow data described the variance and distribution of many elements of traffic flow. This study also described the effect of seasonal, daily, and hourly variations of traffic flow, developing information for control of surveys in the downtown areas.

A network analysis study was conducted to evaluate various models for use in analysis of downtown area traffic flows. As a result of this study, Newell's Intersection Model was selected for use in estimating delays at an intersection. Validation tests were performed and the model was accepted for this use. This Signal Analog Model was developed for use in studying offset relationships between adjacent signals. This model, together with conventional time-space diagramming techniques and the SIGOP program, was used in developing the offset relationships between adjacent signals. The major benefit experienced from use of this model was that the network offset relationships are made visible to the designer in three dimensions, so that the effect of any adjustment may be immediately seen at adjacent intersections.

A fine-grain Network Assignment Model was developed for the downtown Newark study area, using the Bureau of Public Roads assignment system. This model was calibrated and found to be useful for analysis of the functional use of downtown streets. This model is comparable in accuracy to similar models commonly used for analysis of urban area traffic problems.

The Network Assignment Model may be used to determine the over-all efficiency of the network. The over-all average travel speed developed from total trip time and total trip mileage outputs of the network can be used

to develop a network level of service. It is anticipated that the network level of service may become a useful measure for determining priorities for the allocation of funds in relation to need.

The final report has been published as:

NCHRP Report 113, "Optimizing Flow on Existing Street Networks."

As part of the project, a film, "Relief for Tired Streets," was produced. It demonstrates the results that can be obtained by applying sound traffic engineering practices to our nation's urban traffic problems. Loan copies of the film may be obtained through the TRB Audio-Visual Library.

Project 3-15 FY '70

Weaving Area Operations Study

Research Agency:	Polytechnic Institute of New York
Principal Invest.:	Dr. Louis J. Pignataro
Effective Date:	October 1, 1969
Completion Date:	December 31, 1973
Funds:	$300,000

Design criteria for weaving sections on multilane controlled-access highways require revision and updating, taking into account such variables as roadway geometrics, composition of traffic, volumes of mainline vehicles, and volumes of weaving vehicles.

The objective of this research is to analyze and evaluate the procedures recommended in Chapters 7 and 8 of the *1965 Highway Capacity Manual.* Based on the findings the agency is to develop improved techniques for the analysis and design of weaving sections.

A new alogrithm has been developed and evaluated, using both field data and an available data base from FHWA sources. The design and analysis procedures have been developed in such a way that graphical, analytical, and computer solutions can be employed. These techniques have been reviewed and tested by selected State higbway agencies.

The research has been completed, and the final report has been published as:

NCHRP Report 159, "Weaving Areas—Design and Analysis."

Project 3-16 FY '70

Freeway Lane Drops

Research Agency:	System Development Corp.	
Principal Invest.:	Antranig V. Gafarian Diane N. Goodwin	
Effective Date:	Nov. 1, 1969	May 1, 1972
Completion Date:	Apr. 30, 1971	Oct. 31, 1973
Funds:	$99,789	$76,815

Many variables affect the operating conditions and safety of the various lane drop configurations. Sound criteria for thc selection of the proper lane drop design for various traffic and freeway geometric conditions are needed. Accordingly, the objectives of Phase I were:

1. From field data, determine the effectiveness of existing mainline lane drops from the standpoint of safety and traffic operations.
2. Determine the effects of the significant parameters associated with various levels of safety and traffic service.
3. Recommend configurations for lane drops based on the findings of objectives 1 and 2. In this context "configurations" includes distance from the nearest upstream and downstream ramps.

In the first phase, three lane-drop sites with different geometric configurations were studied intensively to determine traffic operations and safety effects. The report on this initial phase was not pnblished; however, microfiche of the report may be purchased (see final page of this section for ordering information).

The Phase II research continued with the same three objectives and the added objective of recommending remedial treatments in a set of guidelines based on analysis of descriptive data and traffic performance from many existing lane-drop sites.

The research has been completed, and the final report has been published as:

NCHRP Report 175, "Freeway Lane Drops."

Project 3-17 FY '71

Improving Traffic Operations and Safety at Exit Gore Areas

Research Agency:	The Pennsylvania State University
Principal Invest.:	James I. Taylor
Effective Date:	January 1, 1971
Completion Date:	November 30, 1972
Funds:	$79,983

This research project addressed the problem of erratic maneuvers, such as backing up and stopping in the gore area, that occur with alarming frequency at freeway exit areas. Specifically, it was directed toward answering three basic questions: What factors cause motorists to make erratic maneuvers at exit gore areas? What remedial devices can be employed to reduce their occurrence at existing sites? And, what changes in design and traffic control criteria can be recommended that will minimize the problem at future sites? The results of this study provide answers to these questions, and the findings can be used by traffic and design engineers to enhance the safety and traffic operations at freeway exit facilities.

Nine exit sites, incorporating different geometric features, were examined for erratic maneuvers during the course of this project. Analysis of the patterns of the erratic maneuvers themselves and on-site driver interviews were used to determine causative factors of these maneuvers. The results indicate that more than one factor

is usually present at any one site and that these factors vary from site to site.

The final report has been published as:

NCHRP Report 145, "Improving Traffic Operational and Safety at Exit Gore Areas."

A 10-min color film, "Safety at Freeway Exits," highlighting the research findings is also available on a loan basis from the TRB Audio-Visual Library (see final page of this section for ordering information).

Project 3-18(1) FY '70

Improved Control Logic for Use with Computer-Controlled Traffic

Research Agency:	Stanford Research Institute	
Principal Invest.:	Dr. Dale W. Ross	
	Dr. Thomas L. Humphrey	
Effective Date:	July 15, 1971	April 15, 1975
Completion Date:	May 15, 1974	June 30, 1977
Funds:	$323,998	$57,662

During the past few years, a large number of general-purpose digital-computer-controlled traffic signal systems have been installed. Although the potential of these systems to improve operations and to increase capacity has been demonstrated, there still exists a sizeable gap between the inherent hardware capabilities and the know-how (software) necessary to use these systems at optimum efficiency.

The object of this research has been to study traffic flow and control interaction and to develop an advance control concept, strategy, and computer program. The research has included development of an operational control program that has the capability of calculating optimal offset patterns for a network of signalized intersections and determining independent and variable signal split adjustments. The program, designed for application under all levels of network traffic volumes, including oversaturated conditions, has been tested and evaluated with actual traffic in the San Jose traffic control system.

A final report describing the research and the resulting ASCOT program package has been submitted. It will not be published in the NCHRP report series, but copies are available on either a loan or purchase basis. A 20-min color film describing the program and its functions is also available on a loan basis for the cost of mailing and handling. The film, "Improved Control Logic for Use with Computer-Controlled Traffic," is available on a loan basis from: TRB Audio-Visual Library; the report may be purchased for $10.00 (see final page of this section for ordering information).

Project 3-18(2) FY '71

Traffic Control in Oversaturated Street Networks

Research Agency:	Polytechnic Institute of New York
Principal Invest.:	Dr. Louis J. Pignataro
Effective Date:	September 1, 1971
Completion Date:	June 30, 1975
Funds:	$200,000

Traffic operations and control techniques that function effectively when street network demands are below saturation deteriorate when severe saturation exists for any length of time. Research is needed to define the scope and magnitude of the problem, nationwide; to determine how the problem can best be combatted with existing control techniques; and to begin a systematic research process leading to improved operation and control of oversaturated networks.

The specific objectives of the first phase of the project, which has been completed, were to:

1. Define the measures of network oversaturation and determine the existing scope and magnitude of the oversaturated street-network problem.
2. Define the root causes of the problem.
3. Evaluate the relative effectiveness of existing operations and control techniques used to combat the problem.
4. Prepare detailed operational guidelines for application of existing traffic operations and control techniques of illustrated effectiveness.
5. Describe alternative concepts of advanced traffic-control techniques for improving the efficiency of traffic operation in oversaturated networks.
6. Formulate a detailed plan and program for systematic development, testing, and application of improved traffic control in oversaturated networks.

A final report on this phase has been submitted. Although it will not be published, unedited draft copies are available on loan upon request to the NCHRP Program Director. The essential findings of this report have been published as NCHRP Research Results Digest 51.

A continuation phase with the following objectives was initiated: to carry out further studies in minimal-response signal policies, nonsignal effects and remedies, and highly responsive policies and to produce a set of recommendations and guidelines for applying solutions to the problems of oversaturation.

The research has been completed, and the final report covering the entire project has been published as:

NCHRP Report 194, "Traffic Control in Oversaturated Street Networks."

Project 3-18(3) FY '75

Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems

Research Agency:	JHK & Associates
Principal Invest.:	Thomas L. Stout
Effective Date:	May 1, 1975
Completion Date:	April 15, 1977
Funds:	$123,267

Improved systematic procedures to evaluate alternative traffic control systems, presented in a readily understandable and implementable form, are needed to aid the traffic engineer in deciding how best to use his budget in choosing among solutions.

The objectives of this research were to develop and to demonstrate a practical total-system cost-effectiveness methodology for the comparative evalnation of alternative traffic surveillance and control systems for signalized street networks. The methodology developed should take into consideration all pertinent factors bearing on the choice of the best control technique, including such factors as types of hardware components used; extent of real-time human operator interface required or desired; degree of automated traffic sensing employed for either on-line control or off-line system support purposes; physical and traffic flow characteristics of the street network being controlled; and technical skills and other resources of the operating agency.

The research effort consisted of four major tasks. The first was to identify the range of systems to be covered, for example, from systems with nonresponsive time-of-day control to those with on-line timing plan optimization. The next task was to develop a systematic methodology for evaluating alternative designs. The third task was to exercise the cost-effectiveness methodology in order to demonstrate its usefulness. Lastly, the results were to be documented in a final report, and the procedure described in a user manual for traffic engineers.

The project's revised final report and a separate manual have been submitted. The research report, "Signal System Evaluation Methodology," will not be published in the NCHRP report series but is available on a loan basis. The manual, "An Approach for Selecting Traffic Control Systems" may be obtained on a loan basis or purchased for $11.00 (see final page of this section for ordering information).

Project 3-18(4) FY '76

Methodology for Performance Evaluation of Signalized Network Control Strategies

Research Agency: Compntran Systems Corporation
Principal Invest.: Dr. H. Nathan Yagoda
Effective Date: July 21, 1977
Completion Date: November 20, 1980
Funds: $148,705

A common problem faced by the traffic engineer is the need to measure and evaluate performance in both grid and linear street networks under two or more traffic control strategies. Often, the magnitude of difference in traffic performance between two strategies is relatively small but, nevertheless, statistically significant. Thus, a need exists for an efficient, practical, and unbiased methodology to determine whether two sets of traffic control strategies are equal or different, with known levels of statistical confidence. Even though the problem is compounded by the existence of uncontrollable extraneous variables affecting traffic performance, it is nonetheless desirable to measure performance empirically under actual operating conditions.

The objective of this research was to develop and demonstrate a practical methodology for the comparative performance evaluation of alternative traffic control strategies for signalized street networks. The research addressed networks of ten or more signalized intersections.

The first part of this research concentrated on the identification of potential MOE's and the conceptualization of a network evaluation methodology. This methodology includes a general model for selecting MOE's suitable for performance evaluation of alternative traffic control strategies, and another model relating the "demand for service" (volume x straight-line distance) to the actual service provided (volume x actual distance traveled between origin and destination) for dealing with the impact of random variations in volume in a street network. An analytic technique for comparing two sets of performance data was also developed. This technique relates a link-level MOE (e.g., vehicle-miles of travel per hour) to the service provided (vehicle-miles of travel) on the link by a linear regression of two parallel lines.

In the second part of this research, field studies were conducted to test and refine the methodology. A linear network comprised of ten signalized intersections on an arterial in Henrico County, Va., was studied. Vehicle-miles per hour as a network MOE and vehicle-miles as a measure of demand proved well suited for traffic signal system performance studies. These quantities can be estimated from data routinely collected by any traffic engineering agency. Vehicle-miles per gallon as a network MOE conld not be properly evaluated because the precision of the fuel consumption hardware was insufficient for measuring 5 percent changes over the distances travelled on the test site. Data collection methods included the floating car technique and aerial photography. Use of cameras for a license matching technique was investigated but abandoned because of limitations in the photographic equipment. The floating car technique proved to be most effective for genceal nse; aerial photography presented significant difficulties in data acquisition and reduction.

The research has been completed, and copies of the agency report are available on a loan basis or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-19 FY '72

Grade Effects on Traffic Flow Stability and Capacity

Research Agency: Midwest Research Institute
Principal Invest.: Andrew D. St. John
Effective Date: September 1, 1971

Completion Date: August 31, 1974
Funds: $220,443

The nonuniform performance capabilities of vehicles are a major detrimental factor in the flow of traffic on two-lane roads and on multilane highways. The performance differences are more significant on grades and increase the likelihood of traffic instabilities, accidents, and loss of capacity.

The objectives of this research were to:

1. Determine and verify methods for calculating the acceleration and speed-maintenance capabilities on grades of a wide range of motor-vehicle types, including trucks and combinations, buses, campers, housetrailers, low-performance passenger cars, and other atypical vehicles normally found on Interstate and primary highway systems.
2. Determine the factors that create instabilities in the traffic stream on grades. Particular attention is to be given to the role of low-performance and unusual-size vehicles in the creation of these instabilities.
3. Determine, through use of appropriate digital-computer traffic-simulation models and by correlated field measurements, the passenger-car equivalencies for the vehicle types enumerated in objective 1.
4. Determine the effects on safety and traffic flow with both restricted and unrestricted operations of 12- and 14-ft-wide loads ou highways in varying terrain. The goal of this objective is to provide guidance for the regulation of these unusual load widths.
5. Estimate, by use of correlations between traffic flow characteristics and accident frequencies, the accident implications for the situations studied in objectives 2 and 4.

The research has been completed, and the final report has been published as:

NCHRP Report 185, "Grade Effects on Traffic Flow Stability and Capacity."

Project 3-20 FY '73

Traffic Signal Warrants

Research Agency:	KLD Associates	
Principal Invest.:	Edward B. Lieberman	
Effective Date:	Sept. 1, 1972	Nov. 1, 1974
Completion Date:	Apr. 15, 1974	Dec. 31, 1976
Funds:	$120,000	$81,935

The purpose of traffic signal warrants should be to determine when the improvement of intersection performance (operation and/or safety) should include the installation of a traffic control signal.

Existing traffic signal warrants as presented in the "Manual on Uniform Traffic Control Devices for Streets and Highways" may not consider all of the factors that should go into a determiuation of need for traffic signal control, or cousider them only in general terms. It is ofteu necessary to temper the numerical warrants with judgment to the degree that the warrants may appear discredited. This is not to say that engineering judgment should be precluded in the decision. Improved warrants should lead to better and more consistent applications.

The objective of this research is to evaluate the adequacy of existing warrants, or the need for revised or additional warrants, in meeting current needs for determining whether a traffic signal should be installed.

The research has been completed, and the final report has been submitted. New warrants have been developed and are presented in the report, which also includes recommended changes for the relevant text of the *Manual on Uniform Traffic Control Devices* dealing with traffic signal warrants. Procedures for field validation of the proposed warrants have also been designed and are recommended in the report.

The report has been provided to the National Advisory Committee on Uniform Traffic Control Devices for consideration. The report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-20A FY '80

Peak-Hour Traffic Signal Warrants

Research Agency:	JHK & Assoeiates
Principal Invest.:	R. David Henry
	Jay H. L. Calhoun
Effective Date:	June 23, 1980
Completion Date:	July 31, 1982
Funds:	$150,000

A traffic signal warrant based on peak-hour conditions was needed to supplement the existing warrants in the *Manual on Uniform Traffic Control Devices* (MUTCD) by providing a basis for determining the need for a traffic signal due to the unique peak-hour conditions that are not fully considered by the other warrants. Several peak-hour warrant elements had been proposed but had not been verified in regard to the acceptability of the underlying assumptions and the actual numerical values. These elements needed to be investigated and verified to determine which should be adopted for general use.

The objective of this research was to evaluate aud verify the peak-hour warrant suggested by the Siguals Subcommittee of the National Advisory Committee on Uniform Traffic Control Devices (NAC) and the peak-hour warrant developed as part of NCHRP Project 3-20. A recommendation with supportiug documentatiou and justification was desired for adoption of a warrant, including either modifications to the above warrants or cousideration of an alternative warrant.

Field studies were conducted at 190 intersections to obtain the necessary data to analyze each warrant element. Intersection delay, percent stops, traffic volume,

and queue length were determined. The field studies included six urban areas and various intersection types.

A new peak-hour warrant was developed based on queue length. In general, a signal is considered to be warranted when there is an average queue of at least four vehicles for one hour on a typical day.

The project report has been published as:

NCHRP Report 249, "Peak-Hour Traffic Signal Warrant."

Project 3-21 FY '74

Motorist Response to Highway Guide Signing

Research Agency: BioTechnology, Inc.
Principal Invest.: Fred R. Hanscom
Wallace G. Berger
Effective Date: April 1, 1974
Completion Date: January 31, 1976
Funds: $272,071

The value of recent research evaluating the effects of guide signs on the motorist has been limited by a lack of validated measures of driver response to various signing alternatives. Validation of both new and existing measures is needed to ensure that sign studies will have a common base and that signing standards can be based on definitive research results.

The first research phase under this project was directed, therefore, to identification of promising measures of driver response to guide signing and to development and validation of such measures. The research has been completed, and copies of the agency report are available on a loan basis upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

The second research phase, NCHRP Project 3-21(2), extends the Phase I effort to address a specific application; i.e., use of changeable-message signs in advance of freeway lane closures.

Project 3-21(2) FY '77

Effectiveness of Changeable-Message Displays in Advance of High-Speed Freeway Lane Closures

Research Agency: BioTechnology, Inc.
Principal Invest.: Fred R. Hanscom
Effective Date: December 1, 1979
Completion Date: August 31, 1981
Funds: $170,993

NCHRP Project 3-21, "Motorist Response to Highway Guide Signing," developed various driver response measures that can be used to determine the effectiveness of different signs. Project 3-21(2) extended the original research by applying the response measures to a specific signing problem.

Varions situations require closnre of one or more traffic lanes as a result of planned or nnplanned conditions (e.g., accidents, unexpected road obstructions, construction, and maintenance activities). Although the *Manual on Uniform Traffic Control Devices* described recommended treatments for typical lane closures, there was a need for improved methods of providing advance information to the motorist.

The objective of this research was to determine effective advance message displays (e.g., words, symbols, and lane signals) for lane closures on high-speed freeways. This research provides, as a result of field studies at selected lane-closure sites, an objective analysis of traffic performance in response to varions changeable-message displays.

Field tests were conducted in Charleston, S.C.; Macon, Ga.; Boulder, Colo.; and Escondido, Cal. Devices that were tested included 3-line and 1-line bnlb matrix signs and a 2-line rotating drum sign; data were also collected for a base condition without a sign for comparison purposes. Both right and left lane closures were studied.

Volume I of the agency's report, containing the major findings from Project 3-21(2), has been published as NCHRP Report 235, "Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures." Volume II of the agency's report, providing greater detail on the field study and questionnaire results, is available from NCHRP for $3.50 prepaid. Microfiche of the report is also available (see final page of this section for ordering information).

Project 3-22 FY '74

Guidelines for Design and Operation of Ramp Control Systems

Research Agency: Stanford Research Institute
Principal Invest.: Dale P. Masher
Effective Date: April 15, 1974
Completion Date: December 31, 1975
Funds: $199,030

The objectives of this project were to analyze existing ramp control techniques and to develop design procedures for freeway ramp control systems. The research considered those types of ramp control designed to keep freeways operating at or near capacity during peak periods with a minimum of manual operation. Merge control, gap-acceptance systems, and computerized control of traffic signals on surface streets in the freeway corridor may be relevant tools, but the development of design guidelines for these techniques was considered to be outside the scope of this project. Additionally, this project did not address guidelines for extensive freeway surveillance features except where these features relate to the control systems.

More specifically, the following tasks were addressed:

1. Preliminary design guidelines for the configuration of traffic control devices for ramp control field installations were developed.
2. Recommendations and supporting rationale were prepared concerning selection criteria for basic control strategies, with due regard to optimization of throughput, fairness (equity), diversion routes, ramp storage requirements, safety, and other appropriate factors.
3. Real-time on-line system control logic was thoroughly investigated. A control system hierarchy for integrated system management applicable to most control system projects was developed.
4. Recommendations and the supporting rationale regarding the selection of electronic hardware were prepared. Procedures for evaluating the cost-effectiveness of alternative techniques for data communication, data processing, and control were also developed.
5. Guidelines for control system adjustment to accommodate changes in traffic patterns, capacity, or operating policy were included.

The final report will not be published in the regular NCHRP series; however, microfiche of the draft report, "Guidelines for Design and Operation of Ramp Control Systems," December 1975, may be purchased (see final page of this section for ordering information).

Project 3-22A FY '77

Guidelines for Design and Operation of Ramp Control Systems

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Charles W. Blumentritt
Effective Date:	February 1, 1977
Completion Date:	March 31, 1981
Funds:	$249,823

Preliminary guidelines were developed in NCHRP Project 3-22 for designing and operating ramp control systems. The objective of NCHRP Project 3-22A was to extend this research to provide more specific guidelines to evaluate the cost effectiveness of alternative ramp control system designs. The three levels of control investigated were local pretimed, traffic responsive, and systemwide.

The researchers identified variables that affect the benefits attributable to the three types of control including variations in flow characteristics, freeway geometrics, frequency of incidents, quality and availability of alternative routes, metering rate constraints, and vehicle occupancy. A comprehensive questionnaire was sent to agencies operating major ramp control projects to obtain detailed operational data. Follow-up personal interviews with selected agencies were conducted to provide a more complete data set.

The MACK computer simulation model was used to quantify the key operational parameters that need to be included in a cost-effectiveness analysis. This model, as modified for use in Project 3-22A, was renamed FREFLO.

Limited field data collection studies were conducted at a control site in Los Angeles. Using the results of the computer simulation analysis and the field studies, a set of guidelines was prepared. The guidelines include a cost-effectiveness evaluation to address: (1) incremental benefits associated with each level of control; (2) user costs, such as vehicle delays, emissions, and fuel consumption; (3) maintenance and system operation costs; and (4) installation costs.

The final report, including the guidelines, has been published as:

NCHRP Report 232, "Guidelines for Selection of Ramp Control Systems."

Project 3-23 FY '74

Guidelines for Uniformity in Traffic Control Signal Design Configurations

Research Agency:	KLD Associates
Principal Invest.:	Gerhart F. King
Effective Date:	April 8, 1974
Completion Date:	July 28, 1977
Funds:	$308,779

The 1971 MUTCD (Part IV "Signals," Sections B and D, and Part VII, Section D, "School Area Traffic Signals") permits a broad range in traffic control signal design configurations and operation. Scientifically based guidelines for uniform standards are needed to reduce the possibilities of confusion and hazard. These guidelines should permit the flexibility needed to meet very unusual conditions.

The purpose of this study was the preparation of such guidelines for optimum traffic control signal design configurations at intersections and mid-block crossing locations. The research included the following objectives:

1. Preparation of an annotated bibliography of relevant literature and research in progress pertaining to traffic control signal design configurations.
2. With reference to Part IV, Sections B and D, and Part VII, Section D, of the 1971 MUTCD, a study of traffic control signal design configurations, including, but not limited to: number and arrangement of lenses in signal faces, size of signal lenses, type of signal lenses (arrows and program visibility signal), visibility and shielding of signal faces, number of signal faces, horizontal and vertical location of signal faces.
3. Identification and consideration of all factors related to the approach to signalized locations that affect or influence the observance, safety, and efficiency of traffic control signals.

4. Development and validation of a detailed set of traffic control signal design guidelines—based on field, human behavioral, and theoretical analyses—that would produce optimum traffic control signal design configurations.

5. Preparation of proposed revisions of the referenced sections of the 1971 MUTCD.

6. Identification of the areas in which further research is indicated.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-24 FY '75

Determine the Luminous Requirements for Retroreflective Highway Signing

Research Agency: University of Michigan
Principal Invest.: Dr. Paul L. Olson
Effective Date: September 1, 1974
Completion Date: April 30, 1977
Funds: $100,000

The purpose of this study was to define the relationship between sign luminance and legibility in a way that would assist in selecting optimum material choices for various signing applications as well as aid in decisions concerning maintenance and replacement.

A laboratory study was carried out to define the effects of luminance, contrast, color, and driver visual characteristics on legibility distance. A computer model was developed to predict the legibility distance of a sign based on the laboratory data as well as geometric and photometric variables. A field study was conducted in which legibility distance predicted by the model was compared with legibility distance measured on a numbr of real and simulated signs. Data were developed that show graphically the relationship between legibility distance and the photometric properties of background and legend materials.

The final report was not published in the NCHRP report series; however, a copy of it, entitled "Determine the Luminous Requirements of Retroreflective Highway Signing," is available at a cost of $7.00 (see final page of this section for ordering information).

Project 3-25 FY '76

Cost and Safety Effectiveness of Highway Design Elements

Research Agency: Roy Jorgensen Associates, Inc.
Principal Invest.: Joseph F. Banks, Jr.
Dr. Richard L. Beatty
Dr. David B. Brown
Effective Date: July 15, 1975
Completion Date: April 16, 1978
Funds: $260,576

The objectives of this research were (1) to identify the key geometric characteristics and combinations of characteristics of road and street designs that affect accident frequency and severity; (2) to quantify the effects of varying the key characteristics and combinations of characteristics on accident frequency and severity; and (3) to develop a methodology that can be used by engineers in measuring the cost-effectiveness of the various levels of each design element.

Abont 50 design features were found to have some relationship to safety. Because only a limited number of design elements could be studied in depth during this research, the features of pavement width, shoulder width, and shoulder surface type for rural two-lane highways were selected for quantifying their relationship to accident and frequency and severity.

A safety cost-effectiveness methodology was developed to incorporate the quantified relationships into a practical design procedure. Utilization of the safety relationships and methodology contained in the final report will provide an optimum design for pavement width, shoulder width, and shoulder type. The methodology does not contain a rigid procedure for selection of the final design, but provides the necessary cost-effectiveness information for the designer to make an objective decision. The final design selected must also consider traffic and vehicle operating characteristics, which may override the design based on safety cost-effectiveness. However, by applying the methodology, the safety ramifications of all alternatives can be determined.

Research has been completed, and the final report has been published as:

NCHRP Report 197, "Cost and Safety Effectiveness of Highway Design Elements."

Project 3-26 FY '77

Investigation of Selected Noise Barrier Acoustical Parameters

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. Sabih I. Hayek
Dr. James M. Lawther
Effective Date: December 1, 1976
Completion Date: February 28, 1980
Funds: $224,494

Noise barriers are becoming increasingly important as noise abatement measures along new highways as well as along existing bighways. Predicting their effectiveness has been difficult, however, because analytical and predictive measures have had some limitations. Even though new barrier design guides are becoming available, there is still a need to examine certain acoustic parameters. Research is needed to assess the importance of these parameters

and to determine how they may best be included in analysis procedures. Specifically, the potential effects of barrier cross-sectional shape, barrier surface characteristics, and barrier influence on ground cover effects are not considered in currently used procedures.

The basic project objective was to complete an analysis of cross-section shape, surface characteristics, and the influence on ground-cover effects. The significance of these parameters was evaluated theoretically in terms of the sensitivity of barrier effectiveness to each, and the bounds of their effects were delineated in the first phase of the project.

The second phase of the project emphasized scale-model experimentation designed to verify the findings of the first phase. The tests included evaluation of insertion loss models applied to the different barrier configurations and study of the ground-effects problem and propagation characteristics related to a pavement adjoined by an impedance-covered terrain.

The agency's final report, results of the scale-model experiments, is available on a loan basis upon written request to the NCHRP or a microfiche copy may be purchased (see final page of this section for ordering information).

Project 3-27 FY '77

Guidelines for Selecting Traffic Control at Individual Intersections

Research Agency: Alan M. Voorhees & Associates, Inc.
Principal Invest.: Philip J. Tarnoff
Effective Date: November 15, 1976
Completion Date: July 31, 1979
Funds: $150,000

To properly evaluate and determine the best type of traffic signal control to use at an intersection, some of the basic considerations that need to be addressed are (a) maintenance requirements, (b) vehicle delays on the major and minor streets, (c) over-all traffic safety, (d) coordination adaptability, and (e) cost effectiveness. The objective of this research was to develop guidelines for selecting the most appropriate type of traffic signal control for an individual intersection in both urban and rural areas. Pretimed, semi-traffic-actuated, and full-traffic-actuated control types were evaluated. An annotated bibliography of previous studies was prepared, and current practices were reviewed in depth with local traffic engineering agencies. Numerous factors affecting the choice of control type were identified.

A cost-effectiveness evaluation methodology was developed to assist in the selection of traffic signal control and addresses such items as (a) initial costs, (b) maintenance costs, (c) over-all delay, (d) percentage of traffic stopped, (e) vehicle emissions, (f) fuel consumption, and (g) other direct and indirect user costs. The incremental benefits of more sophisticated levels of control and operational reliability are fully considered. Cost and operational data are also included in the cost-effectiveness methodology to reduce the data collection requirements of future users. Adjacent intersections are addressed in the guidelines in regard to the selection of coordinated versus independent operations.

Research has been completed, and the findings have been published as:

NCHRP Report 233, "Selecting Traffic Signal Control at Individual Intersections."

Project 3-28 FY '78

Development of an Improved Highway Capacity Manual

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: December 15, 1977
Completion Date: August 15, 1979
Funds: $161,000

The *Highway Capacity Manual,* widely used for the planning, design, and operational aspects of streets and highways, was most recently published in 1965. Since that time, new research findings offer great potential for its improvement and expansion of its scope. Additional research in some areas covered by the Manual is necessary to correct inconsistencies, to evaluate the effectiveness of analytical procedures, and to provide additional data on traffic characteristics. Although substantial research has been completed or is under way, the findings have not been assembled into a single document refining the existing Manual.

Project 3-28 is a multiphase effort with the overall objective of providing the basis for a revision of the *Highway Capacity Manual* (HCM). Phase I (Project 3-28) had the threefold objective of (1) determining the current and future needs of users of the HCM, (2) assembling existing information for dissemination as an interim document prior to revision of the entire Manual, and (3) identifying gaps in the available techniques that require additional research to develop new information for inclusion in the revised Manual.

The second phase of this research includes two projects that have been initiated to satisfy the high-priority research needs identified in Phase I. Phase II research includes NCHRP Projects 3-28A and 3-28(2). The final phase will be directed to assembly of information from work sponsored by NCHRP, FHWA, and others into a form for publication as a revised Manual.

Research on Phase I has been completed. The final report presents the results of an extensive survey of user needs and a summary of related research. In addition, 15 areas of needed research are identified. Copies of the agency's report are available on a loan basis (see final page of this section for ordering information).

Interim materials were assembled and developed in Phase I for immediate distribution, as well as for eventual inclusion in the revised Manual. The Transportation Research Board has published the interim materials as TRB Circular 212 which includes capacity analysis techniques for transit, pedestrians, and unsignalized intersections.

Project 3-28A FY '80

Two-Lane, Two-Way Rural Highway Capacity

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Carroll J. Messer
Effective Date: May 1, 1980
Completion Date: February 28, 1983
Funds: $157,492

NCHRP has initiated a multiphase research effort with the objective of providing the basis for a revised, improved *Highway Capacity Manual* (HCM). Phase I research (Project 3-28) identified the specific needs of users of the HCM, provided interim materials for dissemination prior to development of the revised Manual, and identified additional research projects that should be conducted to provide input to the revised Manual. Project 3-28A was part of the Phase II effort, which was directed to satisfying the highest priority research needs identified in Phase I.

The procedures contained in the 1965 HCM for analysis of traffic operations on two-lane, two-way rural highways are based on the fundamental traffic flow relationships that expressed operating speed as a function of vehicular volume and capacity for various prevailing conditions. Users of the HCM procedures indicated a need for improvement in several elements of the technical analysis.

The objective of this research was to develop an analytical procedure to evaluate the capacity and level of service for two-lane, two-way rural roads in an appropriate form for inclusion in a revised HCM.

Existing simulation models were reviewed with a detailed analysis of the simulation parameters, such as truck speeds, grades, directional volumes, headways, and speed distributions. The MRI simulation model was selected for use in this research.

Field studies were conducted at selected sites in Texas, Pennsylvania, Colorado, West Virginia, and Alberta, Canada, to collect speed, volume, and related data for use in the analytical framework. These field data, combined with prior calibration data and other reported rural highway data, were used to indicate the general level of accuracy for the MRI model.

Relationships between traffic volume, levels of service, and related parameters were determined using the field data and the simulation model. These relationships were structured into an integrated procedure for calculation of directional speed (and other appropriate measures of effectiveness), volume, capacity, and level of service for a wide range of traffic and highway design conditions. A step-by-step analysis procedure was prepared.

TTI's final report includes a draft chapter for the HCM that will be finalized under Project 3-28B. Therefore, the report will not be published in the regular NCHRP series, but is available for $3.00 from the NCHRP (see final page of this document for ordering information).

Project 3-28B FY '82

New Highway Capacity Manual

Research Agency: Polytechnic Institute of New York
Principal Invest.: Dr. Roger P. Roess and Dr. Carroll J. Messer
Effective Date: July 1, 1982
Completion Date: March 31, 1985
Funds: $283,440

NCHRP Project 3-28 is a multiphase research effort with the overall objective of providing the basis for a new *Highway Capacity Manual* (HCM). Project 3-28, the first phase of this research, identified the specific needs of users of the HCM, provided interim materials (*TRB Circular 212*) for dissemination prior to the development of the new manual, and identified additional research projects that should be conducted to provide input to the new manual. The second research phase was directed to satisfying the highest priority research needs identified in Phase I, and included NCHRP Project 3-28A, "Two-Lane, Two-Way Rural Highway Capacity," and NCHRP Project 3-28(2), "Urban Signalized Intersection Capacity."

FHWA also sponsored research for the purpose of providing resource material for the new HCM. For example, the results of an FHWA study on freeway capacity were reported in *TRB Circular 212,* and a major study on quality of flow on urban arterials was conducted. In addition to sponsored research, the TRB Committee on Highway Capacity and Level of Service (A3A10) developed draft materials for inclusion in the new HCM, and related information was obtained from other sources (e.g., capacity manuals from other countries).

The objective of the third phase, NCHRP Project 3-28B, was to assemble and review existing information related to highway capacity, determine the most appropriate material for inclusion in the new HCM, refine and reformat that material as necessary, synthesize state-of-the-art information, and prepare a complete draft of the new HCM.

The new HCM has been published in loose-leaf format as TRB Special Report 209.

Project 3-28(2) FY '78 and FY '79

Urban Signalized Interaction Capacity

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: October 1, 1979
Completion Date: August 31, 1982
Funds: $331,000

NCHRP Project 3-28 is a multiphase research effort with the overall objective of providing the basis for a revised, improved *Highway Capacity Manual* (HCM). Project 3-28, the first phase of this research, identified the specific needs of users of the HCM, provided interim materials for dissemination prior to the development of the revised Manual, and identified additional research projects that should be conducted to provide input to the revised Manual. The second research phase, including Projects 3-28A and 3-28(2), was directed to satisfying the highest priority research needs identified in Phase I.

The objective of Project 3-28(2) was to develop procedures for capacity analysis of the intersection as a complete unit and of each individual intersection approach. This research on urban intersections and a current FHWA project, "Quality of Flow on Urban Arterials," will provide a comprehensive set of capacity analysis procedures for inclusion in the HCM.

Previous research efforts related to intersection capacity analysis were reviewed to determine the adequacy and applicability of existing techniques and simulation models for use in this study. Models and empirical techniques that can be used to relate delay, capacity, level of service, and physical and traffic variables were evaluated. An evaluation of the most promising procedures through illustrative case studies was also completed.

Traffic service measures such as delay, stops, and saturation flow were collected at intersections in Alexandria, VA; Atlanta, GA; and Tucson, AZ. Additional field data were collected in San Francisco, Chicago, and Tucson for validation purposes. In cooperation with the FHWA, the NETSIM computer simulation model was modified for use in this project. The field and simulation data were further supplemented with existing time lapse film data from a previous FHWA intersection delay study for use in the development of the capacity analysis procedure.

Computational procedures to determine the capacity, level of service, and operational features of signalized intersections were developed. The effects of traffic signal timing and phasing are included in the procedures. A draft chapter for the next HCM and a research report were prepared. Copies are available for loan upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 3-29 FY '83

Traffic Signal Display Complexity

Research Agency:	Systems Technology, Inc.
Principal Invest.:	R. Wade Allen
Effective Date:	July 1, 1983
Completion Date:	December 30, 1985
Funds:	$199,628

In urban areas, most traffic problems occur at signalized intersections, where the driving task is demanding and the potential for information processing overload and driver error is high. Inappropriate or overly complex information displays pose a possible source of confusion to the driver. Configurations incorporating such techniques as multiple signal indications and heads, arrows, special phases, flashing modes, and supplemental signs have resulted in drivers having to respond to complex and potentially confusing signals, often at cluttered and hazardous intersections.

A number of requests have been received to change provisions in the *Manual on Uniform Traffic Control Devices* (MUTCD) relating to the complexity of traffic signal displays, and concern has been expressed by the International Association of Chiefs of Police over these matters. Although the MUTCD provides guidance on traffic control signal design configurations, it does not resolve issues related to complexity.

Previous research has considered related engineering aspects of this problem (e.g., NCHRP Project 3-23, "Guidelines for Uniformity in Traffic Control Signal Design Configurations"). However, the human factor issnes associated with complex traffic signal displays and the definition of signal complexity limits have not been adequately addressed. An objective assessment is needed of both the engineering and human factors aspects to determine to what extent drivers are able to handle the multiplicity of traffic control messages, to evaluate the effectiveness of alternative treatments that are presently in use, and to determine if more effective requirements and standards can be developed to give drivers information that can be understood quickly and accurately.

The objectives of this research are to: (1) determine drivers' abilities to deal with complex signal displays and identify the associated response factors; (2) assess the effectiveness of various complex signal display treatments currently in use; and (3) identify potential, future changes.

For purposes of this research, complex signal displays are defined as those where misinterpretation by the driver may result from simultaneously viewing two or more signal and sign messages. Research includes intersection signal displays and combinations specified in Section IV-B of the MUTCD. Guidelines will be developed for providing effective and uniform traffic signal displays for complex situations, and recommended changes to the MUTCD will be identified.

The findings of previous work relevant to the effectiveness of complex signal displays have been reviewed to identify applicable information for use in this research (e.g., traffic signal visibility will only be considered to the extent that other research can be used to relate visibility to comprehension). Two hundred state, county, and city traffic engineers have been contacted to determine (1) the intersection types and geometric designs that cause the most significant problems, (2) the signal configurations (MUTCD and/or other) currently used, and (3) specific display complexity problems. Left-turn movements and

skewed and off-set intersections are considered to warrant primary emphasis.

Laboratory studies were conducted to determine the drivers' abilities to deal with complex signal displays and to assess the effectiveness of various complex signal displays currently in use. These studies determined the specific driver related factors, such as ambiguity, information overload, etc., that cause delayed and/or faulty responses. A limited field study was conducted to validate the most promising alternatives. The operational and safety aspects were evaluated in addition to verifying driver behavior and understanding, mostly for left-turn situation.

The draft final report is in the review process.

Project 3-30 FY '83

Intersection Channelization

Research Agency: Jack Leisch Associates
Principal Invest.: Timothy Neuman
Effective Date: July 1, 1983
Completion Date: May 15, 1985
Funds: $130,000

HRB Special Report 74, "Channelization" has been used since its publication in 1962 as a guide for intersection design and is included as a reference in the draft AASHTO publication, "A Policy on Geometric Design of Highways and Streets." However, changing conditions over the past 20 years suggest that an update of *HRB Special Report 74,* including guidelines, would be of considerable value to design and traffic engineers.

The objective of this research was to prepare a publication updating the information in *HRB Special Report 74* and incorporating information, illustrations, and guidelines on the current state of the art for channelization. This research covered channelization of both new and reconstructed intersections in urban and rural environments. The research included typical intersection types such as 4-way, Y, T, oblique, and multileg intersections, as well as freeway ramp intersections with surface streets.

A mail survey was conducted of all 50 state highway departments/DOTs and 90 local agencies to determine the current practice for channelization of different types of intersections. Information on operational and design characteristics was obtained as well as examples and photographs of typical intersection designs and special treatments. Standards and guides used by the agencies in the design and implementation of channelization and the findings from studies of the effectiveness of various treatments were assembled. Highway agencies with differing philosophies on channelization and/or with novel channelization treatments were visited to obtain the supplementary information, documentation, and photographs needed to cover the full range of applications, designs, and performance characteristics.

Various channelizing techniques and geometric design elements were evaluated in terms of intersection performance, safety impact, energy savings, maintenance problems, costs, and the effects on pedestrians, bicyclists, and the handicapped. The geometric design elements include island size, island type (raised, painted, or depressed), lateral clearance, and tapers approaching and leaving the island.

Channelization guidelines were developed, providing specific principles and criteria (e.g., minimum island size as a function of traffic parameters) on the applicability of channelization techniques. Typical examples of good current practice were documented including fully dimensioned plan views, photographs, and agency insights to the specific applications.

The channelization guidelines have been published with removable inserts for the design drawings as:

NCHRP Report 279, "Intersection Channelization Design Guide."

Project 3-31 FY '83

Guidelines for Evaluating Alternatives for Replacing a Grade-Separated Rail/Highway Crossing

Research Agency: Ernst & Whinney
Principal Invest.: Robert Taggart
Effective Date: September 4, 1984
Completion Date: March 3, 1986
Funds: $200,000

There are currently no widely accepted guidelines to assist management in making decisions on improvement alternatives for deteriorated bridges separating highways and railroads. Increasing bridge replacement needs are accompanied by inflation and limited revenues, putting constraints on public agency and railroad budgets. Many of these bridges are at locations where the cost of reconstructing them to current standards would outweigh potential benefits. In the absence of guidelines it is also difficult to support recommendations made to public administrators, railroad officials, hearing examiners, and the general public.

In making a decision on whether or not to retain a grade-separated crossing, four alternatives must be considered. The first two alternatives retain a grade-separated crossing by either rehabilitating the existing structure or by replacing it with a structure meeting current standards. The third and fourth alternatives eliminate the grade separation structure by replacing it with an at-grade crossing or by removing it and closing the crossing. By selecting the most appropriate alternative, costs may be reduced, providing more funds for other projects.

Grade-separated crossings very often present problems such as deteriorating structures, load limits, horizontal and/or vertical curvature approaching the bridge, occasional slippery bridge decks, and the presence of piers,

abutments, and barriers. At-grade crossings, on the other hand, have the disadvantages of traffic conflicts and restrictions, additional roadside obstacles, energy inefficiencies, restricted movement of emergency vehicles, and crossing maintenance. In addition to these technical problems, it must be recognized that practices vary widely among states in making decisions because of differences in state laws, liabilities, contractual obligations, and administrative policies. Uniform guidelines may alleviate some of these problems.

The objective of this research is to provide a comprehensive framework for use in evaluating alternatives and developing recommendations on whether to replace a grade separation with an at-grade crossing. The framework will be applicable for determining the best alternatives for new crossings and for changes to existing at-grade crossings. Widely applicable techniques, including guidelines for both quantifiable and nonquantifiable factors, are desired to assist in the decision-making process.

A list of the research tasks follows:

1. Determine the current practices of selected government agencies and railroads. A survey of a representative number of government agencies and railroads has been conducted to obtain information on design standards as well as policy and legal positions. A review of technical and legal literature on related topics has also been conducted.

2. Identify and rank factors to be considered and provide detailed documentation of how the relative importance of the factors was established. In addition to cost and safety considerations, factors include: (1) volume and nature of traffic using the intersecting highway and railroad, (2) proximate land use, (3) potential use by emergency vehicles, (4) potential environmental impact, (5) energy consumption, (6) maintenance, (7) liability, and (8) societal implications.

3. Identify sources and methods of obtaining data necessary to support the application of factors. The types of data include: (1) accident data, (2) inventory data, (3) cost information, (4) liability issues, (5) maintenance agreements, and (6) operational and mobility considerations, especially passenger trains, buses, and hazardous materials vehicles.

4. Develop a framework of procedures utilizing the factors identified in Task 2 to assist in selecting one of the four alternatives described above. Detailed analysis guidelines and a recommended format for presenting the evaluation results will be included.

5. The framework of procedures developed in Task 4 will be applied to at least two cases studies.

6. Prepare a final research report that documents the rationale used to select the framework and that describes its application. Prepare a separate user's guide, including examples, on the use of the framework.

Tasks 1 through 5 have been completed, and the final report is being prepared.

Project 3-32 FY '85

Temporary Pavement Markings for Work Zones

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Conrad L. Dudek
Effective Date: May 1, 1985
Completion Date: October 31, 1986
Funds: $150,000

Temporary traffic control has become a larger percentage of the costs on many construction, maintenance, or utility projects. With the prospects of continued inflation, limited resources, and high interest rates, it is imperative that all aspects of temporary traffic control be evaluated for economy in application and benefits to the public.

FHWA has issued guidelines and proposed changes in the *Manual on Uniform Traffic Control Devices* (MUTCD) regarding Temporary Markings for Construction and Maintenance Areas. The proposed changes would require as a minimum 4-ft broken lines as temporary markings on most projects, which is more than double what many states now specify. If adopted as the national standard, 4-ft markings will significantly increase project costs.

Research is needed to determine if the proposed 4-ft markings would actually result in significant safety and operational improvements in comparison to current practice. Perhaps shorter stripes could be just as safe and effective on most projects.

The specific objective of this research is to compare the safety and operational effectiveness of 1-ft, 2-ft, and 4-ft temporary broken line pavement markings in work zones. To ensure that the findings will be applicable to situations in which this type of marking is most typically used, the following scope and test conditions have been identified: (1) surfacing operation on a two-lane, two-way facility; (2) data collection during hours of darkness; (3) dry roadway conditions; (4) tangent and curve sections; (5) use of the test state(s) typical pavement marking cycle (40 to 50 ft); and (6) field tests in real or staged work zones that are open to traffic. In order to meet this objective, the following tasks will be performed:

Task 1. Conduct a critical review of the literature on safety and operational effects of pavement marking in work zones. Recent and ongoing research sponsored by the FHWA and others will also be reviewed.

Task 2. Develop a detailed data collection and analysis plan along with a proposed schedule. The plan should include at least the following: (1) experimental design and analysis plan, including the rationale for selecting the recommended approach and proposed sample sizes; (2) measures of effectiveness (MOE's) to be used to evaluate the three different stripe lengths; and (3) methods and location of field measurements.

Task 3. Collect and analyze data.

Task 4. Prepare a research report including a discussion of the traffic engineering and human factors implications of the research findings to current practice and to the proposed change.

Tasks 1 and 2 have been completed and field tests (Task 3) have been conducted at two Texas sites. Additional tests in Texas and Arkansas will be conducted in early 1986. MOE's include speed, lane placement, and erratic maneuvers. Test driver interviews are also being conducted to obtain qualitative data.

Project 3-33 FY '85

Capacity and Level-of-Service Procedures for Multilane Rural and Suburban Highways

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: June 1, 1985
Completion Date: July 31, 1988
Funds: $400,000

Multilane highways exist in a variety of settings from typical low-density rural environments to suburban areas where development density is higher and traffic friction due to turning vehicles and other factors also increases. Between points of fixed interruption at intersections, multilane highways operate under uninterrupted flow conditions. This flow, however, is usually not as efficient as flow on freeways, because of the various sources of side- and medial-friction that exist on multilane highways, such as: parking lots, driveways, unsignalized intersections, and opposing vehicles on undivided roadways. The visual impact of development fronting directly on the highway also influences driver behavior and contributes to less efficient operation than on comparable freeways.

Chapter 7, "Multilane Highways," of the new *Highway Capacity Manual* (HCM) to be published in 1985, is predicated largely on the limited research used for the 1965 edition and on extrapolation from recent studies of other highway types, especially freeways. In the absence of an adequate data base concerning the operating and capacity characteristics of the multilane highway, research is needed to develop this information and to prepare an improved chapter on multilane highways.

The objective of this research is to confirm and/or develop operational, design, and planning procedures for determining the capacity and levels of service of multilane highways, both rural and suburban. This research will: (1) review the current state of the art, (2) develop an adequate data base and, (3) validate, revise, or develop new analytic procedures. Items to be considered include separation of traffic directions, access characteristics, roadside development, presence of signalized and unsignalized intersections, lane widths, lateral obstructions, geometrics, and other variables that may impede smooth traffic flow. The proposed procedures will replace Chapter 7 of the 1985 HCM.

The major thrust of this effort is focused on multilane highway facilities having four or more lanes. The research, however, will also consider special multilane configurations such as three-lane, two-way operation (2-1 split) and the provision of a continuous left-turn lane. New material developed for these special configurations will be incorporated into the appropriate HCM chapter.

To accomplish this objective the following tasks will be performed in two phases:

Phase I:

Task 1. Condnct a review of the pertinent literature and current research.

Task 2. Evaluate the adequacy of the current state-of-the-art procedures used in analyzing multilane highway capacity and level of service.

Task 3. Prepare preliminary capacity analysis procedures to serve as the basis for a data collection plan. The proposed capacity analysis method may be a refinement or revision of the existing procedures or may require an entirely new concept of multilane capacity analysis.

Task 4. Prepare a field data collection plan to quantify the traffic flow relationships.

Task 5. Prepare a Phase I report, including the proposed data collection plan and a revised, detailed budget for Phase II.

Phase II:

Task 6. Collect field data according to the approved plan.

Task 7. Reduce and analyze the data collected under Task 6 to obtain values for the appropriate traffic flow relationships.

Task 8. Prepare a report describing the proposed final form and content of the capacity and level-of-service analysis procedures.

Task 9. Write a new version of Chapter 7, "Multilane Highways," containing the new analysis procedures.

Research to date has been limited to Tasks 1 and 2.

Project 3-34 FY '86

The Feasibility of a National Heavy-Vehicle Monitoring System

Research Agency: Arthur D. Little, Inc.
Principal Invest.: Lance Grenzeback
Effective Date: November 1, 1985
Completion Date: October 31, 1987
Funds: $399,985

Various types of information on heavy vehicles are collected by federal, state, and local governments to support highway planning and design activities, as well as to carry out weight enforcement programs and tax administration. Collecting and processing this information is extremely costly from the viewpoint of both government

and private industry, and in many cases the data are not as complete or as accurate as desired for the intended purpose. In addition to actual dollar costs, the present system suffers from burdensome paperwork, operator inconvenience and potential hazard, lack of enforcement uniformity, and inconsistency among the individual states. International inconsistency is also a concern. The potential nse of the collected information for other purposes (e.g., by private industry in fleet and operations management, and by enforcement agencies in locating stolen equipment) has also not been fully explored.

New technologies in automatic vehicle identification (AVI), automatic vehicle classification (AVC), and weigh-in-motion (WIM) are considered to potentially offer a more cost-effective approach to the collection of heavy-vehicle data. The interest in AVI systems, integrated with AVC and/or WIM, is so great that a group of western states and Canadian provinces is embarking on a multi-jurisdictional project to demonstrate the utility of an integrated electronic heavy-vehicle monitoring system. This project, called the Crescent Demonstration Project, is limited in scope and is not designed to address all of the questions and problems involved in the implementation of a multijurisdictional, national or international system. For example, the Crescent Project does not fully address the strategies, sample size, data requirements, data collection systems, institutional issues, and costs and benefits of implementing such an integrated AVI/AVC/WIM system.

Therefore, there is a need to evaluate the feasibility of applying these relatively new technologies at the national and/or regional levels and to build on the existing knowledge from the Crescent Project and other related studies. Institutional issues such as privacy, access to competitive information, and potential for manipulation and evasion of the system will be major determinants of feasibility and acceptability. These issues will therefore play a prominent part in the evaluation.

The objective of this research is to identify and evaluate the needs, issues, requirements, and feasibility of using an automated system (AVI/AVC/WIM) as a cost-effective, statistically sound replacement and/or supplement to existing heavy-vehicle data collection systems. This research will encompass: (1) the identification of different system-design configurations for the integration of AVI, AVC, and WIM to provide appropriate levels of monitoring and related confidence levels; (2) amount of equipment/automation to achieve different objectives; (3) site location criteria on a state, regional, and nationwide scale; (4) an economic analysis of the alternative levels of monitoring; and (5) the full range of issues associated with implementation and operation.

The following tasks will be completed:

Task 1—Identify the types and range of existing and potential national, state, and private industry functions (activities) that are or could be supported by heavy-vehicle data.

A representative number of federal and state agencies, trucking companies and associations, and individuals will be contacted to identify the full range of functions. Preliminary estimates of costs and levels of effort under the current system for performing these functions will be obtained. Anticipated cost changes in the current system will also be identified. Institutional, technical, operational, social, legal, constitutional, and other issues that may be raised by the application and use of these automated collection systems will also be identified.

In addition, review, for applicability to a national or regional system, current and past studies related to AVI, AVC, and WIM including, in particular, the results of the Crescent Project.

Task 2—Determine the required deployment density of an automated data collection system to provide an acceptable statistically based level of accuracy for each function. Each statistical design will be coordinated with the sampling procedures included in the *FHWA Traffic Monitoring Guide* based on the Highway Performance Monitoring System and will also be coordinated with any sampling framework established by the AASHTO Strategic Highway Research Program's proposed Long-Term Pavement Monitoring Program.

On the basis of the identified deployment requirements, group functions with similar needs that can be satisfied with a common system configuration of deployment density and level of sophistication (i.e., number of sites, number of vehicles equipped, type of data collection equipment, national/regional area, etc.). Approximately 3 to 5 configurations are anticipated to cover the range of functions, data requirements, and needed levels of accuracy.

Each system configuration should address:

- Industry, State, and National needs.
- Road system differences by functional class.
- Intrastate, interstate and cross-border needs.
- Tie-in with other data systems, e.g., state classification and truck weighing.
- Geographic sampling rate (distance along a route, network, area) and vehicle sample rate (number of vehicles by category).
- Ability to support numerous data gathering objectives.

Task 3—Examine each system configuration against the issues and related considerations identified in Task 1. The function groupings and configurations will then be adjusted as required by this analysis to maximize their effectiveness and deployment potential and to minimize any anticipated negative issues or impacts.

Task 4—Submit an interim report presenting the findings of Tasks 1 through 3.

Task 5—Conduct a cost-benefit analysis for each ap-

proved system configuration (including the incremental cost/benefit associated with each function). The advantages and/or disadvantages of automated systems will be compared to existing data collection and processing systems; and the impact on other data collection, processing, and reporting procedures that would be affected by the use of an automated system will be identified.

Develop recommendations for alternative function groupings and system configurations based on the cost/benefit analysis to maximize the cost/benefits.

Task 6—Describe implementation considerations for each recommended system configuration. These considerations will include the technical, operational, institutional, cost, financial, and legislative issues, the data base management system requirements, and any other considerations identified during the course of the research.

Task 7—Prepare a final report.

Research to date has concentrated on Task 1. A meeting has been held with the Crescent Project principals for coordination purposes.

Project 3-35 FY '86

Speed-Change Lanes

Research Agency:	JHK & Associates
Principal Invest.:	William R. Reilly
Effective Date:	30 months
Completion Date:	
Funds:	$250,000

Changing vehicle and driver population characteristics makes it necessary to periodically reexamine highway design criteria. The speed-change lane is one of the most common highway features because it can be either a permanent feature (terminals, lane drops, etc.) or a temporary feature (construction and maintenance zones).

The more diverse vehicle population on the highways today, ranging from light low-powered automobiles to heavy trucks, makes a reexamination of speed-change lane criteria necessary to keep design parameters current. For example, current speed-change lane design (1) uses the "standard-sized" passenger car as the design vehicle, (2) uses outdated vehicle mix and performance data, and (3) reflects limited driver behavorial data. Further, current design procedures for speed-change lanes often do not take terminal conditions into account; i.e., the roadway type at each end of the speed change lane (freeway, arterial, etc.), ramp geometrics, the merge condition (moving merge, yield, or stop), and the end treatment of the speed-change lane (taper or lane drop).

Therefore, it is desirable to validate current speed-change lane criteria with respect to today's highway operational characteristics. Improved design procedures and updated vehicle/driver characteristics are needed to provide guidance to designers for use in upgrading existing speed-change lanes, as well as in designing new ones. Specific consideration should be given to terminal conditions and ramp geometrics affecting the speed-change lane requirements.

The objective of this research is to examine the current design parameters which establish speed-change lane length. Based on a review of current practice, updated vehicle performance characteristics, and new driver-behavioral data, recommended design procedures will be developed for specific applications taking into account the type of facility, geometrics, and other relevant considerations. This research will address existing and new acceleration and deceleration lanes on freeways. The scope of this research does not include (a) the design of weaving sections, (b) work zone applications, (c) ramp metering, and (d) new accident studies.

To accomplish this objective, the following tasks will be conducted:

Task 1—Review literature and operational experience. Conduct a limited survey of state highway officials to identify existing procedures and to determine the breadth and types of operational problems encountered with speed-change lanes, including the effects of terminals and ramp geometrics. The survey should cover a sample of states to identify the full range of problems and parameters.

Task 2—Update vehicle mix and performance data. Using available published and unpublished data to the maximum extent possible, update the vehicle parameters (e.g., acceleration/deceleration rates) used in speed-change lane criteria. Gaps in the published data will be filled by contacting manufacturers and others and, if necessary, by conducting limited operational tests. Changes in vehicle mix and selection of a new design vehicle(s) will be considered.

Task 3—Determine behavioral characteristics of the driver/vehicle unit in speed-change lanes. Conduct driver information or task analyses to identify the driving tasks required to negotiate a speed-change lane. Driver behavior (e.g., gap acceptance, lane change position) under a range of conditions (e.g., volumes, sight distance, grades, vehicle types, etc.) is of interest. If necessary conduct laboratory, closed field, or field studies to verify the analyses or to fill gaps in available data. Implications of these characteristics to design criteria will be identified.

Task 4—Develop a conceptual framework for design of freeway speed-change lanes, based on (1) the review of current literature, operational experience, and design criteria, (2) updated vehicle performance data, and (3) current driver/vehicle unit behavioral characteristics. This framework will include revised or new design criteria applicable to specific conditions (e.g., facility type, grade, curvature, terminals, volume). Using the output from Tasks 2 and 3, conduct sensitivity analyses to determine which parameters are most critical to the design of speed-change lanes under various operational conditions. The results of the sensitivity analysis should provide the basis for the proposed design criteria.

Task 5—Develop a plan to field test the proposed design criteria. The test sites should be representative of the design/operational problems identified in Task 1.

Task 6—Conduct field test studies.

Task 7—Analyze the field study data to confirm the design criteria developed in Task 4 and, if necessary, modify the design criteria to reflect actual driver/vehicle performance. Also, to ensure that the data summaries account for extreme conditions, outlier data will be identified and described in the final report.

Task 8—Develop application procedures. Using the conceptual framework as the base, prepare detailed procedures for the analysis and design of speed-change lanes. A range of typical projects and conditions will be described including reconstruction and new construction. Guidance on extreme applications (e.g., steep grades, high truck volumes) will also be provided.

Task 9—Prepare a draft final report. One appendix to the report will be a stand-alone design guide tailored to state/local designers. Another appendix will include a description of the method, data, and results from the field studies for use by others who wish to collect similar data for their own specific conditions.

Research should be initiated in early 1986.

AREA 4: GENERAL MATERIALS

Project 4-1 FY '63 and FY '64

Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents

Research Agency:	University of Illinois
Principal Invest.:	Dr. E. J. Barenberg
Effective Date:	Jnne 1, 1963
Completion Date:	October 31, 1966
Funds:	$114,991

This study was directed toward the further improvement of existing methods or the development of new methods of tests which will lead to a way of measuring the effectiveness of various stabilizing agents. The methods are expected to provide definitive data to predict performance under in-service conditions and provide criteria for the design and construction of pavement components involving stabilized materials.

This research was conducted principally by means of laboratory experiments to investigate the effectiveness of viscous and nonviscous materials as stabilizing agents. Type I portland cement and a penetration-grade asphalt were chosen for the study because of their popularity as reflected in current usage, and limited tests of model pavements stabilized with both these materials were conducted in the research agency's test track for the purpose of correlating the results obtained in the laboratory with the behavior of the model pavements.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 4-2 FY '63 and FY '64

A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines

Research Agency:	Purdue University
Principal Invest.:	Dr. R. B. Johnson
	Dr. N. B. Aughenbaugh
	Dr. N. M. Smith
	Dr. T. R. West
Effective Date:	February 15, 1963
Completion Date:	November 30, 1966
Funds:	$63,990

This study was directed toward the development of tests or procedures for predicting the amount and effects of aggregate degradation and the development of techniques for upgrading such aggregates for economic use in highway pavement structures.

Numerous aggregate samples were obtained from highway agencies, together with available test data and information on performance experience. Standard laboratory tests, such as determination of specific gravity, freeze-thaw resistance, and Los Angeles abrasion loss, were conducted by the research agency. Many additional data, primarily of a petrographic nature, were also collected. An analysis was made of the standard laboratory data, the petrographic information, and the reported field performance to determine the group of tests most likely to predict the degradation of an aggregate when used in a roadway base or subbase course.

The research has been completed, and the project report has been published as:

NCHRP Report 98, "Tests for Evaluating Degradation of Base Course Aggregates."

Project 4-3(1) FY '63 and FY '66

Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Research Agency:	Virginia Polytechnic Institute	
Principal Invest.:	Dr. R. D. Walker	
Effective Date:	Mar. 1, 1963	July 1, 1965
Completion Date:	Sept. 30, 1964	Mar. 31, 1967
Funds:	$20,000	$23,337

Research conducted under this study related to the development of a rapid method of test(s) to distinguish

deleterious particles in aggregates and to predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The work was similar to that conducted under Project 4-3(2) at Pennsylvania State University (the same objectives apply) but different in approach. Certain aggregates investigated were common to both studies.

The initial research phase has been completed, and the project report for this phase has been published as:

NCHRP Report 12, "Identification of Aggregates Causing Poor Concrete Performance When Frozen."

The final research phase has been completed, and the project report has been published as:

NCHRP Report 65, "One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete."

Project 4-3(2) FY '63 and FY '66

Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Research Agency:	The Pennsylvania State University	
Principal Invest.:	Dr. T. D. Larson	
Effective Date:	Mar. 25, 1963	July 1, 1965
Completion Date:	Jan. 31, 1965	Aug. 31, 1967
Funds:	$56,457	$49,756

This project involved the development of a rapid test(s) to distinguish deleterious particles in aggregates and thereby predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The study was similar to that conducted under Project 4-3(1) at Virginia Polytechnic Institute (the same objectives apply) but different in approach. A number of aggregates investigated were common to both studies.

The initial research phase has been completed, and the project reports for this phase have been published as:

HRB Special Report 80, "A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research," and

NCHRP Report 15, "Identification of Concrete Aggregates Exhibiting Frost Susceptibility."

The final research phase has been completed, and the project report has been published as:

NCHRP Report 66, "Identification of Frost-Susceptible Particles in Concrete Aggregates."

Project 4-4 FY '63

Synthetic Aggregates for Highway Uses

Research Agency:	Battelle Memorial Institute
Principal Invest.:	M. J. Snyder F. F. Fondriest
Effective Date:	March 1, 1963
Completion Date:	April 15, 1964
Funds:	$14,790

In an effort to determine potential sources of aggregates, this study was authorized to explore the feasibility of utilizing artificial aggregates in highway construction. The study involved a survey of various industries regarding their production of potential aggregates, particularly as by-products. Inquiries were made of such users as highway departments as to desirable characteristics for aggregates. Consideration was given to the production of synthetic aggregates by nuclear or other new techniques.

Research has been completed, and the project report has been published as:

NCHRP Report 8, "Synthetic Aggregates for Highway Construction."

Project 4-5 FY '63

A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture

Research Agency:	Michigan Technological University
Principal Invest.:	Dr. W. M. Haas
Effective Date:	February 15, 1963
Completion Date:	August 31, 1965
Funds:	$64,105

This project involved an extension of present knowledge and understanding of the phenomena of the action of frost and moisture in bases and subbases. Initially, laboratory models were developed which incorporated significant variables as an aid in analyzing the mechanism of frost action and its relation to strength. Hypotheses evolving from the laboratory were checked in the field.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 4-6 FY '65

Projective Coatings for Highway Structural Steel

Research Agency:	Steel Structures Painting Council
Principal Invest.:	John D. Keane
Effective Date:	March 1, 1965
Completion Date:	November 30, 1966
Funds:	$25,000

Considerable information exists in the literature concerning the protection of structural steel from corrosion. This, however, is widely scattered, often contradictory, and has never been critically reviewed and reported on as to which of the numerous coating formulations, coating systems, and practices are best in conjunction with environmental differences. This research involved a state-of-the-art review, field exposure testing on which definitive rankings may be based, and the development of plans for research to acquire needed information where adequate coatings are not available.

Information necessary to review, summarize, and evaluate the current state of the art of protection of structural steel was secured from a search of some 2,000 pieces of technical literature and by correspondence and discussions with numerous individuals, organizations, and societies both in the United States and abroad. A parallel experimental study was conducted to determine the effects of surface preparation on the performance of coatings.

Research has been completed, and the final report has been published as:

NCHRP Report 74, "Protective Coatings for Highway Structural Steel."

In addition, the following documents have been published in extremely limited quantities:

NCHRP Report 74A, "Protective Coatings for Highway Structural Steel—Literature Survey."

NCHRP Report 74B, "Protective Coatings for Highway Structural Steel—Current Highway Practices."

Project 4-7 FY '68 and FY '69

Fatigue Strength of High-Yield Reinforcing Bars

Research Agency:	Portland Cement Association	
Principal Invest.:	Dr. John M. Hanson	
	Dr. Thorsteinn Helgason	
Effective Date:	Oct. 1, 1967	Feb. 1, 1971
Completion Date:	Feb. 28, 1970	Aug. 31, 1973
Funds:	$100,000	$50,000

The AASHO Road Test indicated that the fatigue strength of reinforcing bars is one of the key elements determining the fatigue life of reinforced concrete bridge members. Advances in bridge technology, utilizing high-yield reinforcing bars, increase the possibilities of the fatigue strength of the reinforcement limiting the life of the structure.

The principal objective of this study was to obtain fatigue strength test data on ASTM A432 steel bars (generally Grades 60 and 75) to support realistic design criteria. This was approached through the design and execution of a statistically valid experiment.

Phase I experimental work consisted of repeated-load tests on rectangnlar and T-shaped concrete beams reinforced with a single longitudinal bar. These specimens contained bars ranging in size from No. 5 to No. 11 and having nominal yield stresses from 40 to 75 ksi. Major emphasis in the Phase I study was on stress range, minimum stress, bar diameter, type of specimen, and grade of bar.

Phase II had the objectives of (1) determining the effect of surface geometry (deformation pattern and details) and (2) incorporating the results of Phases I and II into a single final report. A total of 353 fatigue tests was conducted in the two phases of work.

On the basis of the observed behavior, a fatigue design provision was developed for deformed reinforcing bars suggesting a limitation on the service load stress range.

Research has been completed, and the project report published as:

NCHRP Report 164, "Fatigue Strength of High-Yield Reinforcing Bars."

Project 4-8 FY '68

Research Needs Relating to Performance of Aggregates in Highway Construction

Research Agency:	Virginia Polytechnic Institute
Principal Invest.:	Dr. R. D. Walker
Effective Date:	January 1, 1968
Completion Date:	April 30, 1969
Funds:	$55,254

There is concern over the shortage of high-grade aggregates available at reasonable cost in many areas of the country. Efficient use of aggregates is handicapped by lack of quantitative information on the interaction between properties of the aggregate and its performance in a particular environment. The total problem involves (1) identification of the uses for which available aggregates are suitable with normal processing, (2) methods of upgrading available aggregates where necessary to make them acceptable for a particular use, and (3) adapting construction practices to permit use of available aggregates.

The objective of this research was to formulate a comprehensive series of statements of research problems and recommended studies (including estimates of time, cost, and priority) which have as their objective the development of procedures by the use of which a highway materials engineer may evaluate quantitatively the relevant properties of aggregates to be selected for a given class of use in a given environment of service for a given level of performance.

Research has been completed, and the project report has been published as:

NCHRP Report 100, "Research Needs Relating to Performance of Aggregates in Highway Construction."

Project 4-8(2) FY '71

Density Standards for Field Compaction of Granular Bases and Subbases

Research Agency:	Clemson University
Principal Invest.:	J. P. Rostron
Effective Date:	April 1, 1971
Completion Date:	June 30, 1973
Funds:	$95,248

Information is needed on the degree of compaction that should be attained during the construction of highway granular base and subbase courses as a function of such factors as nature of the material, environment, traffic, snbgrade conditions, thickness of layer, and location of

layer within the system. Density standards that provide for these factors are needed. Test procedures used to develop data to set such standards must be suitable for various materials, however they may be used, and must account for these factors as may be appropriate. Often the so-called "degree of compaction" (such as 95% AASHO T 180) is not directly related to the materials' properties or to field performance. Improper setting of density standards results in (a) rejection of materials from which satisfactory bases and subbases can be constructed and (b) construction of bases and subbases that contribute to pavement system failure by subsequent additional compaction.

The objectives of this project were:

1. To evaluate current and proposed procedures and criteria for the setting of density standards.
2. To illustrate examples of inadequate standards and the consequences of such inadequacy.
3. To develop new or revised procedures and criteria for more appropriate density standards.
4. To illustrate that the new or revised procedures and criteria would yield adequate density standards.
5. To draft, in a form suitable for adoption or adaptation by highway departments, proposed new or revised procedures and criteria for the setting of density standards to control compaction during the construction of granular bases and subbases.

The research included a literature review, an information survey, interviews with highway personnel, laboratory tests, and prototype tests.

Research has been completed, and the project report has been published as:

NCHRP Report 172, "Density Standards for Field Compaction of Granular Bases and Subbases."

Project 4-8(3) FY '72 and FY '76

Predicting Moisture-Induced Damage to Asphaltic Concrete

Research Agency:	University of Idaho	
Principal Invest.:	Dr. Robert P. Lottman	
Effective Date:	Sept. 1, 1971	Aug. 1, 1975
Completion Date:	Mar. 31, 1974	Jan. 31, 1982
Funds:	$190,177	$70,860

The loss of bond (stripping) due to the presence of moisture between the asphalt and the aggregate in asphaltic concrete is a problem in many areas of the country and is severe from the standpoint of highway pavement performance in some instances. The problem is influenced by many factors, such as asphalt characteristics, aggregate properties, mix design, construction procedures, environmental conditions, and traffic; however, field experience has indicated almost invariably that the presence of moisture in combination with the other factors is critical with regard to the loss of adhesion between the asphalt cement and the aggregate particles.

The objective of this project is to meet the need for a laboratory testing system that will quantitatively predict the ability of asphaltic concrete to resist the detrimental effects of moisture under field conditions.

Research on Phase I included sampling and laboratory testing of mixtures composed of materials from many pavements in service, some of which were experiencing moisture damage and some not. Effort was made to reproduce in the laboratory the observed response to moisture in the field. The study produced a tentatively proposed system of tests for determining the moisture susceptibility of asphaltic concrete mixtures and a detailed work plan for a field evaluation of the system. The primary research program was conducted by the University of Idaho, with assistance by Battelle-Northwest and the University of Washington.

The final report for Phase I has been published as:

NCHRP Report 192, "Predicting Moisture-Induced Damage to Asphaltic Concrete."

Research on Phase II has been completed. The predicted and observed performance over a 5-year period of 8 asphaltic concrete pavements in various climatic regions provided substantial verification of the tentative system of tests developed under Phase I.

The project report for Phase II has been published as:

NCHRP Report 246, "Predicting Moisture-Induced Damage to Asphaltic Concrete—Field Evaluation."

Project: 4-8(4) FY '84

Predicting Moisture-Induced Damage to Asphaltic Concrete—10 Year Field Evaluation

Research Agency:	University of Idaho
Principal Invest.:	Dr. Robert P. Lottman
Effective Date:	Jnne 1, 1985
Completion Date:	November 30, 1986
Funds:	$25,000

The loss of bond (stripping) due to the presence of moisture between the asphalt and aggregate in asphaltic concrete is a problem in many areas of the country and is severe from the standpoint of highway pavement performance in some instances. Under Project 4-8(3), a laboratory test was developed for predicting moisture-induced damage and the test was used to predict the performance of asphaltic concrete pavements on eight construction jobs. After 5 years of service, ranking of the pavement sections in terms of visual evidence of stripping and strength ratios of cores removed from the pavements was very similar to the predicted ranking produced by the laboratory tests.

The objective of this project is to further verify the ability of the previously developed test methods to predict moisture-induced damage in terms of distress in the asphaltic concrete layer and performance of the pavement surface courses by the collection and analysis of additional

data from the eight pavement test sections after 10 years of service.

Research is in progress.

Project 4-9 FY '69

Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices

Research Agency:	Utah Department of Transportation	
Principal Invest.:	Dale E. Peterson	
Effective Date:	Oct. 1, 1968	Oct. 1, 1972
Completion Date:	June 30, 1971	Dec. 31, 1979
Funds:	$93,494	$144,837

The problem of sealing transverse joints in portland cement concrete pavements to prevent intrusion of objectionable materials is of prime importance to many State highway departments. For several years, a number of States have specified extruded neoprene compression seals for the sealing of these joints. Recently, other types of elastometric preformed seals have also been used for this purpose. Largely because of a lack of sufficient correlation between joint sealing requirements and field performance information, most existing specifications for preformed seals consist of requirements pertaining to the neoprene elastomer used in fabricating the seal and the size, shape, configuration, etc., of the fabricated product. The relation of these requirements to seal performance in service, or their significance as predictors of performance, has not been fully developed. In view of the increasing use of preformed seals, further laboratory and field studies are required to develop design, material, installation, and performance criteria.

The objective of this project was the development of guide specifications for use of preformed elastomeric joint seals in portland cement concrete pavements. The research involved (1) a review and analysis of existing information, (2) an extensive laboratory testing program, and (3) a field evaluation phase.

Research has been completed with successful development and field verification of guide specifications. A major finding of the study is that the ability of elastomeric sealing systems to prevent intrusion of moisture and foreign material is more dependent on the adhesion between the seal and the pavement joint surface than on the pressnre exerted by the compression of the seal. Consequently, selection of and specifications for the lubricant-adhesive used during installation is a very important factor in long-term performance of the system.

The essential findings of the study have been published as NCHRP Research Results Digest 123. The agency report has been distribnted to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series, but loan copies are available upon written request to the NCHRP or a microfiche may be purchased (see final page of this section for ordering information).

Project 4-10 FY '70

Promising Replacements for Conventional Aggregates for Highway Use

Research Agency:	University of Illinois
Principal Invest.:	Dr. C. R. Marek
Effective Date:	October 15, 1969
Completion Date:	March 31, 1971
Funds:	$50,000

Although nationally there is an abundant supply of conventional aggregates suitable for highway construction, there are localized areas, and in some cases regions, in which they are not economically available or are becoming depleted. The problem is compounded because many of the existing sources are becoming unavailable through zoning restrictions, pollution control, and appreciating land values.

It is imperative that studies now be initiated to determine whether available technology can be used to alleviate the problem of diminishing aggregate snpplies in the affected areas.

The purpose of this project was to study the utilization of modern technology as it might apply to the development of substitute materials and/or new procedures for upgrading existing unsuitable materials for nse as aggregates in portland cement concrete, bituminous mixes, and base courses.

This research has been completed, and the project report has been published as:

NCHRP Report 135, "Promising Replacements for Conventional Aggregates for Highway Use."

Project 4-10A FY '70

Waste Materials as Potential Replacements for Highway Aggregates

Research Agency:	Valley Forge Laboratories
Principal Invest.:	Richard H. Miller
Effective Dote:	Sept. 1, 1972
Completion Date:	Nov. 30, 1973
Funds:	$53,663

Although an abnndant supply of conventional aggregates suitable for highway construction exists nationally, there are localized areas, and in some cases regions, in which aggregates are not economically available or are becoming depleted. The problem is compounded by the loss of existing sources through zoning restrictions, pollution controls, and appreciating land values.

The use of waste material as aggregate offers one method of alleviating this problem in highway construction where suitable sources are available in significant quantities. Such utilization will serve the public interest by providing ecologically and economically acceptable means for disposal of wastes in addition to providing

replacements for needed aggregates in urban areas where the shortage is often most severe. Research is needed now to determine the types, sources, and quantities of waste materials potentially useful as replacements for highway aggregates.

NCHRP Project 4-10, "Promising Replacements for Conventional Aggregates for Highway Use," identified the potential for using waste materials as aggregate in highway construction. The objectives for Project 4-10A, as developed from the prior effort, were to:

1. Provide an inventory of the types, sources, and quantities of waste materials potentially suitable for the production of synthetic aggregates or for otherwise replacing conventional aggregates in highway construction.
2. Provide an assessment of the prospects for practical use of specific waste materials for production of synthetic aggregates or otherwise replacing the need for conventional aggregates in highway construction, particularly where aggregate snpplies are scarce.

Accomplishment of project objectives involved:

1. Identification of all types and locations of waste materials available or anticipated to be available in the future in significant quantities that are considered potentially suitable for use in highway construction as replacements for conventional aggregates.
2. Compilation of information essential to evaluating the technical and economic feasibility of using the most promising waste materials as replacements for aggregates in highway construction.
3. Based on the information compiled in Task 2, an assessment of the technical and economic feasibility of current and future use of the waste materials have the greatest potential for use as a replacements for aggregates in highway construction, particularly where conventional aggregates are not economically available or are becoming depleted.
4. Determination of the status of use of waste materials in highway construction as replacements for aggregates.

Based on technical, economic, and environmental evaluations, 30 waste materials were found to have some potential for use as highway aggregates. The basic technology was judged to exist for converting any one of the materials into aggregate, but in most instances much experimentation remains to be done.

Research has been completed, and the project report has been published as:

NCHRP Report 166, "Waste Materials as Potential Replacements for Highway Aggregates."

Project 4-11 FY '75

Buried Plastic Pipe for Drainage of Transportation Facilities

Research Agency: Simpson Gumpertz & Heger
Principal Invest.: Frank J. Heger
R. E. Chambers
Effective Date: September 16, 1974
Completion Date: January 26, 1979
Funds: $200,000

At the time the research problem was conceived, a number of plastic pipe products were available to the transportation industry that appeared to have good potential for economical use as underdrains, storm sewers, culverts, and other drainage structures. However, because of the lack of experience with these products in transportation facilities, their use was limited in these applications. Understandably, there was a reluctance to use them in place of, or as alternates to, more conventional pipe products whose in-service behavior had been established by many years of experience. Accordingly, a need existed for an evaluation of the theoretical considerations and field performance of buried plastic pipe to determine under what conditions they could be used in transportation facilities.

Design, installation and performance criteria were analyzed in order to select pipe systems suitable for transportation applications. Ongoing state installations of plastic pipe were monitored to observe installation practice. Full-scale field tests were performed in cooperation with states to obtain realistic data on the effects of installation conditions and on pipe behavior and performance. Several piping systems were found to be appropriate for transportation drainage applications. Perforated corrugated polyethylene (PE) tubing, perforated polyvinyl chloride (PVC), and acrylonitrile-butadiene-styrene (ABS) pipe were selected for underdrains. PVC pipe and ABS composite pipe were selected for storm drains and small culverts. Advantages and possible limitations, are presented. In addition, guidelines for selecting, designing, and installing plastic pipe were developed including sample design problems, recommended specifications for two types of plastic pipe products (corrugated polyethylene tubing and polyvinyl chloride piping), and a recommended standard for field installation practices.

Research has been completed, and the project report has been published as:

NCHRP Report 225, "Plastic Pipe for Subsurface Drainage of Transportation Facilities."

Project 4-12 FY '77

Upgrading of Poor or Marginal Aggregates For PCC and Bituminous Pavements

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. Philip D. Cady
Effective Date: December 1, 1976
Completion Date: May 31, 1979
Funds: $149,941

The performance of high-type pavements, of either PCC or bituminous concrete, is influenced by many factors. Some of these are materials, environment, traffic

loading, construction practices, and maintenance. One of the most important factors in the satisfactory performance of a pavement is the incorporation of coarse aggregate consisting of sound, durable particles free from objectionable coatings. The rapid depletion or inaccessibility of such high-quality aggregates requires that methods be derived for upgrading poor or marginal materials.

The over-all objective of this study was to advance methods of upgrading poor or marginal-quality coarse aggregates to acceptable durability and structural levels for use in high-type bituminous and PCC pavement mixtures. The procedures for upgrading aggregates in this study were limited to the use of different types of coatings, chemical treatments, or impregnation with plastics or other materials.

The beneficiation addressed recognized problems such as freeze-thaw damage, stripping, degradation, inadequate soundness, alkali-aggregate reactions, destructive volume changes, and objectionable coatings.

This study did not address itself to pavement surface characteristics, such as skid properties, texture and roughness, or mixtures applied as seal coats or thin surface treatments.

The research included the following tasks:

Task 1. (a) Identification of aggregate problems that may be mitigated by beneficiation; (b) review of literature and research in progress; (c) identification of current and potentially available practices and methods for upgrading aggregate quality.

Task 2. Preliminary analysis of practices and methods.

Task 3. Preparation of an interim report that includes the findings from Tasks 1 and 2 and provides recommendations for the evaluation in Task 4 of procedures that appear to be technically and economically feasible.

Task 4. Laboratory development and evaluation of candidate procedures with selected aggregates.

Task 5. Preparation of a final report that includes findings of research and recommendations for possible field evaluation (i.e., pilot study) of selected procedures.

Research has been completed, and the final report has been published as:

NCHRP Report 207, "Upgrading of Low-Quality Aggregates for PCC and Bituminous Pavements."

Project 4-13 FY '77

Temporary Pavement Marking Systems

Research Agency:	Southwest Research Institute
Principal Invest.:	John M. Dale
Effective Date:	November 1, 1976
Completion Date:	February 28, 1978
Funds:	$49,500

Maintenance and construction operations on all classes of highways frequently require temporary pavement markings to provide motorist guidance and safe traffic movement. When existing pavement marking materials, devices, and techniques are used for this purpose, they are difficult to remove in a cost-effective manner without leaving scars on the pavement that may mislead the motorist. There remains a continuing need, for all types of pavement surfaces under all environmental and traffic conditions, for a temporary pavement marking system. Temporary marking systems are defined as those either easily applied and easily removed or those easily applied and self-destructible under controlled conditions.

The general objective of this research is to explore the feasibility of one or more candidate solutions by awarding one or more contracts within the limits of available funds. The specific objectives are: (1) To examine one or more concepts, existing or new, that offer promise for development into workable temporary pavement marking systems. The desired characteristics of these systems include delineation quality, ease of installation and removal, absence of adverse environmental effects, ease of implementation, and cost-effectiveness. (1) To analyze the feasibility of the concept or concepts in comparison with existing practice with reference to, but not limited to: (a) manpower, equipment, and material costs (application and removal), (b) effect on traffic during application and removal, (c) traffic control effectiveness, (d) system durability, (e) material and process availability, and (f) hazards to workmen during application and removal.

The concept of this research was to develop and evaluate additives to be used with existing traffic paints. Research began with lab tests of candidate additives of four types: those with water of hydration, blowing agents, fuels, and oxidizers. No practicable material was found to meet the requirements of the project. A final report has been submitted and is available on a loan basis upon written request to the NCHRP.

Further research of temporary marking materials, pursuing other approaches, has been resumed under Project 4-13A.

Project 4-13A FY '77

Temporary Pavement Marking Paint Systems

Research Agency:	Georgia Institute of Technology
Principal Invest.:	Dr. Charles J. Ray
Effective Date:	April 1, 1978
Completion Date:	September 30, 1979
Funds:	$69,971

Maintenance and construction operations on all classes of highways frequently require temporary pavement markings to provide motorist guidance and safe traffic movement. When existing pavement marking materials, devices, and techniques are used for this purpose, they are difficult to remove in a cost-effective manner without leaving scars on the pavement that may mislead the motorist. There remains a continuing need, for all types of pavement surfaces under all environmental and traffic conditions, for a temporary pavement marking system.

Temporary marking systems are defined as those either easily applied and easily removed or those easily applied and self-destructible under controlled conditions.

The specific objectives of this research were: (1) to examine new paint formulations, primer materials, and related combinations that offer promise for development into workable temporary pavement marking systems; and (2) to analyze the feasibility of the concept or concepts in comparison with existing practice.

A wide range of materials and removal processes was investigated. Coatings based on vinyl chloride copolymers, chlorinated rubber, and acrylic resins were tested. Removal techniques included photolysis, biodegradation, thermal degradation, and chemical degradation. The removal tests were inconclusive.

Research has been completed. The agency's final report will not be published but is available on a loan basis upon written request to the NCHRP.

Project 4-14 FY '78

Coating Systems for Painting Old and New Structural Steel

Research Agency:	Georgia Tech Research Corporation
Principal Invest.:	Dr. D. J. O'Neil F. A. Rideout Dr. Charles Ray
Effective Date:	January 1, 1978
Completion Date:	December 31, 1981
Funds:	$199,231

All state and local highway agencies have steel structures that must be painted to provide protection against corrosion. Available funds dictate the number of structures that can be painted and the grade of surface preparation that can be used.

Although various coating systems intended to protect structural steel are available, users report a wide range of results. Many systems, including those in general use, require a degree of surface preparation and the use of solvents, both in the formulation and for cleanup, that are being increasingly restricted to protect health and environment. In addition, some systems have poor flow characteristics, require a high degree of surface preparation, and require highly skilled applicators.

The objective of this research was the preparation of tentative guidelines for the use of existing and recently developed nonproprietary coating systems for the painting of structural steel with emphasis on such considerations as (a) health and environment, (b) exposure conditions, (c) application requirements, and (d) economics.

Information was collected on current practices by questionnaire responses and visits with state materials and bridge engineers. An accelerated testing program was conducted involving a total of 41 coating systems including 15 different primers and 17 different topcoats, all considered acceptable from a health and environmental standpoint.

Research has been completed with partial accomplishment of objectives. Tentative guidelines for selection of new coating systems have been developed but additional field testing is needed for verification.

Copies of the agency report were distributed to program sponsors and will not be published in the regular NCHRP report series. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 4-15 FY '82

Corrosion Protection of Prestressing Systems in Concrete Bridges

Research Agency:	Wiss, Janney, Elstner Associates, Inc.
Principal Invest.:	Dr. John Fraczek
Effective Date:	July 1, 1982
Completion Date:	November 30, 1985
Funds:	$250,000

The use of deicing salts or the existence of a marine environment presents a potential problem of chloride-induced corrosion of prestressing steel embedded in concrete bridge members—a problem that could ultimately lead to major structural damage. This potential problem is further exacerbated in the newer segmental bridges where the prestressing steel is located in close proximity to the deck or other exposed surface. (In fact, there is a perceived reluctance of some to use the segmental bridge design because of the possibility of prestressing steel corrosion.)

Good quality construction minimizes the potential corrosion of prestressing steel. Unfortunately, this is not always the case under actual field conditions and construction practices. Low permeable membranes and overlays, concrete sealers, and various methods of decreasing the permeability of concrete are being used, but confidence in the long-term protection of prestressing steel is lacking. More positive steps are needed to instill confidence in the use of prestressing steel in a chloride-potential environment.

A first step would be to provide immediate assistance to the design community. Consequently, there is a need to prepare and disseminate a summary report defining currently available methods for corrosion protection of prestressing steel.

A reliable system for the corrosion protection of post-tensioning steel is also urgently needed. It is believed that the basic technology for such a system exists in the form of coated or nonmetallic ducts and encapsulation of anchorages. Standards for a system are needed, and the reliability of the system needs to be demonstrated.

As a last step, a system for the corrosion protection of pretensioning steel is needed. The coating of 7-wire

strands, the most commonly used pretensioning material, poses special problems. The feasibility of protecting 7-wire strands by coating needs to be evaluated.

The objectives of this research are (1) to prepare a summary report of available technology for the corrosion protection of prestressing steel, (2) to develop and demonstrate a coating or duct system of corrosion protection for bonded post-tensioning steel, and (3) to identify a feasible system for corrosion protection of pretensioning strands. Attainment of the project objectives necessitates the following tasks.

Task 1. Identify those techniques that have been used specifically to protect pretensioning and post-tensioning steel, ducts, and anchorages from corrosion; evaluate their effectiveness based on available research and field experience; and forecast their long-term (50 to 100 years) performance. Write a report summarizing the results and identifying promising corrosion protection systems. Specifically recommend a system for the corrosion protection of post-tensioning wires, strands, and bars to be further evaluated under Task 2.

Task 2. Perform mechanical and other tests to demonstrate the practical use of the selected post-tensioning corrosion protecting system in situations encountered in the field, particularly in segmental bridge applications. Such testing should include, bnt not be limited to: (1) friction, (2) bond, (3) mechanical abrasion and damage, (4) continuity of protection at anchors, (5) compatibility with the portland cement concrete and grout environment, and (6) effectiveness of the system in protecting the prestressing steel from corrosion. Based on the test results, write a recommended practice for the design and construction of a corrosion protection system for post-tensioning.

Task 3. Determine performance requirements for nonmetallic coating of 7-wire strands used for pretensioning, including but not limited to the following: (1) chemical and physical compatibility with base metal, (2) effectiveness in controlling corrosion, (3) bond with steel and with concrete, (4) resistance to injury during handling, (5) problems associated with coiling and flexure of the strand, (6) effects of anchorage devices, (7) strain compatibility, and (8) quality control (especially the control of "holidays"). Identify and evaluate candidate coating materials, and determine the feasibility of applying the coatings through direct contact with strand and coating manufacturers and coating applicators. Based on the research done, report on the technical and economic feasibility of a nonmetallic coating system for strands.

Task 4. Prepare final report documenting all research.

The Task 1 agency interim report has been submitted, reviewed, and distributed to all NCHRP sponsors. It is available to others on a loan basis or for purchase of Xerox copies (see final page of this section for ordering information).

Based on recommendations from the Task 1 interim report, an updated research plan was submitted and approved for accomplishing the remaining tasks. Under Task 2, tests for mechanical behavior and corrosion resistance in posttensioning applications include various combinations of plastic, galvanized metal, epoxy coated metal, and bare metal ducts; uncoated and epoxy-coated anchorage hardware and 7-wire strands; and corrosion inhibiting admixtures for gronts. The testing procedures for Task 2 have not changed dramatically from those originally proposed; however, those under Task 3 have.

Task 3 was originally conceived as a feasibility study for epoxy coating 7-wire strand most likely to be used in pretensioning applications. Since the original conception of the project, an epoxy-coated 7-wire strand is now commercially available and is being used in some limited applications. Consequently, work under the updated research plan for Task 3 no longer focuses on feasibility, but on actual tests for mechanical behavior and corrosion resistance.

The testing programs for both Tasks 2 and 3 are now being conducted. Problems occurred in the development of test specimens, delaying the project beyond the existing contract completion date. A new completion date is under review, possibly to fall in the spring of 1986.

Project 4-16 FY '84

Cost and Service Life of Pavement Markings

Research Agency:	Pennsylvania State University
Principal Invest.:	Dr. John J. Henry
Effective Date:	October 1, 1984
Completion Date:	September 30, 1988
Funds:	$200,000

A wide variety of materials is available for the marking of streets and highways. Traffic paints have been the mainstay of marking materials for the past 60 years, but the recognition that such paints have severely limited serviceability in locations of high traffic volumes and/or extreme climate has led in the past 20 years to the increasing use of "dnrable" marking materials.

Traffic paints are either latex-based or solvent-based comprised of alkyd, chlorinated rubber, or epoxy resins. In severe service conditions snch materials may provide 6 months or less useful life. Durable marking materials generally are solventless systems and can be epoxy, polyester, or either hydrocarbon or alkyd thermoplastic materials. Their service life when properly applied can approach 3 or more years. Traffic paints traditionally have been applied by state and municipal forces, whereas durable marking materials are generally applied by private firms under contract.

At present, applied traffic paints can cost from $0.025 to $0.06 per lineal foot (4-inch line), while durable markings can cost from $0.055 to $1.25 per lineal foot. Cost disparities also exist for special markings, such as cross-

walks, turn arrows, and other in-lane markings. A higher initial cost may be justified if the effective service life of the durable material exceeds that of traffic paint in the same location. Higher costs may also be justified by the more intangible benefits of continuous, year-round delineation and reduced exposure of striping personnel and the public to hazardous striping operations. Such benefits are particularly important for special markings. In some cases, environmental restrictions may dictate the selection of marking materials.

The judgment of whether the cost of a material is reasonable for a particular set of circumstances (climate, traffic volume, condition of previous markings, pavement type, highway geometry, etc.) should be made on the basis of its probable service life. However, factual data on which to base such judgments are scarce. Some general information is available from field tests and operational use of various types of pavement marking materials, but there has been little to no specific treatment of the problem of how to select a cost-effective marking material for a particular set of circumstances. In addition, the influence of width (4, 6, and 8 inches) on the effective service life of traffic lines has not been established. This lack of comprehensive data is disturbing in light of stringent budgets.

The objective of this research is to determine the typical "on-road" service life and cost of various types of pavement marking materials and to quantify how major external factors affect service life. In addition, the effect of traffic line width on service life will be determined. Maximum use will be made of existing information from field tests and operational installations, and a limited amount of new field testing will be conducted. Guidelines will be developed for the use of commercially available pavement marking materials, including selection criteria affecting the optimum balance between cost and service life. The materials to be evaluated include: paint, epoxy, epoxy paint, alkyd and hydrocarbon thermoplastics, polyester paints, epoxy thermoplastic, and preformed materials. A list of the research tasks follows:

1. Compile comparative data on the performance and total cost installed of commercially available traffic paint and durable marking materials through a critical review of published results, a survey of selected state and large municipal highway agencies, and personal follow-up where appropriate.

2. Critically analyze the data to develop comparative estimates of the service life of traffic paint and durable marking materials within the ranges of external factors, such as climate, traffic volume, traffic mix, highway geometry, and type and condition of pavement and previous markings. Develop estimated installed costs per foot for each material type.

3. Prepare an interim report with a detailed test plan for Task 4. Prepare a priority listing of *all* tests needed to provide information covering the full range of materials and conditions. From this list, select specific materials and conditions for field testing within the limited funds of this project.

4. Conduct tests according to the approved test plan.

5. Prepare guidelines for selection of the appropriate pavement marking materials identifying the effects of major external factors. The intent of these guidelines is to allow users to determine life-cycle costs for various marking materials.

The first three tasks have been completed and field tests at several Pennsylvania sites are under way. Sites in two other states will also be used. Testing procedures include placing transverse lines on the pavement and using test subjects to evaluate normal centerline markings.

Project 4-17 FY '85

Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA)

Research Agency:	University of Washington
Principal Invest.:	Dr. Richard R. Horner
Effective Date:	January 7, 1985
Completion Date:	August 6, 1987
Funds:	$199,943

Because of the environmental deficiencies of conventional deicers, sodium and calcium chloride, the Federal Highway Administration (FHWA) initiated research to find a suitable alternative. As a result, calcium magnesium acetate (CMA) has been identified as a possible alternative deicing chemical.

To determine potentially undesirable environmental impacts, a chemically pure CMA has been evaluated. Laboratory investigations by Caltrans included impacts to terrestrial vegetation, impacts to aquatic ecosystems, leaching characteristics in the soil, potential atmospheric effects, occupational exposure, impacts to ground and surface water supplies, and public health implications. Results of this preliminary laboratory research indicate that pure CMA has no significant detrimental effects to the environment. However, the manufacture of pure CMA, at this time, is an expensive process. Efforts to develop a more economical method for production of CMA are underway.

Research conducted by SRI International has identified a process to manufacture CMA in large quantities by fermentation of corn grain sugars with bacterium, *Clostridium thermoaceticum*. Based on this preferred process, an FHWA research contract to develop a mutant bacterial strain for large scale production of CMA is underway at the University of Georgia. However, the product of this research may not be chemically pure CMA. Its calcium and magnesium content and its purity may vary from that previously tested in the laboratory. Consequently, the environmental impacts of CMA produced by this method for economical, large scale production may not be comparable to the results of the previous laboratory studies done by Caltrans.

Research is needed on a regional and geographic basis to determine any long-term (multiyear) environmental impacts of CMA produced by the preferred process. Additional laboratory, as well as control plot, studies are necessary to address the environmental aspects of this new material. Field studies to investigate the transport and environmental fate of CMA as a highway deicer are needed to identify and document field effects.

The objective of this study is to evaluate the transport and environmental fate of CMA as a highway deicing chemical. A 2-phase study is anticipated to be required to fully meet this objective. The purpose of Phase I, described herein, is to conduct laboratory and controlled plot studies. An experimental design for Phase II, an anticipated future field monitoring program, will also be reqnired as part of the Phase I study. To accomplish Phase I, the following tasks shall be performed:

Task 1—Laboratory Studies. Using the small test batches of CMA provided, determine the decay rate by bacteria, the removal and fate of the CMA in soil and vegetation, and the impacts to soil water and soil chemistry and physics.

Task 2—Controlled Plot Studies. Using the small test batches of CMA provided, determine the removal and fate of CMA in soil and vegetation, and the impacts to: (a) ground water (b) aquatic and terrestrial ecosystems, (c) soil water, (d) soil chemistry and physics, and (e) runoff water.

Task 3—Phase II Field Study Design. Using the information developed under Tasks 1 and 2, prepare a detailed experimental design for the conduct of field studies to determine the transport and environmental fate of CMA as a highway deicing chemical.

Task 4—Final Report. Document all work performed under Tasks 1 and 2 including interim guidelines for development of environmental impact statements for use of CMA. The Task 3, Phase II Field Study Design shall be an appended stand-alone document.

The laboratory studies of Task 1 are nearing completion with results available in early 1986. Field plots have been established in a nearby University-owned forest. These field plots address all items listed under Task 2. The first CMA applications on these field plots will occur in January–February 1986. A second series of applications will be done in the following winter season.

AREA 5: ILLUMINATION AND VISIBILITY

Project 5-2(1) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents

Research Agency:	Yale University, Bureau of Highway Traffic	
Principal Invest.:	Fred W. Hurd	
Effective Date:	Feb. 15, 1963	Feb. 1, 1967
Completion Date:	May 31, 1966	July 31, 1967
Funds:	$124,319	$21,530

Because of insufficient information on the requirements in freeway illumination, thorough research needs to be performed. A scientific basis for warrants and design criteria for use in installing continuous and localized lighting on freeways is needed, as is evaluation in terms of benefits and costs.

A 5-mile segment of the Connecticut Turnpike in the Bridgeport area was selected for the study site. The light intensity was changed to reflect illumination at both the 0.2 and 0.6 average horizontal footcandle levels. The same study area has been used for Projects 5-2(2) and 5-2(3).

Yale University has evaluated the day and night operating characteristics of traffic flow, driver behavior, and accidents. Traffic characteristic data from more than 400,000 picture frames were transferred to punched cards and analyzed by an electronic computer. Information was obtained on lane use, variation of placement and velocity, headway distributions, vehicle clustering by type, and use of the on-ramp. Evaluations of day and night accident data and traffic volume data have been made.

The project report has been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-2(2) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort

Research Agency:	The Ohio State University
Principal Invest.:	Dr. Thomas H. Rockwell Dr. H. Richard Blackwell
Effective Date:	February 15, 1963
Completion Date:	August 31, 1965
Funds:	$81,187

The objectives of this research supplemented Project 5-2(1), the accent in this contract being on the characteristics of driver response, visibility, and visual discomfort.

In conducting its research, Ohio State made interdisciplinary personnel and resources available. The instrumented vehicle utilized in Project 3-3 was also used in this project, as were various types of lighting and optical instruments developed by The Ohio State University. This project was coordinated with Project 5-2(1) for the phases of the work that were conducted on the Connecticut Turnpike site.

The driver response and roadway luminance data were transformed from the oscillograph record from the survey vehicle to numerical records for the studies conducted on the Connecticut Turnpike. Analytical procedures were prepared to provide a cross-correlation of driver control

activity with roadway geometry, traffic density, subject characteristics, and illumination levels. The analysis tested the correlation of driver variables with the severity of disability glare, and studies were conducted to see if any change in the visual environment was effected by the light intensity change.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-2(3) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort

Research Agency: The Institute for Research at State College, Pennsylvania
Principal Invest.: Dr. Paul M. Hurst
Effective Date: February 20, 1963
Completion Date: February 28, 1966
Funds: $37,460

As with Project 5-2(2), this research complemented that of Project 5-2(1). This study was concerned with only one aspect, that of driver comfort as related to anxiety as measured under various lighting conditions. The Institute for Research, a private research agency located at State College, Pennsylvania, obtained research data from motorists driving through the test area of the Connecticut Turnpike. Driver-questionnaire information was used to determine apprehension based on a numericals core and also to locate those events related to illumination which appeared to be most vexing to drivers.

The analysis included nonparametric tests of the effects of illumination, weather, moon brightness (as a function of elevation and phase), traffic volume, driver experience, driver familiarity, and day vs. night upon DDS scores and NTD scores.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-3 FY '64

Visual Information Needed by the Driver at Night

Research Agency: The Ohio State University
Principal Invest.: Dr. Thomas H. Rockwell
Dr. Ronald L. Erust
Effective Date: September 1, 1964
Completion Date: March 31, 1967
Funds: $100,940

This research was designed to determine minimum information necessary to maintain control stability and identify the information which is normally used. Visual degradation studies were conducted to determine limits of performance stability based on driver performance criteria previously established. Mapping of the visual field through selective degradation was conducted to identify classes of information used by nighttime drivers. Research was conducted to determine times and distances to satisfy information needs for optimal control. Visual cues were scaled by photometric calibration of viewed object contrasts and edge markings. An eye marking unit was employed to assess relative cue importance in maintaining performance. An attempt was made to formulate the effect of freeway informational features on driving performance based on perceptual and highway design factors.

The project report has been published as:

NCHRP Report 99, "Visual Information Needed by the Driver at Night."

Project 5-4 FY '64

Economic Study of Roadway Lighting

Research Agency: The Franklin Institute
Principal Invest.: Arno Cassel
Effective Date: July 20, 1964
Completion Date: August 31, 1965
Funds: $19,412

The purpose of this project was to determine capital cost ranges and operating costs for prevailing light sources in relation to type of luminaire distribution system and light intensity on the pavement.

The researchers collected data for economic comparisons, including costs for hardware, installation, useful operating life, power, maintenance, depreciation, taxes, insurance, and financing for various lighting systems. Sample type and quantity of equipment were analyzed to provide standard illumination levels on typical two-lane, four-lane, and six-lane divided highways. A literature search was made of available lighting cost studies, specifications, design criteria for highway lighting installations, maintenance, and replacement factors. Methods for evaluating capital improvement proposals were reviewed, and the annual cost method appeared to be most suitable for evaluating costs of different roadway lighting configurations. Questionnaires were received from public utility companies, municipalities, and State highway departments to acquire cost information.

The project report has been published as:

NCHRP Report 20, "Economic Study of Roadway Lighting."

Project 5-5 FY '65

Nighttime Use of Highway Pavement Delineation Materials

Research Agency: Southwest Research Institute
Principal Invest.: John M. Dale

Effective Date:	Mar. 1, 1965	July 15, 1967
Completion Date:	Dec. 31, 1966	Sept. 15, 1969
Funds:	$50,000	$100,000

In this study, ways of improving delineation of roadways under wet and dry conditions by either improving techniques utilizing existiug materials or developing new materials and techniques were investigated.

This program was initiated by a field study of the performance characteristics of conventional marking materials. Following this, the researchers conducted studies of the physical nature of reflective materials with particular emphasis on their performance characteristics under various types of water films. Attention was directed to the development of a systematic approach to marking pavements wherein one qualifies the surface to be marked, determines the water film thicknesses to be encouutered, and then selects one of several marking systems that will perform under the imposed conditions.

The project report on the laboratory phase of the research has been published as:

NCHRP Report 45, "Development of Improved Pavement Marking Materials—Laboratory Phase."

The purpose of the continuation phase was to further develop, optimize, and field test the new marking system that emerged from the initial research effort.

The project report on the field phase of the research has been published as:

NCHRP Report 85, "Development of Formed-in-Place Wet Reflective Markers."

In addition to the final report, a motion picture film, "Pavement Marking Materials," was produced describing the results of the research. Loan copies of the film are available from the TRB Audio-Visual Library (see final page of this section for ordering information).

Project 5-5A FY '71

Development of Optimum Specifications for Glass Beads in Pavement Markings

Research Agency:	The Pennsylvania State University
Principal Invest.:	Dr. Luke M. Shuler
Effective Date:	May. 1, 1971
Completion Date:	June 30, 1973
Funds:	$99,350

This study was a continuation of recommended research based on the findings of Project 5-5 as reported in NCHRP Report 45.

Specific objectives were to:

1. Review and analyze world-wide research and practices involving the use and manufacture of traffic marking beads.

2. Identify those variables that markedly influence the effective utilization of glass beads in pavement markings. Evaluate these variables by laboratory and field tests as required in order to rate them in terms of their influence on the effectiveness and serviceability of delineation under actual traffic conditions. Field tests are to include measurements of wet-nighttime reflectivity.

3. Determine the capability and economics of producing glass beads of specified gradation, composition, shape, flow properties, color, etc.

4. Develop practical specifications and criteria for the selection and use of beads for reflectorizing traffic paint markings.

5. Evaluate for one or more states the probable benefits that would accrue should the proposed specifications be adopted in place of current specifications.

The research included a survey of current practice and field applications of test lines using a variety of paint film thicknesses and glass bead samples. A quautitative study was also undertaken of the retroreflective characteristics of glass beads in horizontal markings by calculations based on general mathematical optical theory.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 5-5B FY '72

Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing is Prevalent

Research Agency:	Texas A & M University Research Fouudation
Principal Invest.:	Dr. William M. Moore
Effective Date:	September 1, 1971
Completion Date:	December 31, 1974
Funds:	$200,000

Conventional reflectorized pavement marking systems in common use lose their effectiveness markedly during periods of darkness in rainy weather. Raised reflectorized markers are quite effective under such circumstances and are in use where exposure to snowplows is not a factor. However, such markers may be quickly dislodged or destroyed in a large part of the U.S. where snowplowing is common during the winter months.

Accordingly, the objectives of this research were:

1. Develop one or more innovative concepts for pavement marking systems that are practical, economical, and effective under nighttime wet-pavement conditions and compatiblc with snowplowing.

2. Conduct a laboratory and controlled field evaluation of the system(s) developed in objective 1 and demonstrate its (their) practical and economic feasibility.

Interim reports submitted in September 1972 and October 1973 described the development and testing of the "first generation" markers and the development of the "second generation" markers modified in accordance with

the findings from the first winter field tests. The second generation marking systems were tested at sites in Colorado, New York, Pennsylvania, Virginia, and Texas.

The research has been completed, and the final report has been submitted. It will not be published; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 5-6 FY '68

Highway Fog

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: W. C. Kocmond
K. Perchonok
Effective Date: October 2, 1967
Completion Date: April 30, 1969
Funds: $99,955

The objectives of this research were: (1) to review past and current research of warm and cold fog as it affects highway operation; (2) to prepare a state-of-the-art summary of the review to include, but not be limited to, fog abatement, guidance systems, measures of visibility, and effect on traffic operations; (3) to determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations; (4) to explore the feasibility of warm and cold fog abatement and vehicular guidance systems under highway conditions; and (5) to suggest ways and means of obtaining maximum effectiveness of systems to combat reduced visibility due to fog.

The research has been completed, and the final report has been published as:

NCHRP Report 95, "Highway Fog."

Project 5-6A FY '70

Highway Fog

Research Agency: Sperry Rand Corporation
Principal Invest.: James O. Dyal
Richard T. Brown
William H. Heiss
Effective Date: September 1, 1970
Completion Date: May 31, 1973
Funds: $93,540

This research was a continuation of NCHRP research in the general area of highway fog. The major objectives of the research were to:

1. Analyze the highway fog problem and determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations.
2. Explore the feasibility of active and passive guidance systems for freeways and expressways that will inform and warn the motorist of prevailing roadway fog and traffic conditions ahead, and guide and control traffic more safely and conveniently through the fog area.

The research was addressed principally to the first objective and developed a measurable fog visibility index and related this index to potential actions that can be taken to eliminate or minimize the detrimental effects of fog.

The research has been completed, and the final report has been published as:

NCHRP Report 171, "Highway Fog—Visibility Measures and Guidance Systems."

Project 5-7 FY '69

Roadway Delineation Systems

Research Agency: The Pennsylvania State University
Principal Invest.: Dr. J. I. Taylor
Effective Date: October 1, 1968
Completion Date: June 30, 1971
Funds: $469,526

Vehicles running off the road constitute a substantial portion of the accidents on the nation's highways. Improved pavement and roadway delineation treatments may aid drivers in controlling their vehicles, thus improving the safety aspects of the highway and easing the driving task, especially during adverse weather conditions and at night.

Accordingly, the objectives of this research were: (1) to review past and current research pertaining to roadway delineation; (2) to prepare a state-of-the-art summary of the review; (3) to determine the driver's delineation requirements during various conditions, such as traffic, weather, highway geometry, and illumination; (4) to establish rational technique(s) for determining the effectiveness and any detrimental side effects of delineation treatments and, using the technique(s) established, evaluate existing and proposed delineation systems; (5) to test the more promising delineation systems; (6) to develop practical criteria for the selection of delineation treatments, including factors of cost effectiveness and maintenance problems; and (7) to compare the physical characteristics and performance of colored pavements with those of conventional asphalt and portland cement pavements.

The research has been completed, and the final report has been published as:

NCHRP Report 130, "Roadway Delineation Systems."

Project 5-8 FY '70

Warrants for Highway Lighting

Research Agency: Texas A & M University
Research Foundation
Principal Invest.: Neilon J. Rowan
Ned Walton
Effective Date: March 16, 1970

Completion Date: February 15, 1973
Funds: $198,875

A need existed to establish warrants for fixed roadway lighting on the various classes of roadways in both urban and rural areas; to determine whether the lighting should be continuous or just as specific locations; and to prepare guidelines for the design of lighting. Benefits from fixed-sonrce roadway illumination, including driver performance, comfort, convenience and accident prevention, have needed evaluation.

Warrants for fixed lighting on specific roadway classes and at local highway situations shonld include consideration of benefits and costs of lighting (initial and operating) to satisfy the visual requirements of the driver. A method or methods of evaluating costs and benefits of roadway lighting to maximize returns on the investment shonld be developed for the designer in order to determine the specific design.

The specific objectives of this project were to:

1. Review and analyze world-wide research and practice in roadway lighting. Prepare a state-of-the-art summary of the review.
2. Develop requirements for a suitable visual environment to be obtained by fixed roadway lighting for safe and efficient traffic operations. Provide guidelines for the design of fixed roadway lighting to obtain this environment.
3. Evaluate the possible benefits derived when a suitable visual environment is provided by fixed roadway lighting.
4. Determine warrants (the minimum conditions) for where fixed roadway lighting systems should be installed for continuous lighting and at specific locations including, but not limited to, interchanges and intersections.
5. Analyze the rolc of cost-effectiveness and other evaluation techniques in (a) establishing the need for fixed roadway lighting, (b) setting priorities for fixed lighting projects, and (c) evaluating alternative designs of lighting.
6. Recommend a method of setting priorities for the installation of fixed lighting.
7. Provide typical example(s) of where lighting is warranted and demonstrate the practical application of objectives 1 through 6.

The research has been completed, and the final report has been published as:

NCHRP Report 152, "Warrants for Highway Lighting."

Project 5-9 FY '81

Partial Lighting of Interchanges

Research Agency: KETRON, Inc.
Principal Invest.: Michael S. Janoff
Effective Date: December 1, 1980
Completion Date: January 31, 1983
Funds: $199,999

As a means of facilitating the driving task and redncing the potential for accidents, partial lighting of interchanges has been used for areas where complete or continuous lighting was not deemed to be justified. Use of partial lighting is based on the premise that it will provide, at lower costs, many of the benefits attributable to complete interchange lighting.

The objective of this research was to determine the effectiveness of partial lighting of interchanges and to develop recommendations for its use. A methodology was developed for evaluating the effectiveness of partial lighting relative to no lighting and to complete lighting of interchanges. The methodology is based on measures of visibility (e.g., illumination, roadway luminance, and a visibility index), and traffic characteristics (e.g., ramp speed, acceleration, and erratic maneuvers). The dual function that lighting serves in alerting drivers to an upcoming situation and in providing adequate visibility to execute the required driver maneuvers was investigated. The boundary conditions for roadway and traffic characteristics for which no lighting, partial lighting, or complete lighting is appropriate were determined through field studies at freeway interchanges. A small pilot study to test the field data collection was completed followed by the main field study at a site on the Baltimore Beltway.

The project report has been published as:

NCHRP Report 256, "Partial Lighting of Interchanges."

AREA 6: SNOW AND ICE CONTROL

Project 6-1 FY '63

Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles

Research Agency: IIT Research Institute
Principal Invest.: D. B. Boies
Effective Date: February 15, 1963
Completion Date: September 30, 1964
Funds: $40,000

Research was directed to the development of chemical agents that are not only economical and effective when used as deicing agents but also have minimal harmful effects on metals and concrete. Consideration was given to the relationship of laboratory tests to field conditions.

The project report has been published as:

NCHRP Report 19, "Economical and Effective Deicing Agents for Use on Highway Structures."

Project 6-2 FY '63

Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures

Research Agency: Roy Jorgensen and Associates
Principal Invest.: R. E. Jorgensen
R. D. Johnson
Effective Date: Feburary 15, 1963
Completion Date: February 29, 1964
Funds: $25,000

This study was primarily one of searching the literature and appraising the current statns of knowledge of the subject. In addition to a literature snrvey, contacts were made with highway departments and other agencies that have been confronted with the problem. Designs for structure heating systems as used in the U.S. and other countries have been evaluated, as have other nonchemical methods. The researchers have included in their studies the effectiveness of nonchemical methods and economic losses due to structure deterioration.

The project report has been published as:

NCHRP Report 4, "Non-Chemical Methods of Snow and Ice Control on Highway Structures."

Project 6-3 FY '63

Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents

Research Agency: Battelle Memorial Institute
Principal Invest.: M. J. Snyder
Effective Date: March 1, 1963
Completion Date: Febrnary 28, 1965
Funds: $58,557

Investigations on this project were oriented toward developing new and evaluating existing materials to be applied to concrete surfaces to inhibit concrete deteriorations from deicing agents. Consideration was given to fresh as well as hardened concrete.

The project report has been published as:

NCHRP Report 16, "Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals."

Project 6-4 FY '63

Evaluation and Development of Methods for Reducing Corrosion and Reinforcing Steel

Research Agency: Battelle Memorial Institute
Principal Invest.: A. B. Tripler, Jr.
Effective Date: March 1, 1963
Completion Date: April 30, 1965
Funds: $39,330

Research investigations for this project related to an appraisal of existing methods for inhibiting corrosion of reinforcing steel in concrete. Consideration was given to snch methods as (1) coatings on reinforcing bars, (2) inhibitors in concrete mixtnres, (3) inhibitors in deicing chemicals, and (4) cathodic protection.

The project report has been published as:

NCHRP Report 23, "Methods for Redncing Corrosion of Reinforcing Steel."

Project 6-5 FY '63

Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents

Research Agency: University of Illinois
Principal Invest.: Prof. C. E. Kesler
Effective Date: March 1, 1963
Completion Date: August 31, 1965
Funds: $72,500

This research concerned the relationships between the physical characteristics of concrete and the susceptibility of concrete to damage from freezing and thawing in the presence of free moisture and deicing agents. Studies were made of the effects of varying concrete production methods on potentially durable concrete. Variations in the surface porosity, strength, and air-void system produced by differing finishing techniques were evaluated for typical air-entrained concretes. Large- and small-scale specimens were cast, and effects of period and time of finishing, environmental conditions, and additions of water during finishing were evaluated using surface scaling tests, surface tensile strength tests, and microscopical determination of snrface air-void parameters.

This project has been completed, and the report has been published as:

NCHRP Report 27, "Physical Factors Influencing Resistance of Concrete to Deicing Agents."

Project 6-6 FY '63

To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete

Research Agency: The Ohio State University
Principal Invest.: Prof. R. W. Bletzacker
Effective Date: March 1, 1963
Completion Date: February 28, 1966
Funds: $69,393

In order to insure that finished concrete will conform to those specifications selected to produce adequate resistance to deicing agents, this study was initiated to evaluate and/or develop methods for securing pertinent quality control information at the earliest desirable or feasible age in order that any necessary corrective measures can be applied to the work in progress. Specifically, the study concerned the factors of (1) air content and uniformity of distribution, (2) cement content and uniformity of distribution, (3) water content and uniformity

of distribution, and (4) thickness of cover over reinforcement.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 6-7 FY '63

Estimation of Disintegration in Concrete Structures

Research Agency: Geotechnics
Principal Invest.: Floyd O. Slate
Effective Date: March 1, 1963
Completion Date: August 31, 1964
Funds: $8,547

This study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

The contract was determined with no project report. Research was resumed under Project 6-7A.

Project 6-7A FY '63

Estimation of Disintegration in Concrete Structures

Research Agency: IIT Research Institute
Principal Invest.: Dr. W. J. McGonnagle
Effective Date: February 1, 1965
Completion Date: July 31, 1966
Funds: $44,614

This research study involved the development of instrnments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

The project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 6-8 FY '63

Evaluation of Methods of Replacement of Deteriorated Concrete in Structures

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: Dr. B. D. Tallamy
Effective Date: February 15, 1963
Completion Date: February 29, 1964
Funds: $25,000

This study was directed toward a search of available literature and a canvass of agencies that have been known to employ methods of repair of structural concrete. The researchers attempted an evaluation of the economics and adequacy of the various methods to accomplish the job. Recommendations were made of areas requiring further study.

The project report has been published as:

NCHRP Report 1, "Evaluation of Methods of Replacement of Deteriorated Concrete in Structnres."

Project 6-9 FY '64

Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks

Research Agency: University of Illinois
Principal Invest.: Prof. Clyde E. Kesler
Effective Date: Jannary 1, 1965
Completion Date: Jnne 15, 1968
Funds: $200,000

Some present bridge designs allow a degree of flexibility, which, under traffic and other environmental forces, may cause cracking and opening of existing cracks. This of itself may be structurally unimportant, but in the presence of deicing chemicals may contribute to corrosion of the reinforcing and spalling of the concrete by providing access channels for the corrosive agents. Stresses induced by traffic may augment those of frost action sufficiently to cause scaling in cases where a satisfactory performance would otherwise be expected. The objectives of this research were to establish by laboratory stndies the relationships between performance and displacement in bridge-deck slabs. Air-entrained reinforced concrete deck slabs with restraints similar to those experienced by slabs on structural steel and reinforced concrete beam-type bridges were investigated, and tests were conducted on replicas of actual bridge-deck slabs. Loading and environmental conditions in these tests simulated those encountered in the field.

The final report has been published as:

NCHRP Report 101, "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks."

Project 6-10 FY '68 and FY '69

Develop Improved Snow Removal and Ice Control Techniques at Interchanges

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: L. G. Byrd
Effective Date: September 1, 1967
Completion Date: September 30, 1970
Funds: $95,000

The variety of geometrical shapes of interchange ramps, with associated structures, and their urban or rural locations invariably creates problems with respect to optimum snow removal and ice control techniques in the interchange areas. Furthermore, alternate freezing and thawing of plowed or unplowed snow across superelevated

ramps contributes to problems in snow and ice control. Drifting may further aggravate this problem. Improved snow removal and ice control techniques in interchange areas are vital to the safety of highway traffic.

The purpose of this study was to identify and evaluate the specific problems associated with snow removal and ice control operations at interchanges and to recommend methods for alleviating the problems. The investigation has been completed, and both physical and operational factors that influence winter maintenance operations at interchanges have been listed in the project report. Design considerations and operational procedures aimed at alleviating the problem have been described in a manual submitted as part of the final report.

The project report has been published as:

NCHRP Report 127, "Snow Removal and Ice Control Techniques at Interchanges."

Project 6-11 FY '71

Economic Evaluation of the Effects of Ice and Frost on Bridge Decks

Research Agency:	Midwest Research Institute	
Principal Invest.:	Robert R. Blackburn	
Effective Date:	Sept. 1, 1970	Sept. 12, 1972
Completion Date:	Nov. 30, 1971	Sept. 11, 1974
Funds:	$50,000	$50,000

Ice or frost on bridge decks while the approach pavements remain ice- or frost-free is a known safety hazard. Although little hard evidence has been presented to indicate the extent of the problem, maintenance practice and research on various preventive or remedial techniques often assumes it to be significant. This project was undertaken to fill a need to quantify the problem as a basis for rational decisions concerning the economics of design and maintenance practices.

Phase I of the project consisted of a literature search, a survey of selected State highway departments, the formulation of a cost-benefit methodology, a preliminary model parametric analysis, the collection of cost data on preventive and remedial techniques in current use, the development of a subsidiary net cost model, the formulation and evaluation of a bridge classification model, and the computation of illustrative examples of the cost-benefit methodology.

The application of the methodology developed in Phase I to sample cases identified data that were lacking. Furthermore, the resulting models were found not to be in a convenient form for ready implementation. Phase II of the project was designed to overcome the deficiencies. The continued research was directed at evaluating and implementing the methodology developed so that it could be used more readily by a highway administrator to determine the added design or extra maintenance cost justified to prevent or remedy ice or frost on bridge decks. The cost-benefit methodology developed consists of a cost model and a benefit model. A bridge characterization model was also developed for predicting the annual number of ice and snow accidents to be expected on a bridge, given various characteristics of the bridge. The use of the methodology and bridge model appears promising; however, anyone wishing to apply the process will need to develop a more precise accident data base with regard to bridge and road surface conditions (frost, localized ice, etc.) for the particular area of interest beyond that now being collected. The data base can be generated using data collection procedures developed in the study.

Research has been completed, and the final report has been published as:

NCHRP Report 182, "Economic Evaluation of Ice and Frost on Bridge Decks."

AREA 7: TRAFFIC PLANNING

Project 7-1 FY '64 and FY '65

The Influence of Land Use on Urban Travel Patterns

Research Agency:	Louis E. Keefer	
Principal Invest.:	Louis E. Keefer David K. Witheford	
Effective Date:	Feb. 1, 1964	Apr. 1, 1966
Completion Date:	Jan. 31, 1966	Sept. 30, 1967
Funds:	$62,674	$66,894

This project sought to determine the criteria or values concerning travel patterns created by major traffic generators. Such information is useful in forecasting the effect of various land uses on street networks and in providing a better basis for facility design, as well as for the control of various land uses. The nature of relationship between travel patterns and influencing factors (i.e., travel time, traffic generator characteristics such as location, size, type and intensity of land use, modes of travel, and other pertinent variables) were evaluated.

A report on the initial research has been published as:

NCHRP Report 24, "Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants."

Origin and destination data for 12 commercial airports, 28 shopping centers, and 51 industrial plants from various cities in the United States were used in the analysis.

A report on the continuing phase of the research has been published as:

NCHRP Report 62, "Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols."

This report presents trip characteristics for four specific uses of land. The travel information on hospitals has been derived from the study of data for 77 hospitals located in 16 different metropolitan areas. The findings for college and university travel were developed from 38 institutions

located in 16 metropolitan areas. Travel patterns for six State capitol complexes are presented. The trip characteristics for 20 office buildings located in 9 cities comprise the fourth type of land use studied and reported in the continuation research phase.

Project 7-2 FY '64 and FY '65

Traffic Attraction of Rural Outdoor Recreational Areas

Research Agency:	IIT Research Institute	
Principal Invest.:	Andrew Ungar	
Effective Date:	Feb. 1, 1964	May 1, 1965
Completion Date:	Mar. 15, 1965	May 31, 1966
Funds:	$24,652	$24,844

This research was concerned with determining the traffic attraction and generation of rural outdoor recreational areas, such as those created in many places by the creation of artifical lakes. Knowledge of the traffic patterns generated by such recreational areas would enable rational planning of highway access and parking facilities.

The final report evaluates the attractiveness characteristics and location of 18 Indiana state parks and compares the results to a similar study of reservoir recreational areas in Kansas. A predictive model suitable for application to the planning of new recreational areas is described utilizing trip distribution, a socio-economic activity index of the contributing area, and an estimate of the attractiveness based on the facilities to be provided.

The project report has been published as:

NCHRP Report 44 "Traffic Attraction of Rural Outdoor Recreational Areas."

Project 7-3 FY '64 and FY '65

Weighing Vehicles in Motion

Research Agency:	The Franklin Institute
Principal Invest.:	R. Cyde Herrick
Effective Date:	Feburary 1, 1964
Completion Date:	August 31, 1967
Funds:	$73,391

The purpose of this research was to develop new or improved methodology for weighing vehicles in motion with review and study of existing or new equipment. The ultimate aim was to obtain load magnitudes automatically in a way similar to obtaining traffic volumes by traffic counters.

Franklin Institute's approach to this problem served to complement the studies performed by others rather than to duplicate existing research. The data processing system in block form only was developed on the project. It was planned that no full-scale or field testing would be performed under this contract. Study was primarily given to methods that will allow static weights of the axle to be calculated from a limited number of dynamic load observations.

The methods for estimating the static axle weight from sampled force studied include averaging, dynamic models, the interlacing polynomials, and regression analysis. A preliminary system for the detection and the analysis of weighing vehicles in motion was synthesized.

The project report has been published as:

NCHRP Report 71, "Analytical Study of Weighing Methods for Highway Vehicles in Motion."

Project 7-4 FY '64, FY '65, and FY '67

Factors and Trends in Trip Lengths

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	Alan M. Voorhees Salvatore Bellomo	
Effective Date:	Feb. 1, 1964	Oct. 23, 1967
Completion Date:	Oct. 31, 1966	Jan. 10, 1969
Funds:	$89,250	$61,730

This research involved the establishment of the characteristics of trends in trip lengths. Knowledge of such trends is needed to determine future urban travel demands. It was expected that characteristics of trip lengths will be influenced by factors such as trip purpose, level of service, size and spatial characteristics of urban areas, socioeconomic characteristics, and trip-generating activity location.

The results of the first two years of this research have been published as:

NCHRP Report 48, "Factors and Trends in Trip Length."

This report provides empirical and theoretical analyses from data collected from several transportation studies. Trip length guidelines have been developed to provide transportation planners with tests of reasonableness for travel forecasts.

The project was continued to enable the study of trip length in subareas within metropolitan areas. The objectives of the second phase were to establish various relationships to assist planners in minimizing trip length on a subarea basis and to provide guidelines for checking metropolitan trip length forecasts.

Data were collected for analysis from the two separate origin-and-destination studies conducted in each of the following cities: Detroit, Mich. (1953 and 1965), Sioux City, Iowa (1955 and 1965); Reading, Pa. (1958 and 1964).

The final report provides results of hypotheses formulated and tested to state the relationship over time between trip length and influencing factors. Simulation studies are reported of home-based work-trip analyses for certain hypothetical urban forms and transportation systems.

The results of the continuation phase of the project have been published as:

NCHRP Report 89, "Factors, Trends, and Guidelines Related to Trip Length."

Project 7-5 FY '64 and FY '65

Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage

Research Agency:	Yale University, Bureau of Highway Traffic
Principal Invest.:	M. J. Huber H. B. Boutwell
Effective Date:	Feburary 1, 1964
Completion Date:	November 30, 1966
Funds:	$99,675

This project involved the development of better methods for forecasting and assignment of traffic. Various methods in current use were investigated. Methods were developed to determine the effects a new facility has on the traffic pattern of existing facilities. A major emphasis of the research was to determine the accuracy of the predicted use as compared to the actual use of highway facility.

The project report describes various electronic computer traffic assignment methods with test results compared to actual survey data obtained along the Connecticut River, Pittsburgh Area Transportation Study data and network assignments were obtained to study several forecasts made in the late 1940s.

A computer program was assembled to assign traffic to a network using four different capacity restraint methods. An analysis of statistical inferences from different network loadings was conducted.

The project report has been published as:

NCHRP Report 58, "Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use."

Project 7-6 FY '66

Multiple Use of Lands Within Highway Rights-of-Way

Research Agency:	Barton-Aschman Associates
Principal Invest.:	Harvey R. Joyner
Effective Date:	February 1, 1966
Completion Date:	February 28, 1967
Funds:	$24,220

Controlled-access highways in urban and rural areas include land which was necessarily acquired to provide space for the present and future safe design and operation of the facility but which is not now used. This project assembled information that illustrates what has been and what might be accomplished with these plots of land in the interest of both the highway user and the adjacent community.

The researchers reviewed the literature and prepared an annotated bibliography on the subject. A questionnaire was sent to the highway departments and several cities in the U.S. as well as abroad to survey existing uses being made of highway rights-of-way. Personal visits to various sites were made to acquire more information on the effects of various uses. Policies and legal requirements were reviewed and recommendations made for the use of land within the highway rights-of-way.

The project report has been published as:

NCHRP Report 53, "Multiple Use of Lands Within Highway Rights-of-Way."

Project 7-7 FY '66

Motorists' Needs and Services on Interstate Highways

Research Agency:	Airborne Instruments Laboratory
Principal Invest.:	Martin A. Warskow
Effective Date:	January 1, 1966
Completion Date:	December 31, 1967
Funds:	$99,267

This project was concerned with the needs and desires of motorists traveling on the Interstate Highway System, how these needs and desires are being satisfied, and what additional service provisions should be made. Legal and financial implications for providing various services were studied.

The researchers analyzed three basic classes of services: emergency services, which include out-of-fuel, mechanical failures, accidents, and medical needs; normal necessities, which include need for fuel, food, lodging, and directional information; and supplemental services, which include information on choice of lodging, fuel, and food facilities as to quality, location, brand, etc.

A national questionnaire was mailed to a sample of registered motorists to determine motorists' desires. Emergency service data were collected from various sources. A series of road trips was conducted in seven states in various parts of the country to experience a variety of the geographic aspects of this study. In each state, the researchers visited the local auto club, the State highway officials, and the State police to obtain various types of data.

The project report has been published as:

NCHRP Report 64, "Motorists' Needs and Services on Interstate Highways."

Project 7-8 FY '66

User Cost and Related Consequences of Alternative Levels of Highway Service

Research Agency:	Stanford Research Institute
Principal Invest.:	David A. Curry
Effective Date:	September 1, 1970

Completion Date: April 15, 1972
Funds: $99,070

Techniques for conducting comprehensive economic analyses of planned highway projects can be slow and cumbersome. In view of the evolving nature of the highway planning process, a need exists for an economic analysis supplement to the *Highway Capacity Manual* utilizing the manual's definitions of highway types, levels of highway service, and other key concepts. The *Highway Capacity Manual* describes six levels of service for each of five types of highway facilities and provides detailed procedures for determiniug levels of service under various conditions. At present, however, these levels of service have not been quantified with respect to user costs and related consequences.

The objectives of this project were to evaluate data related to user costs on various highway facilities under different levels of service, volumes, and other conditions, and to develop a methodology that will relate these variables to user costs. Through the means of sensitivity analyses, highway design and situation variables were identified that have major impact on output variables that can be of use to highway decision-makers.

Motor vehicle running cost data were compiled and updated for use in calculating relative road user costs at different levels of highway service and as affected by details of geometric design and traffic performance. By use of Appendix A of the *Highway Capacity Manual,* relationships were derived for peak-hour volume per lane in conjunction with AADT per lane pair. Queuing was analyzed based on the shock-wave method for uninterrupted flow and the deterministic method for interrupted flow. A methodology for estimating vehicle emissions was developed based on a "typical" vehicle configuration.

The research has been completed, and the project report has been published as:

NCHRP Report 133, "Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects."

Project 7-9 FY '73

Development of Models for Predicting Weekend Recreational Traffic

Research Agency: Midwest Research Institute
Principal Invest.: Walter R. Benson
Effective Date: September 1, 1972
Completion Date: May 15, 1974
Funds: $74,983

Traffic congestion occurs frequently on weekends at the fringes of urban areas as well as at recreation sites. For a number of highways serving recreational travel, it has been found that the peak hours of the year are concentrated on weekends. This weekend dilemma is of increasing concern to highway officials particularly, because it is expected to increase with increasing personal income and work-free time. Urban transportation studies, charged with forecasting future travel patterns, have excluded weekend travel.

The objective of this research was to develop techniques for the prediction of weekend recreational traffic capable of responding to changes in recreation demand, recreation supply, and transportation supply.

The principal development was a computer program RTPM (Recreational Traffic Prediction Model). RTPM operates in conjunction with the Urban Planning Battery in a three-stage process as follows:

1. Urban Planning Battery programs are employed to create a highway network representing the primary roads in an area selected for study and to determine travel times between all zones in the network.
2. RTPM generates a trip file consisting of all origin-destination weekend recreational travel for which either the origin or the destination point is within the area selected.
3. These trips, within a user-specified time-of-weekend period, are loaded onto the highway network by Urban Planning Battery programs to provide estimates of traffic on any one or more individual highway segments.

The project report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 7-10 FY '74 and FY '75

Peak-Period Traffic Congestion

Research Agency: Remak-Rosenbloom
Principal Invest.: Sandra Rosenbloom
Roberta Remak
Effective Date: April 1, 1974
Completion Date: March 31, 1975
Funds: $49,624

Peak-period traffic congestion in urban areas is a critical transportation problem. Congestion is due primarily to the inability of transportation systems to meet concentrated spatial and temporal travel demands. The continued building of capital-intensive systems to effect solutions is often controversial in light of economic, social, and environmental impacts. Research was needed to evaluate the full range of possible options to improve peak-period efficiency of transportation systems in large and small urban areas.

The objectives of this project were to (1) conduct a state-of-the-art survey to identify methods currently used or envisioned to alleviate the problem, (2) evaluate methods to ameliorate peak-period traffic congestion and to combine promising mutually supportive approaches into packages, and (3) develop research problem statements in the areas of institutional, energy, and social impacts associated with potentially effective congestion reduction packages.

Techniques to ameliorate peak-period traffic congestion were classified as social, socioeconomic, sociotechnical, and technical. They have been summarized in a state-of-the-art report. Experience with each technique has been described under the following categories: concepts, costs, time frame, funding source, political feasibility, and impact.

Mutually supportive techniques and incompatible techniques were identified. As a result, eight recommended packages of techniques to ameliorate peak-period traffic congestion were developed. These packages carry the following titles: (1) Work Hour Changes, (2) Pricing Techniques, (3) Restricting Access, (4) Changing Land Uses, (5) Prearranged Ride Sharing, (6) Communications Substitutes for Travel, (7) Traffic Engineering Techniques, and (8) Transit Treatments.

To highlight existing deficiencies and knowledge, ten problem statements were developed.

Two reports describe the findings from this project. Volume 1, entitled "Peak-Period Traffic Congestion: State of the Art and Recommended Research," is available either on loan from the NCHRP or in microfiche (see final page of this section for ordering information). Volume 2, entitled "Peak-Period Traffic Congestion—Options for Current Programs," has been published as:

NCHRP Report 169, "Peak-Period Traffic Congestion—Options for Current Programs."

Research was continued under NCHRP Project 7-10(2).

Project 7-10(2) FY '75

The Institutional Aspects of Implementing Congestion-Reducing Techniques

Research Agency: Remak-Rosenbloom
Principal Invest.: Roberta Remak
Sandra Rosenbloom
Effective Date: April 1, 1975
Completion Date: November 30, 1978
Funds: $74,703

Project 7-10(2) was a study of the institutional aspects of the congestion-reducing techniques and packages of techniques identified in Project 7-10. To implement the techniques and/or packages, all institutional factors need to be known, especially those that can help and those that can hinder.

The general objective of Project 7-10(2) was to develop strategies for assuring that congestion-reduction packages are considered rationally within today's institutional framework.

The research found that institutional problems can best be anticipated by recognizing that they derive from three sources. Some are inherent in the individual techniques selected. Others result from needs to coordinate activities of several essentially independent institutions. Still others derive from the character of the community in which the program is being carried out.

The congestion-reducing techniques recommended in NCHRP Project 7-10 were grouped according to common institutional problems they presented and strategies that could be used to overcome them. These groups were: (1) traffic engineering techniques; (2) transit improvement techniques; (3) techniques for restricting automobile use; (4) techniques for changing land use; and (5) techniques relying on employer initiative.

The research has been completed, and the project report has been published as:

NCHRP Report 205, "Implementing Packages of Congestion-Reducing Techniques—Strategies for Dealing with Institutional Problems of Cooperative Programs."

The report discusses the major problems for each group and recommends strategies to overcome opposition and enlist cooperation. Guidance is given, where appropriate, for federal, state, and local levels of government.

Joint implementation, requiring agency coordination, was found to generate institutional problems independent of the particular techniques involved in the congestion-reduction program. The research leads to the conclusion that metropolitan planning organizations (MPO) must integrate local and areawide transportation needs, resolve conflicts in plans of individual agencies, and at the same time ensure that federal and state program requirements are met. Strategies are recommended to assist an MPO or other central authority to effect necessary coordination.

The important institutional factors determined by the character of the community are the unofficial power structure, special-interest organizations, and community attitudes. Because these factors will be unique in each community, only broad strategies were recommended.

Project 7-11 FY '81

Low-Cost TSM Projects—Simplified Procedure for Evaluation and Setting Priorities

Research Agency: Multiplications, Inc.
Principal Invest.: J. H. Batchelder, H. S. Levinson, M. Golenberg
Effective Date: April 6, 1981
Completion Date: November 30, 1983
Funds: $199,988

Reduced transportation funding levels, environmental concerns, and shortages of construction materials were some of the reasons that dictated more emphasis on implementing low-cost Transportation System Management (TSM) projects in the nineteen eighties. Transportation agencies needed to make cost-effective decisions in selecting low-cost TSM projects in order to obtain maximum benefits from the transportation dollar.

The general objective of this research was to improve

the capability of transportation agencies to estimate quickly the impacts of, and to determine priorities for, proposed low-cost transportation actions so that programming decisions can be made on better information. Although effective planning and development of low-cost projects occurred, some basic problems were identified with approaches frequently taken to planning TSM:

- TSM has been viewed as a planning process "requirement" rather than as an expanded set of techniques for solving problems. It has been treated as a product to be developed separately from other short-range planning, design, and operations management activities.
- Analysis of TSM actions often has been conducted in a traditional framework designed for long-range policy, major capital planning and alternatives analysis, rather than in a design process oriented to developing problem solutions in sufficient detail for immediate implementation.

These problems have impeded the effectiveness of TSM as a "quick-response" means of developing and implementing practical, effective, and acceptable actions. As a result of this "systems planning" approach and the failure to relate TSM to actual problem solving, TSM has been dismissed as irrelevant by a large segment of the transportation planning and operations community, even in areas where it might most effectively be applied.

The research conducted under this project has defined a rational, structured framework for planning and programming TSM actions. TSM is treated as a means of solving near-term, identifiable problems or well-defined policy objectives through the implementation of low-cost, workable and publicly acceptable projects. The key features of the process are:

- A consistent assessment of problems and understanding their causes.
- The establishment of realistic objectives for TSM actions designed to solve the problems.
- The setting of fiscal and other guidelines for design and development of actions.
- The identification of potential actions that are appropriate and feasible in the problem setting.
- The systematic design of an implementable project that combines or "packages" actions as necessary to meet the objectives established for problem solution.

A review of design and estimation techniques and other information necessary to support the framework found some gaps. These gaps were generally not in the absence of quick-response estimation techniqnes, but in the lack of (1) guidance for their selection and efficient application to support project design decisions, (2) examples of their application as design tools, and (3) to somc degree, knowledge that certain techniques existed or could be adapted to TSM planning. Another clear gap was a lack of guidance in (1) identifying reasonable actions to solve common problems, and (2) determining their applicability and feasibility in specific local settings.

On the basis of the research results, a three part user's manual was developed to assist practitioners.

Part I of the manual describes a structured and responsive framework recommended for planning and programming TSM actions. The framework treats TSM as a means of solving near-term, identifiable problems and well-defined policy objectives through the implementation of low-cost, workable, and publicly acceptable projects. Chapter 2 presents the overall framework and describes strategic planning activities, such as needs assessments and capital budgeting, that provide a framework for efficient project planning. In many areas, some of these activities would be performed by a state DOT, MPO, or other agency with coordination, funding, or programming responsibilities. Chapter 3 describes tactical or project planning activities required to develop effective solutions. These activities often are conducted by agencies with implementation and operation responsibilities. The use of the manual in project planning is illustrated in Chapter 4.

Part II of the manual is a Reference Handbook designed to support transportation agencies in planning, evaluation, and programming of low-cost transportation actions. It provides practical guidance for transportation planners, traffic engineers, and transit operators in (1) identifying and assessing problems, (2) identifying and screening potential solutions to these problems, (3) identifying information needed to make specific project decisions, (4) selecting and applying techniques to produce this information, and (5) formulating priority improvement programs. The major sections of the Reference Handbook contain action screening aids (tables that identify general approaches and types of TSM actions to consider in developing solutions to problems; profile sheets on TSM actions that present conditions where they are applicable, problems potentially encountered in their implementation and operation, performance and impact measures to be considered in their analysis, and sources for more detailed information on their design and performance), and impact estimation aids and information sonrces (guidelines on preparing an information base and selecting performance measures for an analysis of TSM actions and packages; tables that recommend appropriate, simplified estimation techniques and provide references to documents that describe the techniques in detail and/or illustrate their application; descriptions of estimation techniques that are not presented in readily available literature; a basic reference library for planners and engineers (particularly those in small urban areas) and a list of the primary sources (i.e., federal agencies, institutions, and nonprofit organizations) for obtaining up-to-date information on TSM implementation experience and on simplified analysis and programming techniques).

Part III of the manual contains example applications that illustrate use of: (1) the TSM planning framework, and (2) the reference handbook material to support the planning and programming of TSM solutions.

The manual has been published as:

NCHRP Report 263, "Procedures for Evaluating Low-Cost TSM Projects—User's Manual." The project research report, however, has not been published but a limited number of copies are available at a cost of $6.00 each or microfiche may be purchased (see final page of this section for ordering information).

Project 7-11A FY '81

Low-Cost TSM Projects—Simplified Procedures for Evaluation, Phase II

Research Agency:	Texas A&M University Research Foundation
Principal Invest.:	John M. Mason, Jr.
Effective Date:	March 4, 1985
Completion Date:	March 3, 1986
Funds:	$150,000

Transportation agencies have been implementing low-cost TSM actions in order to obtain maximum benefits from the transportation dollar. To assist in implementation, *NCHRP Report 263,* "Simplified Procedures for Evaluating Low-Cost TSM Projects—User's Manual," provides a procedure to identify appropriate TSM actions and to identify techniques to estimate their various impacts. Furthermore, the manual provides guidance on combining TSM actions to provide cost-effective packages. Inasmuch as *NCHRP Report 263* represents a comprehensive compilation of the best available technology for planning and implementing TSM actions, it is highly desirable to increase its use by practitioners. FHWA has programmed funds for the development of arterial planning workshop materials, based on *NCHRP Report 263* and other reports, for the National Highway Institute to sponsor workshops throughout FHWA regions. These workshops, each expected to last 3 days, will serve to introduce the manual only to a limited audience from most agencies. For the critical masses within agencies to gain use of the manual, a need exists to develop materials that will introduce Report 263 in a day, or less, to practitioners in small and medium-sized agencies. Additionally, self-training materials are needed to supplement the introduction to serve those requiring hands-on experience with the manual. Furthermore, in support of TSM action implementation, audiovisual materials need to be developed to increase awareness of TSM action effectiveness among appointed and elected decision-makers.

The first objective of this project is to disseminate and promote the use of material in *NCHRP Report 263* primarily to technical staffs of states, MPOs, and local governments by developing modular audiovisual (A/V) and computer disks to illustrate use of the Report. The second objective is to describe for decision-making TSM actions and their benefits as alternatives to major capital improvements by developing 35-mm slide presentations.

Progress to December 31, 1985 includes development of the following products to meet the needs of the two objectives. For objective 1, the products are:

1. The Programmed Learning Text intended to present in a simplified manner the detailed technical guidelines for the implementation of TSM.
2. Computer-aided instruction modules:
   - I. Tutorial
   - II. TSM Screening Aids
   - III. Impact Estimation and Analysis Aids
   - IV. Accident Reduction Factors
   - V. Cost Indices
3. Audio-visual, slide-tape show developed in six modules to cover the content of Report 263.

For objective 2, two 35-mm slide presentations have been developed: (1) for medium to large urban areas and (2) for urban areas under 250,000 population. Both are accompanied by written scripts and audio tapes.

All products are in the review and modification process.

AREA 8: FORECASTING

Project 8-1 FY '64

Social and Economic Factors Affecting Travel

Research Agency:	Vogt, Ivers and Associates
Principal Invest.:	Robert S. Vogt
Effective Date:	February 1, 1964
Completion Date:	September 23, 1966
Funds:	$94,558

The purpose of this research was to develop means of estimating intercity travel using known traffic volumes and available economic and social data between selected cities and testing it by application to other pairs of cities between which travel is also known. A review was made of the adequacy of current processes of estimating urban travel using social and economic factors and the applicability of these techniques in estimating intercity travel. This study also researched whether useful and reliable work can be done by using urban transportation study techniques and applying them to other travel areas.

Knowledge gained by this research is useful to transportation planners and design engineers. Extensive use of electronic computers and existing computer programs to extract and classify summarized pertinent origin-destination data from existing studies has been accomplished.

A nationwide network has been produced for trip distribution purposes. More than 3,000 centroids representing each county or county equivalent with basic

population, employment, income, bank deposit, and other social-economic information have been assigned. The centroids are connected by links representing the highway system. External O-D data were acquired and processed for 22 cities in Tennessee, Wisconsin, and Missouri. From these data, regression analyses were run to test various equation forms and the correlation between variables, combination of variables, and transformation of variables for total trips and for trips by purpose. The trips predicted from the regression equations have been compared to actual survey trips.

The project report has been published as:

NCHRP Report 70, "Social and Economic Factors Affecting Travel."

Project 8-2 FY '64 and FY '65

Factors Influencing Modal Trip Assignment

Research Agency: IIT Research Institute
Principal Invest.: Dr. F. C. Bock
Effective Date: February 1, 1964
Completion Date: August 31, 1966
Funds: $298,033

The intent of this research was to improve methods of assigning urban area traffic to the various modes of travel. It involved the identifying of factors underlying choice of travel mode, the determination of the relationships of these factors, and also the development of a method of analysis and forecasting. Methods were tested and found to be practicable for use under real-life conditions. Such methods would be applicable in making better trip assignments in urban transportation systems.

The project report contains a survey of existing modal split models, and analysis of five metropolitan areas having rail rapid transit, a study of factors influencing choice in travel mode, and prediction models for modal choice based on discriminant functions with a comparison of reported trips and computed paths.

A survey of travel choice of IIT Research Institute personnel was conducted. The reported trip time was compared with computed times using the updated 1965 CATS newtork. The Chicago 1960 census data were analyzed to improve predictive techniques for mode choice. A composite Chicago travel network was developed, with an analysis of variance of reported and computed transit travel time.

The project report has been published as:

NCHRP Report 57, "Factors Influencing Modal Trip Assignment."

Project 8-3 FY '64

Individual Preferences for Various Means of Transportation

Research Agency: University of Pennsylvania
Principal Invest.: Dr. Russell L. Ackoff
Effective Date: February 1, 1964
Completion Date: March 31, 1965
Funds: $63,282

This project was designed to probe individuals' transportation preferences as contrasted to the more objective studies that Project 8-2 is concerned with. It was expected that the research would develop additional knowledge as to why and under what conditions persons will use or shift from one form of transportation to another. Better information and estimating bases are needed in order to obtain broad community agreement on plans for transit and highway improvement.

The final report was not published; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 8-4 FY '65

Criteria for Evaluating Alternative Transportation Plans

Research Agency: Northwestern University
Principal Invest.: Dr. Edwin N. Thomas
Dr. Joseph L. Schofer
Effective Date: February 1, 1965
Completion Date: August 1, 1967
Funds: $89,900

Present benefit-cost and other evaluative techniques do not take into account a number of costs, benefits, aud broad policy matters which do not easily lend themselves to numerical computation. This project was intended to identify and evaluate the broad array of factors which should be considered in making an intelligent choice among alternative transportation plans. A system for using these factors should be devised.

To identify and evaluate the broad array of factors which reflect the user's and community's scale of values, the researchers took a systems-analysis approach. A home interview was conducted as a pilot effort to establish user and community values in specific cities. The perceptions and attitudes of the driver were derived, as well as the citizen's views about the transportation system in general. Models were developed to be able to match potential transportation system consequences with specific planning goals. Problems associated with predicting system consequences were studied.

The multi-volume report consists of a section in three parts entitled "Strategies for the Evaluation of Alternative Transportation Plans," and a section entitled "Evaluation of Engineering Projects Using Perceptions of and Preferences for Project Characteristics."

In response to comments of the project panel, some additional material was found to be desirable to be added to the final report. Certain modifications were deemed necessary to relate the findings of the research more closely to the immediate needs of transportation planners.

A continuation contract was executed under NCHRP Project 8-4A for the purpose of modifying the final report for publication.

Project 8-4A FY '65

Criteria for Evaluating Alternative Transportation Plans

Research Agency:	University of Illinois
Principal Invest.:	Dr. Joseph L. Schofer
Effective Date:	October 14, 1968
Completion Date:	January 10, 1969
Funds:	$5,000

See Project 8-4 for general scope and objective of the research.

To improve the flow of ideas throughout the document, the final report of Project 8-4 was modified. In addition, more extensive descriptions of strategies for treating streams of cost and effectiveness indicators were prepared and integrated into the text. Also, several illustrative examples of the application of cost-effectiveness analysis to transportation-plan evaluation were prepared to demonstrate the use of the methodology, as well as to support some of the broader concepts described in the final report.

The project report has been published as:

NCHRP Report 96, "Strategies for the Evaluation of Alternative Transportation Plans."

Project 8-5 FY '65 and FY '68

Transportation Aspects of Land-Use Controls

Research Agency:	Victor Gruen Associates	
Principal Invest.:	Harold Marks	
Effective Date:	April 1, 1965	Aug. 7, 1967
Completion Date:	May 31, 1966	Jan. 15, 1970
Funds:	$25,967	$99,571

Proper land-use controls, properly administered, protect and enhance the public investment in transportation. Zoning, subdivision regulations, and all other land-use controls are intended to shape the pattern of the urban development. The objective of this research was to provide a better understanding of the effectiveness of existing land-use controls on the continuing utility of transportation systems.

The initial research primarily consisted of a literature search and a cauvass of selected highway departments and other agencies concerned with transportation planning in areas of rapid growth and intensive development. The effects of zoning and general plans were studied, as were highway geometry and access control, in regard to protecting the investment of the highway systems.

A first technical report has been published as:

NCHRP Report 31, "A Review of Transportation Aspects of Land-Use Control."

This project was continued to establish principles or guidelines for developing land-use controls and other techniques that will be stable and effective in the protection of highway utility. The research effort was conceptual in nature and presented a variety of ideas and proposals by which the highway investment can be protected. Some of the guidelines were developed in considerable detail. These can be incorporated into the procedures and practices of land-use and highway administrators. Other principles were developed as a base from which more detailed analyses can be undertaken.

The project report discusses basic interrelationships between transportation facilities and land use and how such relationships can cause transportation facility breakdowns. The effects of changing land-use controls on the utility of highways are discussed, with special attention being given to large traffic generators located near freeway interchanges.

The continuation research has been completed, and the project report has been published as:

NCHRP Report 121, "Protection of Highway Utility."

Project 8-6 FY '66

Individual Preferences for Alternative Dwelling Types and Environments

Research Agency:	University of North Carolina
Principal Invest.:	F. Stuart Chapin, Jr.
Effective Date:	February 14, 1966
Completion Date:	March 13, 1968
Funds:	$99,897

In predicting the future demand for transportation, it is imperative that future densities of residential areas be projected. In order that this may be done with confidence, a better understanding must be acquired for the preferences of various housing types and environments.

To measure and report on a representative cross section of the population, the researchers interviewed a sample of 1,476 households in various metropolitan areas. Logical relationships were developed between desired home type, price range, travel access mix, and living qualities. An attempt was made at estimating the number of people expected to move in a specified time period and where they will probably locate.

A national survey in 43 Standard Metropolitan Statistical Areas was conducted in October and November 1966. The information provides a detailed, factual profile on the mobility and residential choice behavior of households in metropolitan areas.

The project report deals with a summary of findings on housing choice of the households interviewed; an analysis of the residential mobility process; an analysis of the housing-choice process; and, drawing on these analyses, a discussion of the elements needed for a model of moving behavior which will have the capability of dealing with both the mobility and choice processes as components of residential changes.

The project report has been published as:

NCHRP Report 81, "Moving Behavior and Residential Choice—A National Survey."

Project 8-7 FY '69

Evaluation of Data Requirements and Collection Techniques for Transportation Planning

Research Agency: Creighton-Hamburg
Principal Invest.: Roger L. Creighton
Effective Date: September 13, 1968
Completion Date: August 28, 1970
Funds: $190,000

Urban transportation planning studies require travel, transportation facility, land-use, and various socioeconomic data. Techniques for obtaining these data are slow and costly. The accuracy, utility, and adequacy of the data and the methods employed for their collection and assembly need to be evaluated in the light of the evolving transportation planning process.

The purpose of the research project was to see what data were needed, first, for the basic transportation planning process such as was required to be undertaken for metropolitan areas by the Highway Act of 1962, and, second, for new kinds of transportation planning that are developing. A very limited number of transportation studies were selected for careful and detailed data analysis to establish recommendations on guidelines for data requirements and collection techniques. The project defined data requirements for both basic and continuing urban transportation studies with regard to travel, transportation facility, land-use, and socioeconomic data. Sensitivity analysis was performed to examine variations of the transportation data for assessing the impact that data errors have on the output of the transportation planning process.

The research included a comprehensive study of the transportation planning process in five cities to determine data collected, how they were used for planning and research, and their times and costs. Sensitivity tests of these data were conducted. Studies of data needs for new types of transportation-planning processes and alternate means of collecting data were also undertaken. Research was conducted on data needs of related planning processes, such as TOPICS Planning and Transit Planning.

The project report has been published as:

NCHRP Report 120, "Data Requirements for Metropolitan Transportation Planning."

Project 8-7A FY '71

Data Requirements and Transportation Planning Procedures in Small Urban Areas

Research Agency: University of Tennessee
Principal Invest.: Dr. William L. Grecco
Effective Date: June 1, 1973
Completion Date: June 14, 1975
Funds: $98,005

Urban transportation planning studies in urban areas of less than 250,000 population have evolved as miniature versions of the transportation planning process in large urban areas. These studies have been time consuming and costly and have had inordinate data requirements. The complexity and expense of these procedures was of increasing concern to highway officials because of the need to establish ongoing, continuing transportation planning processes in small urban areas.

The initial focus of this research was to develop a simplified transportation planning process for small urban areas of less than 250,000 population that is sufficiently flexible so that travel forecasts can be based on a small-sample home-interview survey or simulation. It was found that the existing standardized procedures were incompatible with the possible variations in the nature of the problems, available resources, and expectations of the participants. The digest of responses from the small urban areas examined typifies the difficulty faced when attempting to adapt the planning problem to the planning process, rather than fitting the process to the specific problem. The need for a customization of planning procedures was established, and the current organizational framework and technical practices in both land-use and transportation planning were evaluated from that standpoint.

Land-use planning in small communities was found to be highly standardized in format and content, but not in procedures, which varied significantly in terms of sophistication. It was found to be appropriate for planners to forego elaborate procedures in favor of various hand methods that are heavily dependent on the planner's knowledge of the community and the exercise of professional judgment in an ad hoc, or opportunistic, fashion. The transportation planning procedures appeared to be relatively more standardized.

The research identified and presented four types of transportation planning techniques for application in small urban areas: (a) network simulation based on synthetic models and a small-sample household survey, (b) consumer-oriented transit planning procedure, (c) simple techniques for corridor analysis, and (d) hand-computation-oriented procedure for estimating localized impacts of major traffic generators. Existing techniques were reviewed and tested (to varying levels) within each category. Examples include cross-classification and synthetic models, corridor-growth traffic-forecasting models, use of work-trip data from employers to update continuing transportation studies, development of a consumer-oriented approach to determiuing local transit needs and providing activity-ceuter traffic estimates to assist in assessing the localized impact of land-use changes on the transportatiou system.

Research has been completed, and the project has beeu published as:

NCHRP Report 167, "Transportation Planning for Small Urban Areas."

Project 8-8(1) FY '69

The Impact of Highways upon Environmental Values (Study Design)

Research Agency: Massachusetts Institute of Technology
Principal Invest.: Dr. Marvin L. Manheim
Effective Date: September 16, 1968
Completion Date: March 14, 1969
Funds: $29,654

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design was completed, and the report received but not published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

Project 8-8(2) FY '69

The Impact of Highways upon Environmental Values (Study Design)

Research Agency: Daniel, Mann, Johnson & Mendenhall
Principal Invest.: S. R. Sludikoff
Effective Date: September 9, 1968
Completion Date: March 7, 1969
Funds: $28,950

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design was completed, and the report received but not published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

Project 8-8(3) FY '69

The Impact of Highways upon Environmental Values

Research Agency: Massachusetts Institute of Technology
Principal Invest.: Dr. Marvin L. Manheim
Effective Date: September 15, 1969
Completion Date: July 31, 1974
Funds: $470,000

The increasing emphasis on social and environmental values has focused attention on the need for improving integration of a transportation facility with both the natural and the human environment. To achieve desirable levels of integration, research was programmed by AASHTO to (a) develop a practical method for evaluating the immediate and long-term effects of highways on the social and environmental considerations of communities and (b) test, evaluate, and refine the method by applying it to specific cases covering a range of situations. Because the design process must maximize the probability that significant community values will be considered, even if the state of the art does not allow all of these values to be measured quantitatively or precisely, the research emphasizes development of an approach in the context of the location process. Although the scope encompasses all types of highways, the study findings are applicable to all types of transportation facilities, many other public works projects, and all phases of planning.

In the initial phase, funded in 1969, MIT prepared a study design that served as the working plan to develop a pragmatic approach to the problem. The conclusion to the first phase was an unpublished draft report, "Community Values in Highway Location and Design: A Procedural Guide."

The second and final phase included (1) working with selected State highway departments to implement the proposed approach and adapt it to specific situations; (2) extending the approach for use in metropolitan area and statewide multimodal, systems-level planning; (3) extending, testing, and refining the techniques set forth in the draft Procedural Guide; and (4) revising the Procedural Guide to reflect the additional knowledge.

The approach developed recognizes and considers ten elements basic to the consideration of environmental and social values in transportation planning. They are:

(1) Differential effects.
(2) Community values.
(3) Community interaction.
(4) Evaluation and reporting.
(5) Consideration of alternatives.
(6) Identification of impacts and affected interests.
(7) Process management.
(8) Interrelation of system and process planning.
(9) Institutional arrangements and decision making.
(10) Implementation of the approach.

These elements are described in an overview and discussed individually in detail. To assist in incorporating these elements into the transportation planning process, specific immediately implementable techniques that can be used by transportation agencies are described. Most of the techniques can be adopted individually without difficulty. (They are intended for use in developing and evaluating alternative transportation plans with the participation of other state and federal agencies and local citizens and

officials.) Some of these techniques are already current practice in some agencies. Several have been tried in other professions; others have been recommended in the published literature or were suggested in discussions with federal and State highway officials. Many more stemmed from direct observation of the problems transportation agencies are facing.

Research has been completed, and the project report has been published as:

NCHRP Report 156, "Transportation Decision-Making—A Guide to Social and Environmental Considerations."

The report is closely related to the requirements of the Process Guidelines for the development of Environmental Action Plans as specified in Volume 7, Chapter 1, Section 1 of the Federal Highway Administration's *Federal-Aid Highway Program Manual.* It is structured to assist in the revision and implementation of Action Plans. The overview discussion of the ten elements is roughly analogous in scope and level of detail to the FHWA Process Guidelines. The remaining sections of the report correspond in many ways to the content of an Action Plan.

Project 8-9 FY '72

Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems

Research Agency: Creighton-Hamburg
Principal Invest.: F. F. Frye
Effective Date: September 1, 1971
Completion Date: January 31, 1973
Funds: $100,000

Economic evaluation of proposed new highway facilities traditionally has been on a cost-benefit basis, as is common with other public works projects. On the other hand, evaluation of proposed new transit facilities, as an action of a private company or a public utility, has too often been on a cashbox-revenue return basis. From the point of view of public investment, it is necessary to view these expenditures within a comparable evaluation framework so that the measures of benefits and costs are interchangeable. Such a framework for the economic evaluation of multimodal passenger transportation systems has immediate applicability to urban trausportation studies.

The objective of this research was to develop improvements and expansion of existing processes that evaluate alternative multimodal transportation system plans. These improvements were sought on the basis of increasing the number of relevant criteria used iu the evaluation framework and ensuring that the measuring techniques (economic evaluation criteria) developed represented accurately the impacts of alternative transportation plans.

Research has been completed, and the project report has been published as:

NCHRP Report 146, "Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis."

Project 8-10 FY '72

Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities

Research Agency: Wilbur Smith and Associates
Principal Invest.: Herbert S. Levinson
Effective Date: September 1, 1971
Completion Date: July 31, 1973
Funds: $149,907

Highways are capable of moving large numbers of persons on buses, but, in high-volume corridors, transportation service deteriorates due to peak traffic congestion. In order to move more people at an acceptable level of service, special facilities and control measures can be employed. The desired goal is rapid, convenient, reliable bus transit. Thus, a highway transportation system can be designed to offer a high level of service for peak commuter loads.

The research, now completed, was designed to develop a single reference source of bus priority measures to increase the person-carrying capacity of urban highways.

The interim report, "Bus Use of Highways—State of the Art," published as NCHRP Report 143, contains a literature search and correlative analysis of more than 200 bus priority treatments throughout the world.

The final report, "Bus Use of Highways—Planning and Design Guidelines," published as NCHRP Report 155, contains planning and design guidelines for efficient bus use of highways based on the experience gained from the literature search and state-of-the-art survey. It identifies significant policy implications, contains relevant planning criteria and warrants for various bus priority treatments, suggests measures of effectiveness, presents bus design parameters, and sets forth detailed planning and design guidelines for both freeway-related and arterial-related bus priority treatments and for terminals. For measuring effectiveness, it was found that the variauce of bus times is an important descriptor of bus reliability.

To aid the designer, vehicle design and performance characteristics are given, together with bus capacity considerations. These include queue behavior parameters, bus unloading and loading times, and bus capacity ranges.

Bus priority treatments should be complemented by appropriate policies that encourage and reinforce transit use, such as low bus fares, downtown commuter parking supply and rate adjustments, and strict enforcement of bus priority treatments. Within this policy framework, that recognizes public transport as an essential community service, various types of bus preferential treatments can be applied to specific urban situations.

Project 8-11 FY '73, FY '76, and FY '77

Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility

Research Agency: DACP, Inc.
Principal Invest.: Jonathan S. Lane
Lance R. Grenzebach
Effective Date: September 16, 1974
Completion Date: November 30, 1979
Funds: $354,363

To fully assess the worthiness of any transportation investment including highways and transit, it is necessary to be able to compare the transportation, economic, environmental, and social consequences with the same consequences of not taking any action. This project had as its general objective the strengthening of transportation impact assessment and evaluation procedures; the mechanism for this was the no-action alternative. The research was to define the no-action alternative, determine its role in project evaluation and impact assessment, and review techniques available for assessing the impacts of no-action and other project alternatives.

It was found that existing agency procedures regarding the no-action alternative were inconsistent and confusing. Definitions and role of the no-action alternative varied widely. Reports on a plethora of impact assessment methods were scattered throughout the literature. From these findings came the strong recommendation that the no-action alternative be defined as the maintenance of existing facilities and services in the study corridor and region and that the role of the no-action alternative be that of a benchmark against which all other alternatives be evaluated and assessed.

A December 1975 two-volume interim report is available in microfiche and covers the then existing state of the art: (a) illustrations of alternative definitions; (b) expanded discussion and illustration of alternative methods of plan evaluation and of techniques in current use for social, economic, and environmental impact assessment; and (c) reporting of the four case studies of facilities where no-build decisions had been made (see final page of this section for ordering information).

Research has been completed, and the project report has been published in two volumes, as follows:

NCHRP Report 216, "The No-Action Alternative: Research Report," highlights the findings of the research and documents the research activities, including summary reports of case studies, surveys, and pilot program activities undertaken with nine state agencies.

NCHRP Report 217, "The No-Action Alternative: Impact Assessment Guidelines," details how the research findings may be applied and provides recommended policy and procedural changes to strengthen both assessment and evaluation of all alternatives, presents the recommended approach for the definition and use of the no-action alternative, and includes methods for assessing 13 categories of impacts and evaluating the results. Although the recommendations may require adjustment and "tailoring" by each user agency, the net effect of the Guidelines should be to encourage standardization of practice and more effective use of the no-action alternative.

Project 8-12 FY '75

Travel Estimation Procedures for Quick Response to Urban Policy Issues

Research Agency: Metropolitan Washington Council of Governments
Principal Invest.: George V. Wickstrom
Arthur B. Sosslau
Effective Date: September 3, 1974
Completion Date: December 31, 1975
Funds: $39,895

Most techniques for estimating urban travel demand were developed to evaluate alternative transportation systems for an entire region. Application of these comprehensive techniques to provide timely answers to current policy questions has proven very difficult. This research effort was initiated to assemble and modify existing techniques, as well as to develop new approaches, for use by transportation planners faced with the need to be more responsive to current issues.

This research identified the most significant issues confronting urban transportation agencies that require travel demand information, defined the data requirements to meet those issues, and identified available planning techniques that can provide the needed data. Questionnaires were sent to numerous urban planning agencies to identify the issues requiring travel demand information, and personal interviews were conducted to follow up on the questionnaires. The issues were then classified and grouped to isolate the most pressing requirements of travel estimating procedures, and an exhaustive effort followed to locate the available techniques that would provide the needed data.

These techniques, more than 40 in all, were fully evaluated in terms of input requirements, types of output, potential applications, and complexity. A system was also developed to allow users to quickly locate the technique needed for their specific purpose.

Research has been completed, and the major findings have been incorporated into the research report emanating from Project 8-12A and published as:

NCHRP Report 186, "Travel Estimation Procedures for Quick Response to Urban Policy Issues."

Project 8-12A FY '75 and FY '76

Travel Estimation Procedures for Quick Response to Urban Policy Issues

Research Agency: Comsis Corporation
Principal Invest.: Arthur B. Sosslau
George V. Wickstrom

Effective Date: November 1, 1975
Completion Date: October 31, 1978
Funds: $239,331

This continuation of Project 8-12 has provided a user's guide of travel estimation techniques having quick response capabilities. The techniques are applicable for use by transportation and land-use planners, giving emphasis to the impacts of land-use changes on transportation alternatives and the magnitude of urban activities consistent with differing levels of transportation service. Problems of scale are addressed; e.g., the applicability of techniques to regions, subregions, and corridors.

Detailed descriptions of manual techniques for use in each aspect of travel demand estimation (i.e., trip generation, trip distribution, modal choice, auto occupancy, time-of-day distribution, traffic assignment, capacity analysis, and development density versus highway spacing relationships) were developed in this research. Numerous charts, tales, and nomographs were prepared to simplify each analysis step. Data requirements were also reduced by making maximum use of transferable parameters developed from other studies and urban areas. Three scenario applications of the manual techniqnes were conducted to illustrate the potential usefulness of the various analysis techniques. The presentation of the procedures in the final report is structured to allow their utilization by transportatiou planners with various levels of experience.

Instructional materials for use in training sessions or workshops were developed based on the manual techniques described in the user's guide. These materials include more than 400 slides, 50 transparencies, an instructor's notebook, and a student's notebook. The training package is available from NCHRP on loan upon written request or may be purchased. Requests should be directed to NCHRP.

The research report and user's guide have been published, respectively, as:

NCHRP Report 186, "Travel Estimation Procedures for Quick Response to Urban Policy Issues," and

NCHRP Report 187, "Quick-Response Urban Travel Estimation Techniques and Transferable Parameters—User's Guide."

Project 8-13 FY '75

Disaggregate Travel Demand Models

Research Agency: Charles River Associates
Principal Invest.: William B. Tye
Effective Date: September 15, 1974
Completion Date: January 31, 1976
Funds: $100,000

The urban transportation planning process, as it was developed in the period 1962 to 1977, was characterized by the creatiou of long-range systems plans based on simulatious of regional travel patterns using models developed and calibrated with aggregate zonal data. Three of the basic criticisms made of the regional simulation and planning process was that the then used aggregate models could not be readily used for subregional and project planning; they were not responsive to the policy issues that planners were being asked to address; and they required expensive large travel surveys for model calibration.

To meet the described need, the over-all objective of this research was to develop, in separately funded phases extending over several years, operational travel demand forecasting models consistent with travel choice behavior and with coefficients estimated by use of data at the level of households or individual travelers. It was anticipated that such models will form the basis of improved travel demand estimation procedures.

Models were developed in Phase I using Pittsburgh and Minneapolis/St. Paul data bases. Binary logit models were estimated for (1) the mode choice for work, (2) the mode choice for shopping, (3) the destination choice for shopping, and (4) the trip frequency choice for shopping. A report, "Disaggregate Travel Demand Models: Phase I Report," presents the major findings and is available in microfiche (see final page of this section for ordering information). In the report, the models are appraised in terms of their advantages in travel demand analysis, their low data collection costs, their trausferability, and their flexibility in applicatiou. Several hypothetical applications are provided.

Research was continued as Project 8-13(2).

Project 8-13(2) FY '77

Disaggregate Travel Demand Models

Research Agency: Charles River Associates, Inc.
Principal Invest.: William B. Tye
Effective Date: May 1, 1976
Completion Date: December 31, 1980
Funds: $200,000

This project was a continuation of Project 8-13. The overall objective of the research was to develop operational travel demand forecasting models consistent with travel choice behavior and with coefficients estimated by use of data at the level of households or individual travelers.

In Phase I, Project 8-13 successfully developed policy-sensitive travel demand forecasting models consistent with travel choice theory using 1967 Pittsburgh data at the level of individual travelers. Binary choice logit models were estimated for (1) the mode choice for work, (2) the mode choice for shopping, (3) the destination choice for shopping, and (4) the trip frequency choice for shopping. Phase II extended the Project 8-13 research program: (1) to conduct one or more demonstrations of the disaggregate models applied to policy issues at a state or local planning agency; and (2) to determine au ap-

proach to be used in solving problems that will be incurred in application (such as application of disaggregate models to aggregate data and aggregate forecasting). A worktrip mode-choice model, developed with Pittsburgh, Pa., data was used to predict the share of trips attracted to a new park-and-express-ride bus service in Baltimore. The predicted ridership was approximately one-half of the observed trips. The application uncovered potential pitfalls in the application of disaggregate models, particularly when using aggregate data, that provided valuable information for the preparation of recommendations in the final report. To meet Objective 2, a market segmentation approach was developed to overcome bias problems, when aggregating from households to a subregion and when using aggregate time and cost variables. The Phase II report is available on microfiche (see final page of this section for ordering information).

The project was concluded in a third phase in which disaggregate models were developed for the work trip using the Baltimore Disaggregate Data Set. Guidance on the transferability of these models together with those developed previously using Pittsburgh and Twin Cities (MN) data sets is provided in a final report intended as an "entry point" for transportation planners interested in applying disaggregate models. In addition to transferability, guidance is given on other impediments to the implementation of disaggregate models such as how to aggregate the results for a corridor or urban area and how to overcome problems in using the multinomial logit form of models.

The report is in two parts. Part I is oriented to the technologist with a familiarity of travel demand forecasting techniques who desires to apply disaggregate models. Part II, Appendixes to Part I, is directed to the expert who already has some knowledge of some major issues in the field.

The project report has been published as:

NCHRP Report 253, "Application of Disaggregate Travel Demand Models."

Project 8-14 FY '75

New Approaches to Understanding Travel Behavior

Research Agency:	Boston College
Principal Invest.:	Marc A. Fried John Havens
Effective Date:	January 1, 1975
Completion Date:	April 30, 1977
Funds:	$144,135

Current urban travel estimating procedures have been developed, for the most part, on the basis of identification of associative relationships, without concern for the causal processes from which travel behavior patterns arise. As a result, the procedures may produce reasonably satisfactory estimates of travel under conditions that are essentially unchanged from those existing at calibration, but are largely unable to provide satisfactory estimates of travel behavior under conditions representing significant change from the status quo. For example, decision makers are asking: (1) the consequences of no-build options; (2) the relevance of low-capital options, in and of themselves, and as alternatives to freeway systems; (3) the congestion and energy effects on the level of travel and mode choice; (4) traveler responses to hypothetical systems with specified performance characteristics, and (5) traveler responses to energy shortfalls.

The over-all objective of this research was to develop, test, and operationalize a behavioral theory of travel based on needs and constraints, system availability, and activity site accessibility of potential travelers. This theory will be responsive to today's policy questions and hold potential for being responsive to future policy questions.

A careful review and evaluation was made of the transportation planning, economics, sociology, geography, and psychology literature to identify theoretical elements related to individual travel. This work was synthesized into a travel behavior theory comprised of two components—a microtheory and a macrotheory. The microtheory concept proposes that individuals in similar social status positions, in similar life stages, living in similar environments, will adapt in similar and partially predictable ways. Important to this theory are role patterns and attitude structures. The macrotheory is concerned with how the existence of activity opportunities and constraints modifies or reinforces behaviors specified in the microtheory. The microtheory deals with the individual's demand for activity opportunities; the macrotheory, with the generation of the activity opportunity sets (i.e., transportation supply).

Microfiche of the project report, "Travel Behavior: A Synthesized Theory," is available (see final page of this section for ordering information). The Summary from the project report has been published in Appendix G of NCHRP Report 250, "New Approaches to Understanding Travel Behavior."

The following unpublished, working papers were written and are available on a loan basis upon written request to the NCHRP:

1. Classification and Evaluation of Social Science and Transportation Issues; Marc Fried and John Havens.
2. Preliminary Dimensions for Classification and Evalnation; Marc Fried and John Havens.
3. Toward a Mathematical Framework for Modelling Urban Travel Behavior; John Havens.
4. Issues in the Analysis of Attitudes (Attitude Theory); Marc Fried.
5. Attitudes toward Transportation; Marc Fried.
6. The Theory of Decision Dilemmas and Directions; John Havens.

7. Residential Mobility, Residential Location and Travel Behavior; Matthew Thall.
8. Spatial Cognition and Transportation; Deana D. Rhodeside.
9. A Review of Temporal Cognition; Daniel Rogan.

Research was continued as Project 8-14A. It is incorporating key elements of the synthesized theory into present travel demand forecast methods.

Project 8-14A FY '77

New Approaches to Understanding Travel Behavior: Phase II

Research Agency: Charles River Associates
Principal Invest.: Peter Allaman
Effective Date: January 1, 1978
Completion Date: June 30, 1982
Funds: $221,249

Decisions concerning transportation investment are based partially on forecasts of travel. These forecasts are generally made using models that relate travel time and cost, demographic characteristics, and transportation accessibility to travel. The distribution and assignment models used by most agencies are prime examples. There was no subsuming theory of travel behavior which generates those models; they are merely convenient formulations for expressing and forecasting travel aud assume stable relationships. Disaggregate models, although offeriug significaut advantages over present techniques, dealt almost entirely with individual choices, thus ignoring basic processes that generate travel. A major deficiency in both approaches was their general insensitivity to policy options that are important today. Such options typically involve energy, life styles, and transportation service quality.

In recognition of this deficiency, NCHRP Project 8-14 initiated development of a new approach to understanding travel behavior, concentrating on social and psychological relationships between individuals and their households as they exist in spatial layouts. The research carefully reviewed sociology and psychology literature as well as related fields that pertain to travel behavior. From this, a number of elements were identified that would assist in development of a theory, or theories, of travel behavior. Because of the complexity and extensiveness of the elements proposed, it was further determined that research (Phase II) would concentrate on testing three key elements relating to individual and household behavior and incorporatiug those elements into operational travel forecasting procedures, such as the Urban Transportation Planning System.

The key elements (or concepts) tested included the following:

1. Activity and travel patterns can be related to demographic descriptors such as social class, ethnicity, life cycle, and lifestyle.
2. Intervening factors between activity and travel patterns include social roles and resource constraints.
3. Household activity choice, duration, scheduling, and location determine travel.

Explicitly excluded from consideration were potential models developed from theories of adaptive processes. Although this is a valid subject for future research, the timeliness of useful travel forecasting techniques coming from these theories was questionable. The research approach was to: (1) incorporate the above concepts into trip generation; (2) develop household activity and travel behavior models using the above enumerated concepts and the Baltimore Disaggregate Data Set, with the ultimate objective being the ability to forecast specific travel volumes and flows; and (3) use survey data that measure both variables external to the individual (such as peer-group pressures and family demands) and variables internal to the individual (such as attitudes and perceptions) to determine their interrelationships in influencing travel behavior.

Relationships between individual activities and travel were explored first. In particular, equations for activity time allocation of individual weekday travelers for in-home travel, travel time, and 10 categories of out-of-home activity were estimated. Significant differences existed in the allocation of time to various activities depending upon stage in the life cycle (including the presence of children), employment status, sex, marital status, race, age, income, and education. Forecasting experiments revealed that the greatest impact on time allocation in the future will likely come from the increasing labor force participation rate among women.

Household-level data were also analyzed in the project. The importance of adding household structure and residential location variables to a basic model of trip frequency was shown. The best explanatory variable for household structure is found to be the age distribution of the household members. Residential location was described by population density. Household structure was related to activity time allocations which, in turn, were related to trip time, trip frequency, aud miles traveled. Fuel efficiency and vehicle-miles travelled were used in predicting fuel consumption. Home-based trip generation models were estimated that have potential for use in conventional travel forecasting procedures. Resources did not permit the validation of these equations for other geographical areas nor did they allow for the incorporation of the equations in the Urban Transportation Planning System (UTPS). Nevertheless, analysts should be able to apply them to their own travel demand forecasting system for trial use.

The interim report, entitled "Behavioral Science Con-

cepts for Transportation Planners," is available on microfiche (see final page of this section for ordering information).

The project report has been published as:

NCHRP Report 250, "New Approaches to Understanding Travel Behavior."

Project 8-15 FY '75

State and Regional Transportation Impact Identification and Measurement

Research Agency:	Bigelow-Crain Associates
Principal Invest.:	Charles D. Bigelow
Effective Date:	September 1, 1974
Completion Date:	May 31, 1976
Funds:	$80,000

There was a need for improved means of identifying and measuring social, economic, and environmental impacts for use in State and regional transportation studies. Emerging State and national land-use policies, proposed regulatory revisions, concern for energy utilization, plus heightened environmental and social considerations, served to highlight this need.

The general objective of this research was to develop an improved nnderstanding of specific, and operational, impact identification and measurement techniques, for use by transportation agencies in contributing to a variety of State and regional transportation decisions. To achieve the stated objective, the research was conducted in two phases.

Phase I documented specific identification and measurement techniques in contrast to issues of impact evaluation. The investigation considered the direct and indirect impacts of economic development; land use and housing; air, noise, and water quality; energy utilization; natural resources and ecosystems; and social and community structure.

The Phase I report, "State and Regional Transportation Impact Identification and Measurement," was not published. Loan copies are available upon written request to the NCHRP or microfiche may be purchased (see final page of this section for ordering information).

Project 8-15A FY '75

Economic Impacts of State Transportation Policies and Programs

Research Agency:	Regional Science Research Institute
Principal Invest.:	Dr. Benjamin H. Stevens
Effective Date:	October 1, 1977
Completion Date:	March 31, 1980
Funds:	$117,852

The identification of social, economic, environmental, and energy impact measurement techniques for use by state and regional transportation agencies was undertaken in NCHRP Project 8-15, "State and Regional Transportation Impact Identification and Measurement." This first phase of a two-phase project resulted in an extensive summary of existing impact measurement techniques and identified a wide range of related research needs.

The objective of the second phase, NCHRP Project 8-15A, was to demonstrate the usefulness of available techniques that estimate the impact of alternative transport policies and/or programs on economic activities, and to document the techniques in the form of operating guidelines and demonstration results. The scale of analysis was at the statewide and/or economic region levels rather than urban, and the techniques selected for demonstration included regional input-output analysis and econometric simulation models.

The final report contains a set of guidelines to permit state and/or regional agencies to apply the techniques to policy and/or program alternatives. Two handbooks were prepared: (1) basic input-output analysis, and (2) forecasting and policy simulation.

The final report and handbooks were not published; however, loan copies are available upon written request to the NCHRP or microfiche may be purchased (see final page of this section for ordering information).

Two computer programs are also available from the NCHRP. The input-output model, including two computer tapes, may be purchased for $60 if NCHRP provides the tapes or $20 if the requester provides blank tapes. The forecasting and policy simulation model may be purchased for $30 on NCHRP's tape or $10 on the requester's tape.

Project 8-16 FY '76

Guidelines for Public Transportation Levels of Service and Evaluation

Research Agency:	University of Tennessee
Principal Invest.:	Ray A. Mundy
	Kenneth W. Heathington
Effective Date:	January 1, 1976
Completion Date:	December 31, 1979
Funds:	$489,952

Public transportation traditionally was provided by fixed-route service financially supported through revenues from passengers. Reduced patronage resulting primarily from increased use of the automobile, plus higher operating costs, caused growing deficits. Public concern about energy, environment, auto dependency, congestion, and the quality of urban living in general obliged governments to underwrite these deficits in most urban areas. The rising amounts of required public monies, plus the successful operation of a wide range of services directed at more specialized market segments, posed questions concerning how much financial support is appropriate, what services are required, and how these services should be provided. Public officials needed this information in order to establish appropriate public policies.

Project 8-16 was initiated in order to develop a method that would be used by planners to provide public officials with the desired information and direction for local public-transportation actions. The initial 12-month period of the project was spent conducting an in-depth analysis of present procedures and practices of the urban mass transit industry. Included in this effort were research team visits to 18 urban areas within the United States. From this research process, a descriptive, comprehensive, planning model was developed depicting the necessary information and procedural steps required for the application of market opportunity analysis (from the private business world) to the planning of short-range public transportation. As depicted in the model, the application of market opportunity analysis requires both direction from policy decision areas and data from an engineering data base. When applied, the market segments are identified, the transportation needs are determined, a transportation system is developed to meet the needs, and the system is tested. The model was tested in a neighborhood of Jacksonville, Florida, and is considered applicable to cities in the 50,000 to 500,000 population range.

Research was completed, and the project report published in five volumes, as follows:

NCHRP Report 208, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Procedures for Evaluating Alternative Service Concepts," presents a suggested general procedure to match desirable service attributes resulting from a market segmentation study with alternative service concepts to determine which alternative services are appropriate for a local area. Alternative service concepts were classified as to vehicle type, degree of right-of-way control, and operational strategy (routing, scheduling, and stop location). Also presented are generalized break-even curves for conventional bus, express bus, demand responsive, and ridesharing services. Because various institutional factors (e.g., work rules, public vs. private provider) can greatly affect costs, it is recommended that the planner first complete a rough feasibility analysis to limit the range of alternatives and then perform a "customized" cost analysis. It is proposed that many institutional barriers can be overcome if a viable cost-effective concept can be identified.

NCHRP Report 209, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Transportation Services for the Transportation Disadvantaged," addresses issues arising from the provisions of recent legislation and regulations. Social and economic impacts are substantial. Recommendations are developed on the premise that existing legislation and regulations are susceptible to change. Through an elucidation of the issues and alternative courses of action, this report should help in future selection of more efficient, economical, and socially acceptable approaches.

NCHRP Report 210, "Market Opportunity Analysis for Short Range Public Transportation Planning—Economic, Energy, and Environmental Impacts," contains the recommendation that impact analyses be based on expected market utilization instead of theoretical system capacities. Information is provided both for the Engineering Data Base and the Service Design sections of the model. The findings described in the report will assist the analyst in structuring information to permit an analysis of various public transportation service alternatives in meeting specified objectives even though the objectives may be in conflict.

NCHRP Report 211, "Market Opportunity Analysis for Short-Range Public Transportation Planning—"Goals and Policy Development, Institutional Constraints, and Alternative Organizational Arrangements," presents discussions of the rationale and procedural steps necessary to develop workable goals for urban public transportation. Without such direction, little guidance is given to the decision-maker as to what markets to concentrate on and how to measure systemwide performance. The report addresses the task of determining goals and policies, as well as the issues involved in preparing a goal/policy statement, for public transportation in an urban community. The information developed should serve as a guide for planners responsible for coordinating goal/policy development activities in an urban community.

Also addressed are the critical institutional issues that transportation planner and decision-makers must face when attempting to provide new or improved public transportation services. Various federal, state, and local regulatory and institutional patterns have developed for the provision of urban public transportation services. A thorough understanding of these issues is necessary in order to involve both public and private operators in the provision of public transportation services. The prospective opportunities for new private and minority firms to begin public transportation services have been developed as an integral part of this report.

The report also provides information from which policy decisions can be made regarding appropriate organizational arrangements for providing public transportation services. This material should be of use to two major groups: (a) agencies having the responsibility for developing and implementing the organizational structure for planning and providing public transportation and services at the local level, and (b) agencies having the responsibility for planning, designing, implementing, and operating public transportation services at the local level. It is stressed in this report that with a market-oriented public transportation system management approach the organizational structure must be tailored to the needs of the local area's needs and political environment.

NCHRP Report 212, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Method and Demonstration," adds substantially to the body of knowledge concerning short-range public trans-

portation planning for cities in the 50,000 to 500,000 population range. A descriptive comprehensive planning model was developed depicting the necessary information and procedural steps required for the application of market opportunity analysis (from the private business world) to public transportation planning. As depicted in the model the application of market opportunity analysis requires both direction from policy decision areas and data from an engineering data base. When applied, the market needs are determined, a transportation system is developed to meet the needs, and the system is tested. The model was tested in a neighborhood of Jacksonville, Florida, at a cost of approximately $100,000. The report concludes that further demonstration of the planning model will be required to determine whether the benefits from application outweigh the costs of data collection. If the entire process were duplicated in another test city, the costs would be expected to be 50 to 60 percent of the initial effort.

Each report is aimed at one specific segment of the overall concept model; together they provide comprehensive guidelines for public transportation officials covering the three primary activities described in the model—policy, marketing, and engineering.

Project 8-17 FY '76

Freight Data Requirements for Statewide Transportation Systems Planning

Research Agency:	Roger Creighton Associates, Inc.
Principal Invest.:	Frederick W. Memmott Richard B. Blackwell
Effective Date:	July 15, 1975
Completion Date:	February 15, 1977
Funds:	$231,147

The general objective of this research was, first, to determine the type, amount, and relative importance of freight data required to develop statewide transportation system plans; and, second, to design and develop techniques, methods, and procedures for assembling these data.

This research was conducted in two phases. Specific tasks completed in Phase I were to:

1. Identify the types of freight data necessary for statewide transportation systems planning purposes. Recommend what type of data and the scale of detail that will be required in view of the current and proposed planning methodologies.
2. Rank these data requirements in terms of their relative importance to statewide transportation systems planning.
3. Given the data requirements, catalogue and determine the existence of available data in reference to the planning data requirements determined in Task 1. Investigate the institutional problems and constraints in the use of freight data (e.g., disclosure restrictions, proprietary nature of shipper and carrier data, and joint use and reciprocity agreements among private and public parties).
4. Identify deficiencies in existing freight data and evaluate the criticality of such deficiencies to statewide transportation systems planning.
5. Develop and evaluate alternative strategies for resolving such deficiencies.

Specific tasks completed in Phase II were to:

1. Prepare a manual describing in detail appropriate techniques for the assembly and understanding of existing freight data and the collection and understanding of such additional data as may be required by statewide transportation systems planning.
2. Provide illustrative, realistic examples of how to apply these techniques to typical problems encountered in statewide transportation systems planning.

Research has been completed, and the two-volume project report has been published as:

NCHRP Report 177, "Freight Data Requirements for Statewide Transportation Systems Planning—Research Report;" and

NCHRP Report 178, "Freight Data Requirements for Statewide Transportation Systems Planning—User's Manual."

Project 8-18 FY '76

Techniques for Evaluating Options in Statewide Transportation Planning/Programming

Research Agency:	Planning Environment International, A Division of Alan M. Voorhees & Associates
Principal Invest.:	Dr. Salvatore J. Bellomo Dr. Joseph R. Stowers
Effective Date:	September 1, 1975
Completion Date:	June 30, 1978
Funds:	$300,393

Evaluation techniques have traditionally been thought of in the context of "plan evaluation" (i.e., comparison of alternative system networks), or "route evaluation" (i.e., comparison of locations for a given proposed facility). Although these evaluations and the techniques applied to them (such as user costs and benefits; balancing of travel demands assigned to a network with network capacity; and, more recently, localized corridor impact analyses) may still be valid for certain planning needs, the techniques suffer from a combination of large expenditures of time, high cost, extensive data requirements, and complex simulations.

The general objective of this research was to provide transportation planning methodologies that are policy-sensitive, allowing the testing and evaluation of options

to produce timely results for decision-making. This research addressed reasonable-cost, sketch-planning-type techniques having an application to issues of statewide transportation planning as part of the programming process. This research was conducted in two phases.

Phase I has been completed, and the final report has been published as:

NCHRP Report 179, "Evaluating Options in Statewide Transportation Planning/Programming—Issues, Techniques, and Their Relationships." A comprehensive classification of transportation issues, data requirements, and existing techniques is included.

Phase II, consisting of test applications in Maryland (priority programming system—PPS), Georgia (energy conservation forecasting techniques), and Kentucky (highway user revenue model—HURM, and short-range capital resource availability model—SCRAM), has also been completed, and the final report has been published as:

NCHRP Report 199, "Evaluating Options in Statewide Transportation Planning/Programming—Techniques and Applications." The computer programs for PPS, HURM, and SCRAM may be purchased upon written request to the NCHRP.

Project 8-19 FY '77

The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel

Research Agency:	Cambridge Systematics, Inc.
Principal Invest.:	Earl R. Ruiter
Effective Date:	December 1, 1976
Completion Date:	November 30, 1978
Funds:	$199,954

The concept that highways generate their own demand and subsequent vehicle-miles of travel (VMT) had been so widespread that it gained legitimacy if only by sheer repetition. Yet studies conducted to estimate future travel demand had not shown significant correlation between VMT and highway supply variables. A clear understanding of the effect of highway supply on VMT was needed to adequately address the interrelationship of transportation, air quality, and energy issues.

The objective of this project was to determine whether a relationship exists between measures describing urban highway supply and VMT and, if so, to quantify the relationship for practising planners through preparation of appropriate graphs and nomographs.

The research approach hypothesized that VMT can only be expressed and predicted in terms of its components—vehicle trips and vehicle trip lengths—if it is to be validly predicted. These components, in turn, were predicted using a structural model system—one which employs both travel demand and supply models in a framework which approximates network equilibrium. The recognition of trips, and not VMT, as the appropriate unit for measuring demand was the key to the research approach.

The research results indicate that VMT changes do occur as highway supply changes, but the changes are small (e.g., ½ percent in the peak hour for a new urban freeway) and the relationship is a complex one. To quantify the relationship, the following variables must be considered: trip frequency, trip distance, auto occupancy, and mode split. Different results may be anticipated depending upon (1) the type of highway supply change, (2) the scale of the highway supply change, (3) the context within which the supply change takes place, and (4) the time scale. The complexity of the relationship has two important consequences: first the direction of VMT change for a given highway supply—change can vary; second, there are many variables that affect both the direction and the magnitude of VMT changes.

Because the model system was applied to only two highway supply cases, it was not possible to develop the graphs and nomographs needed to quantify the relationship. Nevertheless, short-range results for two urban radial freeway cases (1) new construction and (2) expansion were obtained. For the new freeway case, VMT increased as highway supply increased, both in peak and off-peak periods. In the freeway expansion case, peak-period VMT increases were offset by off-peak decreases to produce a slight, overall decrease in VMT. The most important components of VMT changes for both facilities were total person trips, which increased; and average trip distance, which decreased. Less important (by an order of magnitude) were the auto mode split and auto occupancy components.

None of the existing, aggregate, areawide VMT models was successful in matching the model system results obtained in this project for both test facilities. Although this fact in itself did not invalidate either modeling approach, it did suggest that areawide models are severely limited in their potential usefulness because they fail to consider differences in types of highway supply changes.

Although VMT increased for one test facility, and slightly decreased for the other, VMT-related impacts for both cases generally improved when studied at the urban area level. Measures of urban mobility, quality of travel service, air quality (with the exception of the relatively less critical level of NO_x pollutants), fuel consumption, and travel safety all were improved.

Two measures, directly relating VMT and highway supply, were recommended. These were the fraction of new capacity "used" (Δ VMT/Δ VMC) and the elasticity of VMT with respect to vehicle-miles of capacity (E [VMT/VMC]).

Microfiche of the agency final draft report is available and the results are summarized in Research Results Digest 127 (see final page of this section for ordering information).

Project 8-20 FY '78

Improved Methods for Vehicle Counting and Determining Vehicle-Miles of Travel

Research Agency: John Hamburg & Associates
Principal Invest.: Charles C. Francis, Jr.
Effective Date: January 2, 1978
Completion Date: July 31, 1980
Funds: $200,000

Traffic volume counts are the most basic means of monitoring highway use. The need for more reliable and detailed traffic data has expanded to support analysis of other transportation concerns, such as land use, air and water quality, noise abatement, energy conservation, modal split, and safety.

The objective of this research was to develop improved cost-effective procedures for conducting highway vehicle counting programs and determining vehicle-miles of travel (VMT). Research addressed the collection of traffic counts, processing of such counts, and productiou and use of traffic information. Although the primary thrust of the research was directed toward state-level programs, the findings include appropriate applications at sub-state, rural, and urban jurisdictional levels.

The research evaluated present traffic-counting programs and techniques, including administration, interagency coordination, collection, processing, presentation, and application of traffic information. Cost-effective techniques and procedures were developed for direct application in a highway traffic volume information program. An "Idealized Traffic Volume Information System" was prepared using sample traffic counts to reduce collection costs without sacrificing accuracy. Estimation of VMT at the state and substate levels by functional and administrative class of highway is also included in the System, using the sample counts. The relationship of the volume-counting and VMT estimation procedures to vehicle classification, vehicle weight, census of transportation, and other similar programs was addressed.

A three-volume final report was prepared: (1) State of the Art, (2) Traffic Counting Program Design, and (3) Idealized Traffic Volume Information System. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 8-21 FY '79

Guidelines for Use of Vanpools and Carpools as a Transportation System Management Technique

Research Agency: George Washington University
Principal Invest.: Marian Misch
Joseph Margolin
Effective Date: March 1, 1979
Completion Date: June 30, 1981
Funds: $265,937

The emergence of ridesharing as a significant transportation mode has been rapid and accompanied by changes in both technique and technology. Ridesharing is one of the most immediate, economical, and flexible methods for dealing with problems arising from energy shortages, air pollution, congestion, and transportation emergencies. Its development requires relatively little lead time and no special appropriations or taxes. Furthermore, the design of each program can fit the unique needs of each community or population segment. Ridesharing at its simplest represents a quantum increase in the productivity of the automobile. Although commuting has been the primary focus of ridesharing programs, they may be applied to shopping, to recreational events, and potentially to such industries as tourism. However, despite considerable work on the economic, technical, and management issues, a combination of problems has limited the success of vanpooling and carpooling. These involve motivational aspects: (1) Lack of a sufficient range of incentives for attracting all but the more ready acceptors (the self-convinced), and for diminishing obstacles to acceptance—particularly in light of the fact that ridesharing is a social, as well as economic, activity requiring behavioral incentives. (2) The need for better methods to develop such incentives: (a) methods for learning the needs, perceptions, attitudes and likely behaviors of potential ridesharers and of their employers; (b) techniques for meetiug the requirements thus discovered, for both vanpooling and carpooling. (3) Absence of an appropriate program and policy guide based on behavioral, social, economic, and transportation realities; a guide useful at local, state, and national levels to both private and public sectors; one based on behavioral transportation research and focusing on management of carpool and vanpool organization and maintenance systems.

The general objective of this research was to identify effective policies and their impacts to encourage vanpooling and carpooling use based on an uuderstanding of individual and household preferences and behavior. Specifically, the research analyzed individual and household attitudes, preferences, and behaviors related to ridesharing. The goal was to use the analysis results to develop a manual for transportation practitioners and policy-makers for selecting techniques that are compatible with other TSM strategies and were likely to result in significant increases in ridesharing over the short term (2 to 5 years).

Important policy issues emerged from the findings: (1) The shift to small cars could impede carpooling, but facilitate vanpooling and park-and-ride carpooling. One policy option might be to take advantage of the family needs of many solo drivers and encourage large cars, but with lower power for fuel conservation. (2) The current dislike of mass transportation has been documented by a recent Census Bureau study and by this research. (In a

forced choice of selection of nonsolo driving commute alternatives were they all available, 76 percent opted for the private, ridesharing modes; 24 percent for a bus or subway.) In the light of this dislike, it will be even more important in the future than in the past to encourage ridesharing to achieve fuel savings and relief from congestion and air pollution. (3) Parking is a powerful issue and incentives must be emphasized. (4) Active outreach programs that also personalize the process continue to be crucial. These can certainly be joined to a base of computer matching, but computer matching cannot be expected to be effective by itself. (5) The entire ridesharing program effort needs to be geared to the more difficult late acceptors who now remain. This means careful market acceptance studies (and adaptation of existing findings), as well as careful market segmentation. Ridesharing program personnel must be encouraged and trained to change approaches that cannot convince the far less ready potential acceptors who remain in most large metropolitan areas. (6) Because of the complexity of the task indicated in (5), a brokerage approach may be the most realistic in many areas. The consumer orientation, freedom of choice and flexibility of such approaches will be more effective ways to achieve solo driver behavior change than single, mode-dedicated programs. However, it must be recognized that these can be more costly in all the resources involved, particularly staff training and staff time. (7) There is a critical need for developing formative program evaluation techniques that take into account not only such necessary base data as the number of pools formed, maintained, and dissolved, but also why these effects occur. It is a program approach that allows for continuous feedback and direction change as necessary in response not only to program difficulties but to changing economic, transportation, and social conditions (such as a target group shift to more reluctant potential acceptors or the impacts of inflation).

The manual is designed to assist both existing and new ridesharing agencies in their continuing development as successful, community-oriented service organizations. It integrates the results of literature search, contacts with local ridesharing agencies, and findings from decision analysis panels and surveys conducted in four metropolitan areas of the United States. The manual provides guidelines for the several stages that any local ridesharing agency will experience in setting up a community ridesharing program; it also details these stages, which are briefly described as follows:

- Understanding the goals and nature of ridesharing and of ridesharers.
- Understanding the community conditions and characteristics that affect ridesharing programs.
- Adopting program design guidelines or policies suited to the community and its commuters.
- Planning the ridesharing program.
- Implementing the program.
- Operating the program while encouraging and/or responding to indirect incentives, such as high occupancy vehicle lanes.
- Evaluating and improving the program.

Research has been completed and the manual has been published as:

NCHRP Report 241, "Guidelines for Using Vanpools and Carpools as a TSM Technique." Appendix D of the project report summarizes the research findings on which the manual is based. Detailed findings and survey data are documented in the agency's final report, "Using Vanpools and Carpools as a Transportation System Management Technique: Research Report." The agency research report may be purchased for $11.50. Microfiche is also available. See final page of this section for ordering information.

Project 8-22 FY '79

Transportation Financing Within the Context of Energy Constraints

Research Agency:	System Design Concepts, Inc.
Principal Invest.:	Dr. Joseph R. Stowers
Effective Date:	March 26, 1979
Completion Date:	February 27, 1981
Funds:	$100,000

The general objective of this research was to determine the impacts of energy conservation policies and proposals on state transportation financing. A methodology was developed to enable States to assess the impact of existing and proposed energy conservation policies on travel and fuel consumption and to determine user and non-user impacts on the various revenue sources currently used to finance highway construction, operation, and maintenance.

The research identified possible modifications of existing State-level revenue sources and/or proposed new sources which would lend themselves to creating some stability and reasonable growth in future over-all highway transportation funding.

The researchers reviewed procedures used at the national and state levels to estimate vehicle-miles of travel and fuel consumption. The procedures included trend-based methods, econometric models, and less complex techniques. Also, revenue sources for each state were summarized. A catalog and description of applicable methodologies and supporting state and national baseline data that are available to the states to predict highway travel and fuel consumption in their jurisdictions under existing and proposed energy conservation policies were developed.

Research has been completed, and the findings have been published as:

NCHRP Report 231, "State Transportation Finance Within the Context of Energy Constraints."

Project 8-23 FY '79

Fuel Supply Limitations and Passenger Travel

Research Agency:	Charles River Assoc., Inc.
Principal Invest.:	Timothy Tardiff
Effective Date:	April 2, 1979
Completion Date:	September 1, 1980
Funds:	$110,000

The future of energy supplies, particularly petroleum, was uncertain in the 1970s. Numerous forecasts showed significant differences in the magnitude of shortfalls between supply and demand from the early 1980s up through the year 2000 and beyond. If such shortfalls or extended interruptions occur, personal travel was thought likely to be affected. Yet our knowledge of the nature of such changes in travel was extremely limited. Because the nation and its cities, states, and regions continued to be faced with this problem, research was needed to understand and forecast the nature of travel behavior under energy constraints, and the key impacts of probable energy supply futures on travel, transportation investments, and the economy.

The research project synthesized planning methods, appropriate for use by professional planners, to evaluate policy alternatives for likely future energy shortfall scenarios. These methods were applied to four energy-deficient scenarios and the resulting changes in travel estimated. The four scenarios were based on a literature review and evaluation of current events during the course of the research. These scenarios considered magnitude, frequency, and duration of shortfall, gasoline price, and government actions to conserve gasoline (odd/even purchasing, gasoline rationing, etc.). Methods chosen were incremental logit models for work trips and linear equation models for nonwork trips. For the four scenarios, policy alternatives were evaluated in terms of modal shares, VMT, bus miles of travel, private vehicle fuel consumption and transit fuel consumption. A comparison of scenario testing results with the selected models provided an indication of the relative effects of price, contingency actions, and sticker plan on fuel consumption. Contingency actions included free tolls for carpools, bus priority treatment at intersections and traffic signals, exclusive contraflow bus lanes on highways, increases in parking fees, and reductions in on-street parking. Driving restriction imposed by the sticker plan led to the highest reduction in private vehicle fuel consumption. The second highest reduction resulted from higher gasoline prices in the range of $2.00 to $3.00 per gallon.

Research has been completed, and the project report has been published as:

NCHRP Report 229, "Fuel Supply Limitations and Passenger Travel."

Project 8-24 FY '80

Forecasting the Basic Inputs to Transportation Planning

Research Agency:	John Hamburg & Associates, Inc.
Principal Invest.:	Dr. George T. Lathrop
Effective Date:	January 21, 1980
Completion Date:	April 30, 1982
Funds:	$81,000

Changes in transportation planning in the late 1970's gave increasing importance to the accuracy, simplicity of approach, reliability, and acceptability of travel forecasts. Transportation planners forecasted travel demand and resulting transportation impacts on the basis of changes of socioeconomic variables such as population, employment, vehicle availability, income, and household size. Errors in the forecasts of some variables were carried forward creating the potential for substantial errors in information provided to decision-makers in the evaluation of transportation alternatives. Furthermore, local involvement in the transportation planning process had increased considerably and local officials were often reluctant to accept forecasts of socioeconomic variables, particularly if declines in populations, income, or employment were forecasted.

The research has produced a concise reference for transportation planners concerned with using projected socioeconomic and demographic characteristics in transportation planning. Guidance is provided on the accuracy and usefulness of various projection techniques for various levels of aggregation and periods of time.

Two general areas of research were pursued:

1. The sensitivity of the transportation planning process, particularly trip generation, to variation in input socioeconomic and demographic variables.
2. Review and evaluation of methodology for producing study area level projections either on the basis of other projections or independently.

The analysis indicated that *trip generation* is extremely sensitive to population projections, but much less sensitive to projections of numbers of households (or household size) if population is controlled. Given population and household size, household auto ownership and income substantially enhance the explanation of variation in household trip generation. Auto ownership is more powerful than income, and the level of interaction between the two and the marginal improvement offered by the use of both, suggest strongly that only one—auto ownership—should be used in trip generation.

Socioeconomic and demographic data also play a strong role in *mode-choice* models. Again, auto ownership (or availability) appears to be the stronger and more useful of the two variables.

Because of significant tradeoffs between complexity and required resources on the one hand, and theoretical con-

tent on the other, clearly preferred or recommended methodologies for projecting population, household size, auto ownership, income, and employment were not identified.

For planners with adequate resources, the widely used and available cohort-component population projection models are superior. They do require some time and effort, as well as computational resources.

Economic models for projection of income and employment are generally unsatisfactory unless considerable resources are available, in which case econometric models appear preferable.

For the planner with limited resources (of time, staff, or money) the best procedure is to "step-down" from national, state, or multicounty projections prepared using complex, sophisticated techniques. Several examples of such projections are cited, as well as the techniques used for their preparation.

Other major conclusions and recommendations include the following:

- Research is needed in disaggregating study area level projections to subareas—districts or zones—and in examining sensitivity at the subarea level.
- A competent review and presentation of techniques for disaggregation, interpolation, and projection of income are needed. The complexities of inflation and the use of means, medians, and income categories have caused considerable confusion for transportation planners.
- When family size and auto ownership or income are controlled, other variables, such as the sex of the household head, explain very little of the variation in tripmaking. However, the influence of labor force participation, unemployment and work attendance on work tripmaking is not well understood or known. It, too, deserves further research.

Research is to be continued. Initial results are published in NCHRP Report 266, "Forecasting Inputs to Transportation Planning."

Project 8-25 FY '80

Intercity Bus Transportation Planning

Research Agency: Peat, Marwick, Mitchell & Co.
Principal Invest.: John F. DiRenzo
Effective Date: April 1, 1980
Completion Date: January 31, 1982
Funds: $200,000

For the past ten years the bus passenger market has been in a constant decline except for a brief surge during the 1974 fuel shortage. Since 1971 the net operating revenues and the return on equity of the interstate carriers have fallen significantly. The decline in profitability is due to the fact that costs have increased at a faster pace than operating revenues. It is generally concluded that intercity bus ridership will continue its recent downward trend.

The objective of this research was to investigate intercity travel requirements, including those of small urban and rural areas, and to evaluate the role and potential of intercity bus services in meeting those requirements. Procedures were developed to determine appropriate level-of-service requirements for intercity bus services. The procedures are designed for use by state and local transportation planners as a means of identifying the relative needs of communities or sets of communities for intercity bus transportation, and as a tool for prioritizing the potential recipients of public assistance for the provision of such services.

Alternative bus service designs were developed that utilize the potential resources of intercity bus carriers to satisfy the public transportation requirements. The alternative service options include using smaller size vehicles, employing student or part-time drivers, truncating or extending a route, changing service frequencies, using local or regional operators, adding new stops, altering schedules, and coordinating service with local rural transit operations. The feasibility of these options was tested through case study applications in selected intercity corridors in California, Michigan, Minnesota, Pennsylvania, and South Carolina.

Actions state and local agencies can take to help the intercity bus operators meet the intercity service requirements were also identified. These actions include financial assistance such as fuel tax relief, registration fee reductions, and direct terminal equipment and operating grants; technical assistance such as distribution of intercity bus information, marketing, providing input to terminal location decisions, and coordination with other modes; and removal of regulatory and other barriers to intercity bus travel, as well as initiation of positive incentives to encourage greater utilization of services.

Research has been completed. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 8-26 FY '81

Development of Highway Traffic Data for Project Planning and Design in Urbanized Areas

Research Agency: JHK & Associates
Principal Invest.: Neil J. Pedersen
Effective Date: May 15, 1981
Completion Date: December 31, 1982
Funds: $100,000

Transportation agencies concerned with highway project planning and design in urbanized areas have implemented the conventional trip generation, distribution,

modal split, and assignment process for system traffic estimation. In addition, traffic counting programs usually exist that provide some historical time series data on traffic characteristics. However, at the present time, there are no nationally accepted or widely used procedures to translate the results of highway system-level traffic assignments, historical data, land-use information, and other factors into traffic data for individual highway projects.

The objectives of this research were to (1) identify, review, and evaluate typical procedures currently being used to develop highway traffic data for project planning and design in urbanized areas; and (2) using existing techniqnes to the maximum extent possible, develop a user-oriented manual containing procedures for the full range of planning and design needs together with illustrative case studies.

Procedures and analysis techniques that have been proven reasonably successful were grouped and critiqued in terms of criteria including required degree of precision, resource requirements, ability to replicate the effort, and rationale. In addition, input data requirements such as system-level assignments, historical traffic count data, land-use information, and other factors were addressed.

A user-oriented manual was developed describing recommended procedures. Each procedure includes a commentary describing the benefits, shortcomings, and the circumstances that may require alternative steps. Design project "cases" with appropriate traffic estimating steps are described. Cases were selected to ensure coverage of the full range of applications and include: (1) use of refinement procedures for upgrading of a limited access highway, (2) use of windowing procedures for evaluating an arterial improvement, and (3) application of procednres to highway design.

Research has been completed, and the final report has been published as:

NCHRP Report 255, "Highway Traffic Data for Urbanized Area Project Planning and Design."

Project 8-27 FY '80

Cost-Effectiveness of Transportation Services for Handicapped Persons

Research Agency:	Transportation Center University of Tennessee
Principal Invest.:	Kenneth W. Heathington Frederick J. Wegmann
Effective Date:	September 1, 1981
Completion Date:	April 30, 1983
Funds:	$200,000

Recognizing the mobility problems faced by physically and mentally handicapped people, transportation providers have been trying to develop cost-effective ways to meet the transportation needs of these people. Existing transportation services were often competitive, thereby draining away available public resources. The objectives of this research were to determine the cost effectiveness of alternative transportation services for handicapped persons and to develop guidelines for state and local planners, transportation providers, and decision-makers on determining the most cost-effective way of meeting the transportation needs of handicapped people.

The research found that transportation-handicapped people constitute a small, but highly diverse, segment of the population. Their functional limitations and abilities, frequency of travel, desire for additional travel, economic status, and access to private automobiles vary considerably. Therefore, it is important that planners stratify the transportation-handicapped population into distinct market segments so that transportation solutions can be more closely tailored to the needs of each. The most important and useful ways of segmenting the transportation-handicapped population are by overall ability to use public transportation, functional disability, and access to private automobiles.

Transportation-handicapped people generally travel less than half as much as other people. However, much of this difference in trip-making is because most transportation-handicapped persons are unemployed. The transportation-handicapped 16 years of age or older make about one-fourth as many work trips as other individuals in this age group, but they make about 70 percent as many nonwork trips. Although it may be important to narrow and possibly close the 30 percent gap in nonwork travel, this gap, nevertheless, is not as large as commonly believed. Barrier-free transportation, therefore, could have a much greater impact on the mobility of transportation-handicapped persons if it enabled a larger number of them to gain employment rather than to enable simply some of them to make a few more nonwork trips. However, it is doubtful that barrier-free transportation services will significantly lower the unemployment rate of transportation-handicapped people. Nearly half of all transportation-handicapped persons are over 65 years of age, and a lack of transportation is not one of the major reasons why many younger handicapped people are unemployed.

Although the transportation-handicapped do not travel very often, their latent demand for additional travel appears to be surprisingly low. Various measures of latent demand show that it is only a fraction of the current average daily trip rate of transportation-handicapped people. Even if a barrier-free transportation service could satisfy the apparent latent demand, the resulting average daily trip rate would still be much lower than that of the general public.

Three general approaches to improving the mobility of handicapped people have been suggested and tried in the past—modification of existing fixed-route bus systems, specialized door-to-door transportation services, and subsidies to individual transportation-handicapped people to enable them to use available taxi services at lower fares. The average additional cost of operating a fixed-route bus

system that has been made accessible to the handicapped is approximately $2,000 annually per lift-equipped bus. Depending on lift use, the cost per lift user can range from a few dollars to over $50. Specialized transportation services can cost between $8 and $23 per vehicle-hour of service. The cost per trip depends on many factors and can range from $2 to $15. The average cost of subsidizing taxi use can vary from less than $1 to over $7 per trip.

To date, none of the foregoing approaches has had a significant impact on the mobility of large numbers of handicapped people. Accessible fixed-route bus systems, specialized transportation services, and user-side subsidy programs have not been heavily used by most handicapped people. In most cases, a few people have accounted for a large majority of the trips made under each of these alternatives.

NCHRP Report 261, "Cost Effectiveness of Transportation Services for Handicapped Persons," documents the results of the research. Conclusions drawn are:

1. Equipping conventional transit buses with wheelchair lifts is not, in most instances, a cost-effective way of meeting the transportation needs of large numbers of wheelchair users.
2. Door-to-door specialized transportation services with either lift-equipped or ramp-equipped vehicles constitutes one of the few alternatives that can potentially serve all types of handicapped people for all types of trips. This service cost effectiveness varies widely—in some instances it can be delivered at acceptable cost.
3. A *taxi*-based, user-side subsidy program can be singled out as the one likely to be the most cost effective for many segments of the transportation-handicapped population.

It is not possible to recommend a single transportation solution that is clearly the most cost-effective for all handicapped people in all situations. The cost-effectiveness of any alternative can vary widely, depending on local conditions and many other factors. A solution that may work well in one community can easily fail in another. Most likely, some combinations of alternative solutions will be required, each focusing on particular needs of particular market segments. For these reasons, the research conducted under NCHRP Project 8-27 has resulted in the publication of two documents: *NCHRP Report 261,* "Cost-Effectiveness of Transportation Services for Handicapped Persons—Research Report," and *NCHRP Report 262,* "Planning Transportation Services for Handicapped Persons—User's Guide." This report (NCHRP Report 261) documents the results of a study of the cost-effectiveness of alternative transportation services for handicapped persons. The companion document (NCHRP Report 262) provides planners and decision-makers with guidelines on how to evaluate alternative transportation services for handicapped persons and to identify the most cost-effective solutions for their communities.

AREA 9: BITUMINOUS MATERIALS

Project 9-1 FY '64 and FY '65

Asphalt Durability and Its Relation to Pavement Performance

Research Agency:	American Oil Company	
Principal Invest.:	Dr. A. W. Sisko L. C. Brunstrum	
Effective Dates:	Feb. 1, 1964	Nov. 1, 1965
Completion Dates:	July 31, 1965	Apr. 30, 1967
Funds:	$50,000	$50,000

Research is needed to determine those fundamental properties of an asphalt which contribute to the durability of pavements and to develop suitable methods of tests for determining such properties. These tests are needed to provide improved bases for asphalt specifications to assure products which, when properly used, will result in durable asphalt pavements. The general properties with which this over-all problem was concerned involve rheological, chemical, and physio-chemical properties of the asphalt alone and as influenced by its interfacial relationship with aggregates. These properties and their values in the original asphalt and the retention of these values over a period of time in service are of importance.

Research has been completed, and the project report has been published as:

NCHRP Report 67, "Relation of Asphalt Rheological Properties to Pavement Durability."

Project 9-2 FY '65

Asphalt Durability and Its Relation to Pavement Performance—Adhesion

Research Agency:	Montana College of Mineral Science and Technology
Principal Invest.:	D. W. McGlashan
Effective Date:	January 1, 1965
Completion Date:	October 31, 1967
Funds:	$101,903

This research was concerned with asphaltic concrete pavement performance, particularly with regard to the influence of asphalt-aggregate adhesion. The research approach was based on the principle that interfacial activity occurring at the boundary between an asphalt cement and an aggregate is influenced by the characteristics of the particular asphalt and aggregate and that this activity, measured in electrical quantities, provides a comparative assessment of the adhesion between the asphalt and the aggregate.

A data acquisition system was developed for making electrokinetic measurements of interfacial activity when

asphalt cements were forced through porous plugs under controlled temperature and pressure conditions. The porous plugs contained aggregates that were being tested for adhesion. Data were collected and analyzed using 15 asphalt cements and a number of different aggregate types to demonstrate the ability of the procedure for assessing the adhesion of an asphalt-aggregate mixture.

The project report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 9-3 FY '65

Evaluation of Pavement Joint and Crack Sealing Materials and Practices

Research Agency: Rensselaer Polytechnic Institute
Principal Invest.: Dr. John P. Cook
Effective Date: June 1, 1965
Completion Date: June 30, 1966
Funds: $24,996

Under environmental, structural, and traffic requirements, highly variable and inadequate performance may result from the materials and construction practices regarding the sealing of joints in new pavements and the maintenance of joints and cracks in old pavements. All aspects of the sources of the deficiencies need to be identified so that corrective measures may be established either in terms of improved materials or improved construction practices. The objectives of this research were to (1) prepare a state-of-knowledge report on joint and crack sealing materials, joint design, specifications, test methods, and construction practice; (2) make a critical analysis of the information and define needs to improve performance; and (3) recommend a feasible research program. Bituminous and nonbituminous materials were included, and due consideration was given to such factors as economics and practicalities of usage.

Research has been completed, and the project report has been published as:

NCHRP Report 38, "Evaluation of Pavement Joint and Crack Sealing Materials and Practices."

Project 9-4 FY '72

Minimizing Premature Cracking of Asphaltic Concrete Pavements

Research Agency: Materials Research & Development
Principal Invest.: F. N. Finn
Keshavan Nair
Effective Date: November 1, 1971
Completion Date: June 30, 1973
Funds: $99,560

The premature cracking of asphaltic concrete pavements is a continuing problem and often results in large expenditures of money to maintain a necessary level of pavement serviceability. Many factors, such as asphalt properties, mix design, construction procedures, aggregate properties, subgrade support, environmental conditions, and traffic loadings, influence the ability of the pavement to resist cracking.

The objective of this project was the determination of suitable materials specifications, paving mix design criteria, and construction requirements that will result in the ability to design and construct asphaltic concrete pavements to carry design traffic with a minimum of premature cracking.

Research has been completed, and the project report has been published as:

NCHRP Report 195, "Minimizing Premature Cracking in Asphaltic Concrete Pavement."

Project 9-4A FY '76

Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress

Research Agency: Woodward-Clyde Consultants
Principal Invest.: F. N. Finn
W. S. Smith
Effective Date: September 15, 1975
Completion Date: November 1, 1978
Funds: $204,194

NCHRP Project 9-4 findings contain recommendations intended to reduce possibility of premature cracking of asphaltic concrete pavements and a proposed verification program. The generally accepted approach to verification has been to monitor performance using statistical analysis for evaluation of the variables. An alternate approach has been to verify an analytical model using a small experimental program and case histories of in-service pavements. One of the findings of NCHRP Project 9-4 indicates that these two approaches are not realistic for verification of the project recommendations because the cost, time, and scope required for such a program to reach definitive conclusions would be excessive.

In the same report, the Bayesian approach is suggested as an alternate for verification and updating of project recommendations. It uses the past experience of engineers in a meaningful statistical format combined with experimental data and experience gained from observation of field performance of new construction.

The objectives of this project were (1) development of a procedure based on Bayesian statistical concepts for verifying recommendations to minimize pavement distress and (2) pilot implementation of the verification procedure for the specific distress mode of cracking from repetitive traffic loading.

Research has been completed, and the project report has been published as:

NCHRP Report 213, "Bayesian Methodology for Ver-

ifying Recommendations to Minimize Asphalt Pavement Distress."

Project 9-5 FY '80

Design of Emulsified Asphalt Paving Mixtures

Research Agency: The Asphalt Institute
Principal Invest.: V. P. Puzinauskas
B. F. Kallas
Effective Date: April 1, 1980
Completion Date: December 31, 1983
Funds: $150,172

Asphalt emulsions are increasingly being used for sealcoats, surface treatments, and base- and surface-course mixtures both in new construction and in maintenance and rehabilitation of existing pavements for reasons that include environmental concerns, energy conservation, and ease of construction. Users have raised questions regarding the proper use of asphalt emulsions in order to obtain performance comparable to that obtained in the past with other asphalt materials. Of particular concern is the ability of current design methodology to produce paving mixtures consisting of a variety of materials that will perform with a high degree of reliability over a range of environmental conditions.

The objective of this research was to verify and/or modify the Asphalt Institute and University of Illinois asphalt emulsion mix design methods described in Federal Highway Administration Reports No. FHWA-IP-79-1, "A Basic Asphalt Emulsion Manual," and No. FHWA-RD-78-113, "Mix Design Methods for Base and Surface Courses Using Emulsified Asphalt."

Research has been completed with partial accomplishment of objectives. It was found that neither of the two mix design methods is totally satisfactory for determining optimum asphalt emulsion and water contents and that there is a lack of compatibility between the methods. Modifications to the methods are recommended. The field studies indicate that construction practices and field activities influence performance of emulsified asphalt pavements to a greater extent than laboratory mix design.

The project report has been published as:

NCHRP Report 259, "Design of Emulsified Asphalt Paving Mixtures."

Project 9-6 FY '85

Development of Asphalt-Aggregate Mixtures Analysis System

Research Agency:
Principal Invest.: In development stage
Effective Date:
Completion Date:
Funds: $350,000

Improved asphalt concrete mix design methods should optimize the selection of asphalt binders and aggregate materials to produce pavements uniformly resistant to all forms of distress such as rutting, fatigue cracking and moisture damage. The Asphalt Advisory Committee of the Strategic Highway Research Program (SHRP) has recognized that currently used asphalt concrete mix design methods are not adequate for the laboratory evaluation of improved or new asphalt binders that are to be developed under SHRP and that any improved binders should be evaluated within the context of an improved asphalt-aggregate mixture analysis system.

The objective of this project is to develop an asphalt-aggregate mixture analysis system for the laboratory evaluation of asphalt binders and aggregate materials with regard to resistance to all forms of distress, both load and environment associated, when used in the construction of asphalt concrete pavements. The evaluation system should include such elements as the preparation of test specimens, conditioning of the specimens, testing the specimens, and criteria for acceptance.

This project is being funded from a portion of the $1,000,000 included in the FY '85 program for research on properties of asphalt cements with the provision that the research be coordinated with the strategic Highway Research Program activities on asphalt research.

AREA 10: SPECIFICATIONS, PROCEDURES, AND PRACTICES

Project 10-1 FY '64

Development of Guidelines for Practical and Realistic Construction Specifications

Research Agency: Miller-Warden Associates
Principal Invest.: W. B. Warden
Effective Date: November 15, 1963
Completion Date: November 14, 1964
Funds: $25,000

It is recognized that many existing specifications do not properly consider variations in work and materials which are inevitable and characteristic of the best construction possible today. In a development of guidelines for adequate specifications, this project included such areas as surface smoothness for subgrades, bases, and pavements; thickness measurements for bases and pavements; gradatiou and other requirements for aggregates and aggregate mixtures; and a summary of selected current specifications pertinent to the areas of study. Consideration was given to the validity of specifications with respect to need in the accomplishment of purpose, economic impact inherent in specifications, uatural variations inherent in work aud material, and variations inherent in methods of measurement and control test procednres.

The final report for this project has been published as: NCHRP Report 17, "Development of Guidelines for Practical and Realistic Construction Specifications."

Project 10-2 FY '64

Evaluation of Construction Control Procedures

Research Agency: Miller-Warden Associates
Principal Invest.: S. B. Hudson
Effective Date: November 4, 1963
Completion Date: February 1, 1966
Funds: $59,750

This research was initiated to obtain needed basic information for the formulation of standards for evaluation and acceptance of work, materials, and highway construction. Its objectives included a study to determine variations inherent to measurement methods, testing techniques, and sampling methods and procedures. The scope of this study was confined to the examination and investigation of gradation of aggregates. It includes a review of measurement and test procedures to determine those not including precision statements and a study involving statistical techniques for evaluating gradation test procedures, sampling methods, and variations inherent in aggregate gradations.

Initial phase research has been completed, and the project report has been published as:

NCHRP Report 34, "Evaluation of Construction Control Procedures—Interim Report."

Project 10-2A FY '65

Evaluation of Construction Control Procedures

Research Agency: Materials Research and Development
Principal Invest.: S. B. Hudson
Effective Date: July 15, 1966
Completion Date: November 14, 1967
Funds: $70,945

The continuation phase of Project 10-2 was conducted by Materials Research and Development, Inc., Miller-Warden Associates Division. The reserch specifically considered (1) the variations in gradation of aggregates, including fine aggregates, drawn from the bins of operating hot-mix plants, with sampling error, short- and long-term variations, and the effect of cold-feed variations to be included; (2) a statistically designed experiment to determine the effect of variation in gradation of coarse aggregate, within the range found to be inherent under existing controls, on the strength and workability of laboratory-prepared concrete; (3) the effect of increment size with respect to maximum particle size and accuracy of the results of sampling to provide additional information as to the shape and minimum capacity of tools to be used for sampling coarse aggregates; and (4) further study of the basic pattern of variation of gradation.

Research has been completed, and the project report has been published as:

NCHRP Report 69, "Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects."

Project 10-3 FY '64 and FY '65

Effects of Different Methods of Stockpiling and Handling Aggregates

Research Agency:	Miller-Warden Associates	
Principal Invest.:	S. B. Hudson	
Effective Date:	Oct. 22, 1963	Oct. 15, 1964
Completion Date:	Apr. 30, 1964	Oct. 16, 1965
Funds:	$25,000	$30,000

The difficulties associated with producing aggregates and providing them at the job site within desirable specification limits have been recognized for many years. To provide further knowledge for a possible solution to these difficulties, the over-all objectives of this research were to (1) find the effects of stockpiling and handling on the properties of an aggregate, including segregation and degradation, and (2) establish suggested procedures for better practices in stockpiling and handling.

Initial research was directed principally to the aspects of stockpiling, and the results have been published as:

NCHRP Report 5, "Effects of Different Methods of Stockpiling Aggregates."

Continuation of the initial research was authorized to expand the scope to include, in addition to further stockpiling investigations, the effects on aggregate properties of several routine methods for handling, spreading, and compacting bases. This work has been completed, and the project report has been published as:

NCHRP Report 46, "Effects of Different Methods of Stockpiling and Handling Aggregates."

Project 10-4 FY '64 and FY '65

Rapid Test Methods for Field Control of Construction

Research Agency:	Clemson University	
Principal Invest.:	Dr. A. E. Schwartz	
Effective Date:	Feb. 1, 1964	May 1, 1965
Completion Date:	Feb. 28, 1965	Feb. 28, 1967
Funds:	$30,000	$69,320

It has been recognized that there is a need for improved methods of sampling and testing to keep pace wth accelerated production rates and increased volumes of materials being used in highway construction. In an effort to fulfill this need, this research project proposed to seek out areas in which rapid test needs are most critical and to explore and summarize existing knowledge in these areas with the ultimate aim of accelerating the development of new methods of meeting these needs.

Work in the initial phase of this project consisted of a survey of the state of the art in the development, need, and use of rapid test methods for field control of construction. Areas of greatest need were determined; the present knowledge and state of development of various methods for meeting these needs were investigated; and those methods with greatest promise for satisfying the needs in the areas of bituminous paving mixtures, base-conrse construction, and soil compaction were selected for detailed study and development. An additional study was made of quality control and acceptance-sampling plans in respect to the number of tests required to provide adequate statistical information for acceptance or rejection of highway materials within given limits of risk and confidence.

During the continuation phase, emphasis was placed on further development and evaluation of improved test procedures in the areas of asphalt content of bituminous paving mixtures, density of aggregate base courses and bituminous layers, gradation of aggregates, and soil compaction.

Research has been completed, and the project report has been published as:

NCHRP Report 103, "Rapid Test Methods for Field Control of Highway Construction."

Project 10-5 FY '64 and FY '65

Density and Moisture Content Measurements by Nuclear Methods

Research Agency:	Research Triangle Institute	
Principal Invest.:	Dr. R. P. Gardner	
Effective Date:	Jan. 15, 1964	Apr. 1, 1965
Completion Date:	Jan. 31, 1965	Oct. 7, 1966
Funds:	$28,801	$59,835

For the past several years, investigators have studied the application of nuclear devices for determining moisture content and density of subgrade, subbases, and base components. Some of the researchers have indicated such devices are applicable for field control, while others are still evaluating the technique. If these nuclear devices are capable of accurate and reliable determinations, there is a possibility that considerable economy may result in construction and control procedures. The objectives of the initial research were (1) to review the literature and other available data to determine what has been done by others in the evaluation and correlation of nuclear equipment, (2) to evaluate and analyze assembled data considering such factors as accuracy and precision, and (3) to make recommendations for the development of needed equipment.

Research on the initial phase has been completed, and the project report for this phase has been published as:

NCHRP Report 14, "Density and Moisture Content Measnrements by Nuclear Methods—Interim Report."

The objective of the continuation phase was to investigate, in depth, the promising findings from the initial research. Theoretical investigations were supplemented by field experiments to establish a technique for calibrating nuclear gauges to provide improved accuracy in the measurement of soil moisture content and density. In the pursuit of these objectives, calibration standards were developed which are applicable to nuclear gauges currently in use.

Research on the continuation phase has been completed, and the project report for this phase has been published as:

NCHRP Report 43, "Density and Moisture Content Measurements by Nuclear Methods."

Project 10-5A FY '68

Optimization of Nuclear Density and Moisture Content Measurement Methods

Research Agency:	North Carolina State University
Principal Invest.:	Dr. R. P. Gardner
Effective Date:	February 1, 1968
Completion Date:	January 31, 1970
Funds:	$51,214

In recent years, there have been numerous investigations of nuclear methods for determining the moisture content and density of subgrade, subbase, and base components of highway pavements. Nuclear devices have been evaluated and found to be potentially more accurate and faster than conventional measurement methods. During the conduct of Project 10-5 the primary problems associated with these devices were identified as sensitivity-elemental composition, nonuniform response to the sample due to the nonhomogeneous nature of soil and aggregate materials, surface roughness of the measurement area, and gauge calibration. Several nuclear gauge calibration methods were developed utilizing calibration model, energy discrimination, and dual-gauge principles.

The essential objective of this study was to optimize nuclear gauge calibration methods and thus improve operational performance of the gauges for control of moisture and density during construction of highway subgrade, subbase, and base components. The objectives of the research have been met. Procedures have been developed for optimization of nuclear backscatter-type density gauge calibration, a quantity factor approach has been developed for evaluating the over-all performance of density gauges, and a tentative model is available for improved calibration of nuclear moisture gauges. The research has also provided a basis for design of even better nuclear backscatter-type density gauges.

Research has been completed, and the project report has been published as:

NCHRP Report 125, "Optimization of Density and Moisture Content Measurements by Nuclear Methods."

Project 10-6 FY '64 and FY '65

Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods

Research Agency: IIT Research Institute
Principal Invest.: K. E. Feith
Dr. S. D. Howkins
Effective Date: February 1, 1964
Completion Date: October 31, 1966
Funds: $108,821

Present methods of measuring the thicknesses of highway pavements are time consnming and generally do not provide data early enough for the contractor to alter operations so as to comply. It is recognized that a nondestructive technique would be advantageous, both cost- and time-wise, in comparison to present methods. In initiating this research, four objectives were outlined. They included: (1) a study of all past and present methods of measuring thicknesses of highway pavements to determine if any existing method may be suitable; (2) a feasibility study of proposed methods now under development; (3) proposals for other feasible methods; and (4) recommendations for promising methods for development of instrumentation.

Research has been completed, and the project report has been published as:

NCHRP Report 52, "Measurement of Pavement Thickness by Rapid and Nondestructive Methods."

Project 10-7 FY '64

Potential Uses of Sonic and Ultrasonic Devices in Highway Construction

Research Agency: The Ohio State University
Principal Invest.: Dr. F. Moavenzadeh
Dr. R. C. McMaster
Effective Date: February 1, 1964
Completion Date: March 31, 1965
Funds: $24,310

The use of sonic and ultrasonic devices is well known in some fields. Present practical application of sonic and ultrasonic frequencies and the results of recent experiments indicate a wide range of potential uses of such devices in highway construction. It is felt that possible uses may include pile driving, mixing and compaction of materials, sampling of materials, drilling, cutting, aud many other applications. In an effort to evaluate potential uses, this research study was initiated with the objectives of studying available information on present uses of high-frequency vibrations and making a feasibility study of possible applications to highway construction.

This research has been completed, and the project report has been published as:

NCHRP Report 25, "Potential Uses of Sonic and Ultrasonic Devices in Highway Construction."

Project 10-8 FY '70

Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position

Research Agency: Pennsylvania Dept. of Transportation
Principal Invest.: W. G. Weber
R. L. Grey
Effective Date: March 2, 1970
Completion Date: July 31, 1973
Funds: $151,982

The measurement of portland cement concrete pavement thickness and the determination of the position of reinforcing steel are necessary to establish conformance with design and construction specification requirements. The conventional method for making these determinations—by cutting cores from the hardened concrete and performing the related operations of handling, and testing—is time consuming and costly as well as destructive to the finished pavement. Furthermore, the determinations thus made, although of value for record purposes, are of little use during the construction process.

The determination of strength, although part of the overall problem, was not included in the research conducted under this project.

The objective of this research was limited to the field evaluation of available uondestructive systems of inspection testing for determining pavement thickness and reinforcing steel position at the construction site, either before or soon after the concrete has hardened, to permit the elimination of, or substantial reduction in, the coring of pavements.

To accomplish this objective, the research agency:

1. Conducted a state-of-the-art study and a preliminary evaluation to select the devices and procedures for determining concrete pavement thickness and reinforcing steel placement that have been developed to the point that field evaluation is now feasible.
2. Selected candidate procedures for field evaluation.
3. Developed and conducted a field evaluation program in cooperation with several State highway agencies.
4. Analyzed and compared field data with current practices with regard to such considerations as practicality, accurac, ease of operation and nondestructiveness.

All research on the project has been completed. The Ohio State ultrasonic gauge was found to be capable of measuring the thickness of both plain and reinforced concrete pavements with sufficient accuracy for construction control, as was also an eddy-current proximity gauge for use with plain (nonreinforced) pavements only. A pachometer was found to determine steel depth with sufficient accuracy for construction control. Statistical-type specifications were found to be required when the devices are used in construction control.

Research has been completed, and the project report has been published as:

NCHRP Report 168, "Rapid Measurement of Concrete Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems."

Project 10-9 FY '70

Criteria for Need of Seal Coats for Bituminous Pavements

Research Agency:	University of Minnesota
Principal Invest.:	E. L. Skok
Effective Date:	November 1, 1969
Completion Date:	February 28, 1974
Funds:	$50,000

In order to most economically maintain bituminous-surfaced pavements in serviceable condition, seal coats may be periodically required. Determinations of the need for seal coats, the type required, and the proper time to apply are important. Premature sealing results in a needlessly early expenditure of funds, while tardy action may result in excessive deterioration or unsafe conditions and greater total maintenance expenditures. Currently available methods of rating pavements for the need of sealing are not totally adequate. They are time consuming, require the use of costly equipment and highly skilled personnel, rely on the judgment of experienced personnel, or are not reproducible. Methods and criteria for determining when sealcoat applications should be made are needed.

The objectives of this project were to develop, and evaluate in the field, guidelines for the programming of seal coats on bituminous pavements.

The essential findings of the study have been published as NCHRP Research Results Digest 48. The agency report has been distributed to the Program sponsors and other interested persons, and microfiche of the report may be purchased (see final page of this section for ordering information).

Project 10-10 FY '74

Acceptance Criteria for Electroslag Weldments in Bridges

Research Agency:	United States Steel Corporation
Principal Invest.:	W. P. Benter, Jr. C. G. Schilling
Effective Date:	May 1, 1974
Completion Date:	September 30, 1978
Funds:	$300,000

Engineers are hesitant to permit use of the electroslag welding process for weldments subject to bridge loadings because sufficient research has not been conducted to determine their performance. Some states are permitting use of the electroslag process based on a very limited number of tests, some with borderline results. Most engineers will not permit its use on a bridge of major proportions because of the existing uncertainties; therefore, this program is of the utmost importance if this economical tool is to be widely used in the fabrication of bridges. The principal areas of concern are the physical and metallurgical properties of the weld and the heat-affected zones. The adequacy of current electroslag welding specifications for bridges has been questioned. Thus, a thorough analytical and experimental program of evaluation of all parameters is needed.

The over-all objective of this project was to develop and verify acceptance criteria for the use of electroslag butt welds in bridges. Research was conducted in two phases. The specific objective of Phase I was to define necessary acceptance specifications based on the most complete study, using laboratory specimens from full-size welds, that current knowledge and testing equipment could provide within the allotted funds. The specific objective of Phase II was to verify the findings of Phase I by conducting dynamic tests of full-size bridge girders.

Research has been completed, and the project report has been published as:

NCHRP Report 201, "Acceptance Criteria for Electroslag Weldments in Bridges."

Project 10-11 FY '77

Development of a Performance Specification For Bridge Deck Joint-Sealing Systems

Research Agency:	Howard Needles Tammen & Bergendoff
Principal Invest.:	Arthur Linfante
Effective Date:	December 1, 1976
Completion Date:	April 30, 1978
Funds:	$29,996

A large majority of bridge deck joint-sealing systems in use today are proprietary products. These products are designed in companies and corporations where a full range of experience with bridge deck behavior, field installation conditions, dynamic loading effects, climatic conditions, and pavement maintenance procedures is often not available. As a consequence, these products do not always function in the structures as intended. Some require costly maintenance, and others actually fail to survive more than a few years. Because most of these systems are furnished without a guarantee of any kind, public agencies are forced to assume responsibility for their adequacy, even though they are furnished and installed by project contractors. To avoid the worst of the systems, most agencies specify what appear to be the most practicable proprietary systems for their installations.

This specifying practice, when combined with current contract bidding procedures, has an adverse effect on the quality of sealing systems. Because contracts are normally awarded to the low-bid contractor, all contractors must, if they are to survive, devise ways to furnish and install products that will satisfy contract requirements at the least cost. Because this procedure emphasizes least cost rather than quality, the manufacturers of sealing systems are also forced to modify their designs and procedures to be competitive. But a competitive position can generally be attained only by a reduction in performance and quality and by a corresponding increase in maintenance and replacement cost. After several product-modification and cost-reduction cycles, initial benefits achieved by the use of such systems do not justify their substantial ultimate costs.

Optimum cost, which considers long-term performance as well as first cost, should be the goal for bridge deck joint-sealing systems. This goal can be attained by applying an effective performance specification. A side advantage will be a reduction in the use of publicly funded structures for experimental installations for the development of proprietary products. Yet the private sector would be encouraged to design and develop the kind and quality of products that are needed today by most transportation agencies.

There is need to develop an effective performance specification for the joint-sealing systems being installed in the great majority of the bridge decks currently being built.

The ultimate objective of this research was to develop an effective performance specification for prefabricated, surface-mounted bridge deck joint-sealing systems designed for a total horizontal movement of 4 inches or less. This study included the following tasks:

1. Review of available performance specifications applicable to bridge deck joint-sealing systems.
2. Assessment of the performance of currently used bridge deck joint-sealing systems.
3. Evaluation of present design, construction, and maintenance practices of the various transportation agencies with respect to the performance of present bridge deck joint-sealing systems.
4. Development of reasonable performance criteria for bridge deck joint-sealing systems.
5. Recommendation of a performance specification in a form suitable for consideration for adoption by AASHTO.
6. Identification of bridge deck joint-sealing system problems in need of further research.

Research has been completed, and the final report has been published as:

NCHRP Report 204, "Bridge Deck Joint-Sealing Systems—Evaluation and Performance Specification."

Project 10-12 FY '77

Acceptance of Aggregates Used in Bituminous Paving Mixtures

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Dr. R. L. Lytton
Effective Date:	September 1, 1977
Completion Date:	June 30, 1981
Funds:	$174,411

The supply of aggregates that are presently accepted for highway construction is limited in some areas of the United States and will be depleted in many other areas. Some presently used acceptance methods preclude the use of aggregates that have been shown to function adequately in certain bituminous paving mixtures. A need existed for an evaluation of methods for accepting or rejecting aggregates, with emphasis on identifying methods for considering the use of aggregates that are currently classified as unacceptable by present methods. The objective of this study was to evaluate currently used methods for the acceptance or rejection of aggregates used in bituminous paving mixtures.

The research was conducted in two phases. Under Phase 1, four overall schemes for evaluating the quality of aggregates to be used in bituminous paving mixtures were formulated, based primarily on various combinations of current state highway department practices. The four schemes were evaluated for their relative usefulness (utility) using a utility decision analysis computer program developed by the researchers. The schemes showing the most utility were comprised of conventional physical and chemical tests of aggregate samples.

Consequently, Phase 2 was designed to evaluate various tests on aggregate samples for their ability to predict bituminous pavement performance. A decision was also made to include some bituminous mixture tests and subjective petrographic ratings and to consider climate or geographic regions. Aggregate samples representing a range of quality and performance histories in actual bituminous pavements were obtained from several states and tested. Test results, subjective petrographic ratings, and regional factors were statistically evaluated by regression and correlation techniques for their significance in predicting separately derived pavement performance ratings. Pavement performance ratings were based on subjective assessments by individuals experienced with the performance of pavements containing the selected aggregates.

The research has been completed and the agency final report distributed to all NCHRP sponsors. A limited number of extra copies of the final report are also available to NCHRP sponsors. Copies of an agency interim report documenting Phase 1 and the agency final report, which concentrates on Phase 2, are also available for loan upon written request to the NCHRP. In addition, microfiche

of both reports may be purchased (see final page of this section for ordering information).

Project 10-13 FY '79 and FY '82

Ultrasonic Measurement of Weld Flaw Size

Research Agency:	The Welding Institute (England)	
Principal Invest.:	Timothy J. Jessop	Peter J. Mudge
Effective Date:	July 1, 1979	October 1, 1982
Completion Date:	October 31, 1981	August 31, 1985
Funds:	$126,000	$250,000

There is an urgent need for ultrasonic testing procedures that can be used to measure the dimensions of weld discontinuities (flaws) with sufficient accuracy to permit evaluation using a fracture-mechanics approach. Most State transportation agencies use the provisions of the American Welding Society Structural Welding Code AWS D1.1 to determine the acceptability of structural welds. These provisions are based on an assumed relationship between the ultrasonic "Indication Rating" and flaw size. The results of the first phase of research as well as other experience indicates that this relationship is not valid. Research is needed to develop improved ultrasonic testing procedures, using equipment presently available, that will permit accurate measurement of the dimensions of flaws common to weldments. These procedures are needed for use in both shop and field inspection of weldments to determine acceptance during construction and for in-service evaluation. Reliable procedures for ultrasonic testing will obviate the costs and delays of unnecessary repairs while reducing the probability that defects, which may lead to structural failures, will be improperly evaluated.

The overall objective of this study was to identify or develop, and to validate, ultrasonic testing procedures for accurate measurement of flaw dimensions that will allow fracture-mechanics analysis.

This study was addressed primarily to evaluation of complete joint penetration groove welds containing planar-type flaws snch as cracks or incomplete fusion.

In the first phase of research, laboratory tests on intentionally flawed specimens were used to determine the applicability and limitations of AWS D1.1-80 ultrasonic testing procedures for measuring the dimensions of flaws in welds. Phase I also included an evaluation of procedures that extend available ultrasonic techniques and have a potential for accurate measurement of flaws typically found in structural weldments. The accuracy, precision, reliability, and reproduceability of the time-of-flight and probe movement techniques were investigated.

The final report on Phase I has been published as:

NCHRP Report 242, "Ultrasonic Measurement of Weld Flaw Size."

The specific objectives of Phase II, designated NCHRP Project 10-13/1, were (1) to develop recommendations for applications of tandem-probe techniques for the characterization of vertical, planar defects and (2) to refine the time-of-flight system for sizing through-thickness flaw dimensions.

The research in this second phase included a review of all relevant literature and test data in order to develop a more realistic means of assessing vertical planar defects within the framework of the currently used AWS D1.1 code. Time-of-flight equipment was designed and assembled and subsequently evaluated in the laboratory in order to establish the accuracy of the equipment in measuring through-thickness dimensions for a variety of weld defects. Finally, a field evaluation of the equipment was performed in order to establish its accuracy and applicability, as well as to provide recommended procedures for use.

The research has been completed, and the final report is presently being reviewed. The report is expected to be published in 1986 as NCHRP Report 286.

Project 10-14 FY '79

Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques

Research Agency:	Georgia Tech Research Corporation
Principal Invest.:	Dr. J. D. Echard Dr. W. J. Steinway
Effective Date:	April 2, 1979
Completion Date:	March 1, 1981
Funds:	$99,850

An ability to locate voids beneath portland cement concrete pavements by periodic nondestructive surveys would permit replacement of support material before the development of pavement distress and loss of structural qualities. Developments in recent years in the field of pulsed electromagnetic wave technology indicate good prospects for locating and defining the extent of voids beneath pavements by nondestructive methods.

The primary objective of this project was to determine the practicality of pulsed electromagnetic wave technology for locating voids beneath reinforced and nonreinforced portland cement concrete pavements up to 18 inches thick. Another objective was the identification or development of a data processing technique suitable for use with the equipment that can be operated by field personnel and that will provide information on the parameters of voids beneath pavements. It was further desired that the voids beneath pavements be defined with an accuracy of at least ± ½ inch in depth and ± 6 inches in horizontal dimension.

Research has been completed with reasonable accomplishment of objectives. Theoretical modeling of signal

returns from voids led to suitable techniques for locating and sizing voids beneath pavements. Very short pulse radar was connected to a microcomputer to provide real-time processing of the radar signal return. Measurements made inside a laboratory-controlled environment verified the procedure. Additioual measurements were made on specially constructed outdoor pavement sections at 100 F, 70 F, and 32 F. At temperatures of 70 F and below, the measurements provided excellent estimates of void location and size, but at 100 F the measurements were not as successful.

The project report has been published as:

NCHRP Report 237, "Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques."

Project 10-15 FY '80

Structural Strength Evaluation of Existing Reinforced Concrete Bridges

Research Agency:	Engineering Computer Corporation	
Principal Invest.:	Roy A. Imbsen	
Effective Date:	April 1, 1980	April 1, 1984
Completion Date:	Sept. 30, 1982	Sept. 30, 1985
Funds:	$125,000	$100,000

Bridge safety has received increased emphasis during the past decade due to catastrophic bridge failures. As a result of these failures a concerted effort was expended to develop and disseminate procedures for systematic and periodic bridge inspections, particularly for steel structures. Although bridges with concrete superstructures rarely fail catastrophically, gradual deterioration can affect their structural capacity. The procedures for inspecting and rating bridges with concrete superstrnctures are limited and provide little information that can be nsed to evaluate structural strength.

Full-scale load tests of concrete bridges have indicated that their actual strength can significantly exceed the strength predicted by common analytical methods. Further, many of the strength-determiuing characteristics of the in-service bridge are known, whereas they must be assumed in the original design calculations. Recognitiou of these factors can have a great influence on the realistic evaluation of the structural capacity of existing concrete bridges.

A recent change in AASHTO policy may be interpreted as requiring a concrete bridge to be posted for restricted loading if the computed stresses exceed the allowable stresses, notwithstanding the fact that it had been carrying normal traffic for au appreciable length of time and shows no distress. There is a need to use the results of analytical and prior experimental investigations to enable engineers to predict safe load capacity of existing concrete bridges so that unnecessary replacing, strengthening, or load posting can be avoided.

Strength determinations need to address the states of deterioration and distress of the bridge and the results of rational analyses that more nearly predict the structural behavior.

The objective of this project was to develop improved methodology for evaluating the structural capacity of existing reinforced concrete bridge superstructures and to present it in a specification format suitable for consideration by AASHTO.

The final report on the first Phase I of the research included findings and recommendations related to methods of predicting structural capacity for load-rating concrete highway bridges. The limit-state approach to bridge evaluation recommended in this report appeared to be promising; however, some of the factors included in the report are not well documented, and the recommended approach is not yet ready for widespread application.

The Phase I final report will not be published, but copies of the agency's draft final report were distributed to NCHRP sponsors early in 1983. Copies are available ou loan or on microfiche (see final page of this document for ordering information).

Phase II of the research had as its objective further development of the limit-state approach to evaluate the structural capacity of reinforced concrete bridge superstructures. The recommended procedures will be presented in a format suitable for consideration by AASHTO.

The research in the second phase included a statistical analysis of information from the FHWA's computerized national bridge inventory system in order to identify typical reinforced concrete superstructure types that were applicable to this study. A sensitivity analysis was conducted to determine the effects of modifications to the load and resistance factors in the limit-state approach to evaluation. The factors to be used in the limit-state approach were identified and evaluated, and a calibration of the proposed method was performed using available test data. Finally, the results of the proposed method were compared with results from the currently used methods. The proposed method, its rationale, and the justification for its adoption will be presented to the AASHTO Bridge Committee in the spring of 1986.

The research has been completed. The final report has been received and is presently being reviewed. It is expected that the Phase II report will be published in the regular NCHRP series in 1986.

Project 10-16 FY '81

Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline

Research Agency:	Byrd, Tallamy, MacDouald & Lewis
Principal Invest:	Martin Rissel
Effective Date:	February 16, 1981
Completion Date:	December 1, 1982
Funds:	$150,000

Federal and state legislation requires periodic inspection and appraisal of all bridge elements. A substantial amount of information is available on repair methods for superstructures and substructures above the waterline, but procedures for use below the waterline have received little emphasis and application is complicated by inaccessibility. As a result, deficiencies including scour and structural distress, damage, and deterioration are sometimes undetected or endured until the potential for a major failure becomes apparent. Information is urgently needed to guide engineers in assessing the condition of bridge elements below the waterline and in selecting appropriate methods to arrest further deterioration.

This study was intended to use and extend earlier research reported in NCHRP Synthesis of Highway Practice 88, "Underwater Inspection and Repair of Bridge Substructures."

The objectives of Project 10-16 were; (1) to develop improved methodology for evaluating the effects of below-the-waterline deficiencies on the structural capacity of the substructure, and (2) to develop solutions to specific deterioration problems that are found in bridge substructures below the water surface and in the splash zone. Accomplishment of these objectives involved the following tasks:

Task 1. Addressing the deficiencies cited in the previously mentioned synthesis report, (a) review and snmmarize the present state of the art of structural strength evaluation techniques for bridge substructures below the water surface, with particular emphasis on quantifying the consequences of the deficiencies on the structural integrity of the bridge, and (b) for these deficiencies, develop guidelines for assessing the seriousness of the problem, a rating system to identify the urgency for corrective action, and practical methods to predict structural capacity.

Task 2. Task 2. Addressing the second part of the objective, (a) based on available information, identify and evaluate methods used to arrest deterioration below the water surface and in the splash zone, and (b) develop new or improved methods that may prove effective in arresting deterioration below the water surface and in the splash zone.

Task 2 was limited to the following elements and problem areas:

- Bridge elements—concrete piers and footings, prestressed concrete piles, and reinforced concrete piles.
- Problem areas—deterioration due to corrosion, freezing and thawing, chemical attack, and abrasion.

Task 3. A final report was prepared documenting the study findings and presenting the results in a practical format.

Research has been completed, and the final report has been published as:

NCHRP Report 251, "Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline."

Project 10-17 FY '81 and FY '83

Use of Antistripping Additives in Asphaltic Concrete Mixtures

Research Agency:	David G. Tunnicliff
Principal Invest:	David G. Tunnicliff
Effective Date:	March 1, 1981
Completion Date:	November 1, 1987
Funds:	$349,809

There is an increasing awareness of asphaltic concrete pavement failures caused by stripping of asphalt cements from the aggregates. Consequently, more highway agencies are requiring the use of antistripping additives. If an additive is used when it is not needed, the added cost is an economic waste. If an additive is used ineffectively, the pavement may require early and costly maiuteuance and/or rehabilitation. Highway agencies need information on the selection, effectiveness, and use of antistripping additives.

The long-term general objective of this research is to provide information on the selection and use of antistripping additives (materials used to improve the asphalt-aggregate adhesion in asphaltic concretes). However, the specific objective of the initial phase is to develop guidelines for the incorporation of antistripping additives in asphaltic concrete paving mixtures considering the influence of such factors as (1) storage and handling of the additives, and (2) stability and effectiveness of additives during mixing and storage of asphaltic concrete.

Research has been completed on the initial phase with accomplishment of the objectives. The test method for predicting moisture damage in asphalt concrete pavements described in NCHRP Report 246 was modified to reduce test time and control the degree of saturation. The modified test method was used to evaluate effects of storage and handling of asphalt aggregate mixtures on antistripping additives. Guidelines were developed for using antistripping additives based on previous research and limited testing using the modified method.

The FY '83 program contained $200,000 for the field evaluation of the test method for predicting the performance of asphalt concrete pavements containing antistripping additives. A detailed work plan for the field evaluation phase has been approved by the project panel and the contract amended to provide for the expanded scope of work, increased funds, and additional time. Research is in progress. Test sections with and without antistripping additives will be included in regular paving projects in six states. Laboratory tests will be conducted using the actual aggregates, asphalts, and additives from the projects to predict pavement performance.

Research on the field evaluation phase is in progress. Asphalt concrete overlay projects have been selected in

Arkansas, Georgia, Maine, and Virginia for inclusion in the study and the test sections with and without antistripping additives have been built. Data collection by the cooperating state highway agencies is in progress. Suitable projects for the construction of test sections are being selected in Colorado and Texas. The FY '87 program contains a continuation allocation of $150,000 to provide for test sections in three additional states.

The final report for the initial phase has been published as:

NCHRP Report 274, "Use of Antistripping Additives in Asphaltic Concrete Mixtures—Laboratory Phase."

Project 10-18 FY '81

Specifying and Obtaining Entrained Air in Concrete

Research Agency:	Construction Technology Laboratories/PCA
Principal Invest:	David C. Stark Dr. David Whiting
Effective Date:	May 5, 1981
Completion Date:	June 1, 1983
Funds:	$73,585

The inclusion of entrained air within the matrix of portland cement concrete has long been recognized as an effective means for improving the durability of concrete exposed to the highway-type environment. However, in recent years there has been a trend toward requiring higher air contents. This trend has primarily been in response to the nationwide problem of premature bridge-deck distress.

Field control of the higher air contents has proven to be very difficult. The higher dosages of air-entraining admixtures used to achieve the higher air content levels apparently interact with other concrete ingredients in a nonuniform and frequently unpredictable fashion. This is particularly true in low slump concrete with high cement factors and low water-cement ratios. Small increases in water have been noted to cause a substantial increase in the amount of entrained air. This may impair the concrete performance.

The objective of this research was to develop practical guidelines for specifying and obtaining the optimum amount of entrained air in concrete. Consideration was given to interations between typical concrete ingredients and various admixtures.

Research has been completed and the project objective accomplished in the form of guidelines for field control of air-entrained concrete. A state-of-the-art report on air-entrained concrete was also prepared and copies printed for distribution to program sponsors. Loan copies are available (see final page of this section for ordering information).

The final report including the guidelines has been published as:

NCHRP Report 258, "Control of Air Content in Concrete."

Project 10-19 FY '81

Adding Dust Collector Fines to Asphalt Paving Mixtures

Research Agency:	The Pennsylvania State University
Principal Invest:	Dr. David A. Anderson
Effective Date:	March 1, 1981
Completion Date:	November 30, 1982
Funds:	$49,926

In the past decade, many states have promulgated strict air pollution control codes and standards regarding the emission of particulates into the atmosphere. This has brought about an increase in secondary dust collection equipment for the production of asphalt paving mixtures. The inclusion of baghouse filters as secondary collection equipment has generated large quantities of heretofore uncollected fines. To help offset the cost of this equipment, and to avoid accumulation of a waste product, asphalt plants in many instances are using the collected fines as a partial or total replacement for mineral filler in paving mixtures. A study by The Asphalt Institute indicated that baghouse fines perform as well as standard filler materials. However, the study further revealed that to achieve such performance the collected fines should be obtained from good quality parent aggregate and should be introduced to the mix in a manner that yields a controlled mix. Unfortunately, the realities of asphalt concrete production operations are often not consistent with the guideline provided by the Institute's findings. Consequently, the quality and variations inherent in the aggregates used and the resulting baghouse material become questionable.

The objectives of this project were: (1) to conduct a state-of-the-art survey of studies dealing with the effect of dust collector fines on asphalt concrete and current practices for specifying and handling these fines, and (2) to characterize by generic type those dust collector fines now in use. Of particular concern was the dust collected in baghouses.

The state-of-the-art survey required to accomplish objective (1) was conducted. A tabulation of state practices and the types of plant equipment used were included. To accomplish objective (2), samples of baghouse fines from various asphalt production plants and different aggregate types were obtained. The types of equipment for handling dust and the operating conditions were recorded for each plant where samples were taken. Within-day, day-to-day, and plant-to-plant variations in baghouse dust particle sizes were determined. Guidelines for the handling of dust have also been recommended.

Research has been completed, and the final report has been published as:

NCHRP Report 252, "Adding Dust Collector Fines to Asphalt Paving Mixtures."

Project 10-20 FY '81 and FY '83

Elastomeric Bearings Design, Construction, and Materials

Research Agency:	University of Washington	
Principal Invest:	Dr. C. W. Roeder	
	Dr. J. F. Stanton	
Effective Date:	February 1, 1981	June 1, 1983
Completion Date:	June 30, 1982	May 31, 1986
Funds:	$74,715	$150,000

The full potential of elastomeric bridge bearings will not be realized in the United States unless design specifications are up to date.

Because of the desirable performance characteristics, maintenance-free durability, and first-cost economy of elastomeric bearings, there has been a burgeoning of applications and a proliferation of sizes for bridge bearings. From the initially small, unreinforced elastomeric bearing pads for short-span prestressed beams, applications for laminated elastomeric bearings have grown—especially abroad—to such an extent that today designers are considering bearing capacities of 1500 tons. The AASHTO specification for elastomeric bearings, in use when this study was initiated, was probably, in large measure, a catalyst for the accelerated growth of elastomeric bearing applications in the United States; yet it no longer reflected the best information available.

These specifications were limited in a number of ways. For example: axial load capacity for steel-reinforced bearings was below that allowed by other codes; axial loads were not related to rotation or translation, separately or in combination; shear forces that are generated by temperature-induced translation were undefined; laminate reinforcement was not related to load levels; and the relationship between compression stress and compressive strain was not specified.

Innumberable elastomeric bearing research projects have been completed in recent years both in the United States and abroad. The findings of much of this research have been presented in detail in published papers receiving broad distribution. But much other work, especially that by commercial concerns and independent research organizations, has received only limited circulation or none at all. Performance data on actual bearings in the United States and abroad may be available. Because most design engineers have not had the time or opportunity to assimilate this information, it was not reflected in the AASHTO specifications and has not had much effect on the design of elastomeric bearings.

To recognize the full potential and efficiency of elastomeric bearings, specifications must be based on the best information available on the behavior and capacity of plain and reinforced elastomers.

The objective of the first phase of research was to develop specifications for unconfined, plain and reinforced elastomeric bridge bearings.

The findings of Phase I of Project 10-20 were published as:

NCHRP Report 248, "Elastomeric Bearings Design, Construction, and Materials," and included recommendations for improved specifications for unconfined, plain and reinforced elastomeric bridge bearings. These recommendations were based on currently existing information. In 1985, AASHTO adopted many of the recommendations of the Phase I research, substantially revising the provisions for elastomeric bearings in the Standards Specifications for Highway Bridges.

The objective of the second phase of research is to develop a more sophisticated specification for special applications and to improve the simplified provisions recommended in Phase I. The Phase II research includes the following tasks:

1. Evaluation of low-temperature effects in elastomers by analysis and testings.
2. Confirmation and simplification of theories of behavior.
3. Determination and assessment of failure modes.
4. Evaluation of material behavior.
5. Development of improved specifications.
6. Preparation of a draft interim report at the end of the 20th month and a draft final report at the end of the 33rd month.

Through December 31, 1985, research on Tasks 1 and 2 is essentially completed, and substantial progress has been made on Tasks 3 and 4. The interim report was submitted in May 1985 and reviewed by the project panel at a meeting in August 1985. At that time, the panel decided to proceed with a third phase of research that will provide recommendations for manufacturing procedures and tolerances as well as acceptance test procedures for unconfined elastomeric bearing. The third phase will also prepare a synthesis on the design, construction, and use of confined elastomeric (pot) bearings with and without sliding surfaces.

Project 10-21 FY '81

Performance of Bridge Deck Concrete Subjected to Traffic-Induced Vibrations During Placement

Research Agency:	Transportation Research Board
Principal Invest.:	Dr. Paul E. Irick
	Mr. T. L. Copas
Effective Date:	February 1, 1980
Completion Date:	September 30, 1981
Funds:	$25,000

In repairing bridge decks, extra costs are sometimes expended to avoid the possibility of detrimental effects from displacements caused by traffic in lanes adjacent to the fresh concrete. Reliable information is needed so that engineers can make proper decisions regarding traffic control during bridge deck repair projects.

The objective of this study was to determine the effects of traffic-induced vibrations on concrete for various bridge deck repair and widening procedures and to indentify criteria for materials, design, construction, and traffic control procedures to alleviate any negative effects. The research included consideration of the following factors associated with bridge deck concrete used in overlays, full and partial-depth restoration, and widening: (1) bonding to substrate and adjacent concrete: (2) bonding to reinforcing steel; (3) differential consolidation; (4) interaction between concrete properties and differential consolidation; (5) differential deflections; (6) frequency of vibration (traffic induced); (7) porous planes of weakness; (8) traffic control criteria; (9) design criteria (including bridge type); (10) construction practice (including deck preparation); (11) crack development from all sources; and (12) mix design effects.

The study included the following tasks:

1. Identification of relevant research and field investigations.
2. A survey of current practice and attitudes on maintaining traffic during bridge deck restoration or widening.
3. Follow-up contact with a number of highway agencies to gather more detailed information on the field performance of bridge decks that have been restored, patched or widened in the presence of traffic induced vibrations.
4. A recommendation for additional research to be directed toward determining the causes and possible solutions for any negative effects determined to be associated with such vibrations.

NCHRP Project Panel D10-21 decided that a preliminary study should be carried out under NCHRP Project 20-5. "Synthesis of Information Related to Highway Problems," and $25,000 of the $250,000 that was originally allocated for this study were reallocated for this purpose. Research has been completed, and the final report has been published as:

NCHRP Synthesis of Highway Practice 86, "Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs."

The draft final report included an evaluation of research needs with recommendations for specific work to meet these needs. The project panel accepted the synthesis topic consultant's recommendation to not carry out additional research on this subject. This recommendation was based on the fact that no convincing evidence was found in this study to indicate that the performance of concrete bridge decks is degraded by traffic-induced vibrations during placement. The unused portion ($225,000) of the allocated funds has been returned to the AASHTO Research Committee for reallocation to other NCHRP projects.

Project 10-22 FY '82

The Performance of Weathering Steel in Bridges

Research Agency:	Sheladia Associates, Inc.	
Principal Invest.:	Dr. Pedro Albrecht	
Effective Date:	April 1, 1982	July 23, 1984
Completion Date:	February 29, 1984	January 22, 1986
Funds:	$74,963	$99,988

Weathering steel has been used in the construction of about 2,000 bridges in the United States with the great majority of these structures concentrated in a few states. Under the proper conditions, this material is expected to form its own protective surface layer and to require no painting. It therefore offers the potential for considerable savings in life-cycle costs by elimination of the need for painting bridges, particularly those over major highways, electrified railways, or bodies of water. Under some environmental conditions, corrosion has continued at a rate more rapid than anticipated, and there are concerns regarding the long-term performance of this material. Hence, the use of weathering steel in bridges has been more limited than might be expected in view of the potential cost savings. Information on the performance of weathering steel is available, but a need exists to assemble and evaluate the data in order to facilitate the decision-making process and place it on a more rational basis.

The objectives of the first phase of research were (1) to assemble a systematic body of information on the performance of weathering steel, and (2) to document and evaluate the current state of practice.

The first phase of research has been completed, and the final report published as:

NCHRP Report 272, "Performance of Weathering Steel in Bridges."

The second phase of research has as its specific objectives (1) to fatigue test 8-year weathered A588 transverse stiffener specimens under constant loading in air and aqueous environments, and (2) to develop practical guidelines for design, construction, maintenance, and rehabilitation of weathering steel bridges.

Research on the second phase is nearing completion. The agency's preliminary draft final report is expected by January 1986.

Project 10-23 FY '82

Removal of Lead-Based Bridge Paints

Research Agency:	Midwest Research Institute
Principal Invest.:	Michael K. Snyder
Effective Date:	July 1, 1982
Completion Date:	June 30, 1983
Funds:	$81,118

In the removal of old lead-based paints from steel bridges in preparation for repainting, particulate matter consisting of the old paint plus the grit used in sandblasting can be deposited in air, water courses, and on

adjacent lands. Containing and disposing of lead-based paint is a very difficult and costly proposition. Highway agencies have had partial success in limiting the paint waste with relatively moderate efforts, such as tarps, vacuum blasting, rigid enclosures, and chemical removal with containment. In addition, the FHWA had a study for the development of a prototype unit to prepare steel surfaces using controlled water jet cavitation. Extracting information from the varions state and government agencies of previous work could be used to identify possible ways to modify, optimize, or redesign equipment and procedures.

Furthermore, the toxicity of lead is well documented, but there is little evidence whether the type and amount of lead compounds used in bridge paints are hazardous to the environment when they are removed. Several agencies have been required to test toxicity levels of paint and abrasive wastes. High levels of potential toxicity may require disposal in hazardous waste disposal sites which are limited and costly. In addition to the toxicity of lead itself, highway bridge officials are being faced with problems of dust pollution, silica sand toxicity, and solid paint waste disposal.

Consequently, research was performed to: (1) identify the severity of pollution related to bridge cleaning and (2) recommend improved techniques for removal and recovery of lead-based bridge paints. Environmental pollution and toxicity information associated with lead paint removal and disposal, euvironmental regulations pertaining to lead paint removal, and environmental test methods for lead paint residues were reviewed and commented on. Removal and recovery methods were summarized and evaluated. Concepts for improving existing technology and comments on new techniques nnder development were generated.

Research has been completed, and the project report published as:

NCHRP Report 265, "Removal of Lead-Based Bridge Paints."

Project 10-24 FY '82

Rapid Replacement of PCC Pavement Segments

Research Agency:	ARE Inc.
Principal Invest.:	Dr. A. H. Meyer
	R. F. Carmichael III
Effective Date:	March 15, 1982
Completion Date:	March 14, 1988
Funds:	$240,000

States and local agencies are having to spend millions of dollars annually for the repair and replacement of worn-out portland cement concrete (PCC) pavements. Mnch of the money is being spent on improvement projects reqniring work to be completed at spot locations in less than 24 hours. At the present time there is little information available to measure the relative effectiveness of the various rapid repair techniques to replace segments of PCC pavement. Nor is there much information available regarding service life of the replacement sections, the costs of construction, or the possible adverse effects on adjoining pavement slabs. The lack of such data undoubtedly is causing money to be wasted on designs that are too costly to construct and to maintain. Cost and performance data on these various rapid replacement techniques are needed to enable the engineer to call for the most cost-effective alternatives.

The objective of this research is to identify, describe, and evaluate methods that have been and are being, used for rapid replacement of lane-width segments of both continuously reinforced and jointed PCC pavements relative to costs, placement conditions, traffic characteristics, performance and expected service lives. Accomplishment of the project objectives will require completion of the following tasks:

Task 1. Through contacts with FHWA, states, and toll authorities, and through review of available literature, identify, describe, and categorize those rapid replacement methods (successful and unsuccessful) that have been, and/or are being, scheduled to be used. Make follow-up contacts for additional information with those agencies where the initial contacts indicated favorable opportunities for further field evaluations of promising methods. Recommend further field evaluations of selected methods considering availability of design, material, and construction information; accessibility of sites for field study; traffic characteristics; elimatic conditions; and indicated willingness of the agency to cooperate in the project. The recommendations for field evaluations should include both proposed and in-service projects.

Prepare interim report no. 1 describing the results of Task 1 along with an updated working plan for Tasks 2 and 3. NCHRP approval of the methods aud sites recommended for further field evaluations shall be obtained prior to proceeding with Task 2.

Task 2. Compile descriptive information for each of the finally approved sites. Pertinent plans and specifications for each project site shall be assembled and expected traffic noted. Construction data shall be collected including: costs, methods of determining replacement limits, materials, admixtures, placement methods and equipment, significant dates and times, difficulties encountered, unusual circumstances, temperature and humidity at time of placement (if cast-in-place), and any other information that may affect future performance or method of selection.

Task 3. Evaluate effectiveuess of each method. Each site shall be monitored on a scheduled basis throughout the remaining contract period to assess the performance of the replacement slabs and the adjacent pavement. Snrface texture, rutting or wear, crack distribution aud severity, riding qualities, pumping, faulting, and other pertinent factors shall be noted.

Interim report no. 2, covering a preliminary evaluation

of the effectiveness of the various rapid repair methods under study, shall be prepared immediately following the initial visits to the field sites.

Task 4. Prepare a final report documenting all research.

Research is in progress; interim report no. 1 was submitted and accepted by the NCHRP project panel. The interim report contained recommendations for field sites in six States: California, Illinois, Minnesota, Michigan, Texas, and Virginia. The field site locations represent a variety of environmental regions and PCC pavement types (i.e., jointed plain, reinforced, and continuously reinforced concrete pavements).

Interim report no. 2 has been submitted. Findings to date indicate little variety in materials being used, but design and replacement techniques vary. Troublesome issues are determining the limits of segments needing replacement and determining the number and size of replacement segments before a major reconstruction is recommended. Interim report no. 2 has been distributed to all state highway departments. Copies are available to others for loan or purchase on request to the NCHRP.

The remaining contract period will be devoted to continued monitoring of the field sites by affected state personnel and the researchers. Some of the sites have been lost to overlay projects. Apparently, initial repairs are symptomatic of more serious problems in some cases.

Project 10-25 FY '83

Measurement of Cement and Water Content of Fresh Concrete

Research Agency:	U.S. Army Corps of Engineers Waterways Experiment Station
Principal Invest.:	Richard L. Stowe, Alan D. Buck, Tony B. Husbands, Joe G. Tom
Effective Date:	October 13, 1983
Completion Date:	November 30, 1985
Funds:	$149,995

Concrete is unusual among construction materials in that it is manufactured as used and cannot be tested for acceptance in advance. Because it gains strength over a long period of time and the level of strength assumed in design may vary from that attained in a period ranging from one day to three months, acceptance is commonly based on strength tests at an advanced age. There is, therefore, at any given time, a large amount of concrete in-place, on most projects, the acceptability of which has not been determined. Clearly, a need exists to assess the quality of concrete much earlier, ideally before it is placed.

It is universally agreed that the most important parameter for determining the quality of concrete is the water-cement ratio. If the quantities of cement and water can be determined in concrete before it sets, or if the water-cement ratio can be determined directly by a reliable method, significant progress will have been made. A 1972 survey by the AASHTO-ARTBA-AGC Task Force on Rapid Testing cited the need for methods for measuring the cement and water content of plastic portland cement concrete. Two-thirds of the 43 state agency respondents affirmed the need for such methods.

Several methods have been developed or proposed. None of those developed to date are rapid enough to enable a decision on acceptance to be made before concrete is placed in the forms. Nevertheless, if they were reliable they could be used to audit the performance of the concrete produced and could lead to a much qnicker response to correcting production problems than is now possible. A 1980 West Virginia Department of Highways report ("State of Technology for Quality Assurance of Plastic Concrete: Phase I—Feasibility Study," FHWA/WV-80/006) is an excellent summary of the methods, their advantages and disadvantages, and various operating details.

A critical examination and evaluation of these methods was needed to assess their adequacy and to provide support data to allow development of standardized procedures. Questions related to the reliability of the methods when used to test concretes with different aggregates, different cement factors, additives and admixtures had to be answered.

The objective of this research was to establish the applicability and accuracy, along with the limits of validity, of test methods for the determination of water-cement ratio and/or cement and water content of freshly mixed concrete. The following test methods were investigated: (1) US Army Construction Engineering Research Laboratory/Kelly-Vail (CERL/K-V), Rapid Analysis Machine (RAM), FHWA nuclear device, a centrifugc test, and an x-ray emission spectrometer for determination of cement content; and (2) CERL/K-V, hot plate and microwave oven for the determination of water content.

Research is complete. The agency final report is now under review for publication in the NCHRP report series early in 1986.

Project 10-25A FY '85

Instantaneous Determination of Water-Cement Ratio in Fresh Concrete

Research Agency:	Wiss, Janney, Elstner Associates, Inc.
Principal Invest.:	William G. Hime
Effective Date:	June 1, 1985
Completion Date:	August 31, 1987
Funds:	$300,000

Concrete is unusual among construction materials in that it is manufactured as used and cannot be tested for acceptance in advance. Because it gains strength over a long period of time and the level of strength assumed in design may vary from that attained in a period ranging

from one day to three months, acceptance is commonly based on strength tests at an advanced age. There is, therefore, at any given time, a large amount of concrete in-place on most projects, the acceptability of which has not been determined. Clearly, a need exists to assess the qnality of concrete much earlier, ideally before it is placed. It is generally agreed that the most important parameter for determining the quality of concrete is the water-cement ratio. If the quantities of cement and water can be determined in concrete before it sets, or if the water-cement ratio can be determined directly by a reliable method, significant progress will have been made. Several methods have been developed that may be suitable for quality assurance programs; they have been evaluated in side-by-side comparisons under previous NCHRP contract. However, it is felt that these present procedures are not adaptable to the ideal solution—the instantaneous measurement of water-cement ratio to allow a go/no-go decision on an actual batch. A research program is needed that will lead to a direct reading probe that could be placed in the delivered concrete prior to discharge.

The objective of this research project is to develop a method of measuring the water-cement ratio in concrete that could form the basis of an acceptance test at the job site. The desirable characteristics of such a method are: (1) rapidity—results should be obtainable within 2 minutes or less, (2) accuracy—measurement of water-cement ratio to within 0.02, (3) cost—the equipment should be of such price (under $5,000) that a testing ageney might reasonably be expected to acquire several items, (4) convenience—the method should consist of a probe to bc inserted directly into a central or truck mixer, (5) versatility—the test should be capable of being performed at any time from first mixing up to the maximum delivery time allowable (approximately 90 minutes at a concrete temperature of 70°F), and (6) simplicity—the probe should be easily calibrated so that the effects of changing concrete material and temperature may bc accommodated. It is anticipated that a method based on a direct determination of the water-cement ratio is most likely to satisfy all of the above requirements, but an approach that measures cement and water contents separately can be pursued if justified. Some methods that may be appropriate are measurement of dissolved ions, radioactive detection of soluble or insoluble species, and chromatographic analysis of volatile compounds. The following three tasks shall be addressed to achieve the project objective.

Task 1—Evaluate and demonstrate in the laboratory the feasibility of using an element(s) or compound(s) naturally occurring in cement that can be instrumentally measured to define the water-cement ratio of a concrete mixture. The element(s) or compound(s) identified should not occur in typical concrete admixtures or concrete aggregates in sufficient quantity or form to have a significant effect ou instrumental (probe) analysis.

Task 2—Investigate candidate materials to be added to cement during its manufacture that can be readily measured and whose concentration will suitably reflect the water-cement ratio of concrete. The selection of a material(s) must consider: (a) the cost of the basic prototype material, and of the procedures and equipment which could be used to add the material to the cement; (b) the potential availability of analytical equipment of adeqnate accuracy of discrimination; and (c) the interference from usual concrete ingredients including admixtures. The first step in this task is to identify candidate materials and measurement schemes. Based on estimates of cost and feasibility of additions, one or more materials should be used in the laboratory to demonstrate performance in a high pH environment and to determine if measurements can be made with the required accnracy.

Task 3—Having selected the most promising element(s) or compound(s) whose concentration is to be measured, demonstrate the feasibility of performing measurements quickly in the field. The demonstration may consist of using a commercially available probe, if such exists, or developing a prototype probe for each element or compound to the point where it is apparent that a small rugged commercial model is possible.

Research is being conducted under Tasks 1 and 2. Primary emphasis will first be placed on trying to find a technique under the Task 1 concept, i.e., without the addition of a detectable ingredient.

Project 10-26 FY '83

Data Bases for Performance-Related Specification for Highway Construction

Research Agency:	ARE, Inc.
Principal Invest.:	Dr. W. Ronald Hudson, Dr. Alvin H. Meyer
Effective Date:	June 15, 1983
Completion Date:	September 14, 1984
Funds:	$60,000

Performance-related specifications are specifications that require tests and/or control measures the results of which have been shown to correlate with performance of the completed project. With an increasing need to reduce costs and make the most effective use of limited staffs, a number of states and FHWA continually examining their specifications and test programs. Their goal is to determine which are truly related to pavement performance and are cost effective.

One means of reaching this goal is to correlate the results of condition surveys on existing pavements with the original construction and materials test data. It is possible that most records for existing pavements and foundations are not readily retrievable, no longer exist, or are not suitable for correlating with performance. Consequently, there was a perceived need to establish the

state of existing records and to make record-keeping recommendations for ongoing construction. Such records would be an integral part of a pavement management system.

The objective of this study was to establish the state of test records on construction and materials control for pavement structures and foundations. The primary aim was to establish which, if any, of the available records were useful for development of performance-related specifications.

Assessments of various sources of data and statistical techniques for use in developing performance-related specifications resulted. Guidance for future endeavors was given.

Research is complete; copies of the agency final report, "Data Bases for Performance-Related Specifications for Highway Construction," were distributed to all state highway departments. Copies are available to others for loan or purchase. (See final page of this document for ordering information.)

Project 10-26A FY '84

Performance-Related Specifications for Hot-Mix Asphaltic Concrete

Research Agency:	The Pennsylvania State University
Principal Invest.:	Dr. David A. Anderson and Dr. David R. Luhr
Effective Date:	Contract pending
Completion Date:	
Funds:	$250,000

Performance-related specifications are those that require tests or other control measures on materials and construction, the results of which correlate to a known degree with performance of the completed highway facility. It can be argued that using control measures that cannot be related to performance wastes staff time and increases costs without benefit. The need to use staff effectively and to reduce sampling and testing costs has required a continuing examination of specifications by the states and the Federal Highway Administration. These examinations have convinced many of the need to identify effective performance predictors and their variability limits, to develop specifications based on these predictors, and to apply cost-effective sampling and testing plans to assure compliance.

One of several ways of establishing performance predictors is to correlate the results of condition surveys on pavements directly with original materials and construction test data. However, previous research has demonstrated the difficulty of establishing these direct relationships, especially when they are attempted nationwide with existing data from in-place facilities. A more promising approach may be to recognize the establishment of design factors as predictors of ultimate performance and then to use materials and construction testing as a means to ensure adequate compliance with or achievement of the design factors. As an example, for asphaltic concrete construction, stiffness (elastic modnlus) and tensile strain would be possible design factors, while asphalt content and percent air voids would be possible materials and construction test data.

Although the relationships among materials and construction tests, design factors, and performance are of primary interest, the relative impact of other factors cannot be ignored. Factors such as quality of construction, environment, and reliability of testing techniques are among many that can have significant effects.

Establishing or verifying the causal relationships and the sensitivity of these relationships among performance, design factors, and test data requires first the development of an overall conceptual model or framework. This conceptual model should make use of established relationships already identified in the literature. Once the concept has been formulated, the variables and data needs must be identified. Existing, suitable data should be used to the extent possible; however, it is unlikely such data will be available or meet the needs of all data requirements. Therefore, laboratory and field experiments will have to be defined to generate supplemental data. With the identification or generation of data, previously established or conceptual relationships can be verified and further analyzed for the predictive sensitivity of each variable and its reliability. The ultimate purpose will be to develop materials and construction specifications that relate to the actual performance of the facility. This process will be an iterative one, but careful planning will produce meaningful results promptly and with minimum waste.

To limit the problem to a manageable undertaking, and to mesh with ongoing and upcoming research by the Federal Highway Administration, the scope of NCHRP Project 10-26A is confined to performance-related specifications for hot-mix asphaltic concrete.

The objective of this study is to identify the relationships between materials and construction test data and the performance of hot-mix asphaltic concrete. Causal relationships among performance, design factors, and test data should be verified or established with the ultimate aim of formulating specifications that directly (or through identifiable indirect means) relate, within acceptable tolerances, to the performance of hot-mix asphaltic concrete in a pavement cross-section. In some cases, this will require establishing design factors that relate to performance and then establishing the materials and construction tests that will control those design factors. It is noted that all existing materials or construction tests may not be related to performance, and, conversely, the present study may identify the need for tests not currently in use.

In order to accomplish the objective of this study the following tasks will be required:

Task 1—Develop a conceptual model or framework focusing principally on the relationships among perform-

ance, design factors, and materials and construction test data, while at the same time recognizing the overall context in which these relationships exist and are affected (e.g., the influence of weather, construction quality, and actual traffic and axle loadings).

Task 2—Identify all variables and types of data needed to evaluate and test the Task 1 concept. Variables and data sets needed to establish relationships are expected to fall into one of the following categories: (a) significant, known relationships among variables for which data sets exist for any needed verifications, (b) suspected relationships for which data sets exist for the needed analyses, (c) suspected relationships for which no or limited data sets exist and new data must be developed, and (d) data that exist, hut for which no relationships are expected and, therefore, can be eliminated from unnecessary analytical work.

Task 3—Locate existing, suitable data to meet the needs identified in Task 2. (The initial NCHRP Project 10-26 identified some potential sources and the Federal Highway Administration has supported studies that may also have bearing.)

Task 4—Determine the types of laboratory and field tests or experiments required to supplement existing data. Consideration should be given to the importance and relevance of accelerated testing techniques. Develop appropriate plans for such tests and experiments, including time and cost estimates.

Task 5—(a) Submit an interim report that defines in detail the conceptual model or framework including draft performance-related specifications, the variables and data needed to test the concept, the existence of suitable data, and the types of testing and experimentation needed to supplement existing data. (b) Append to the interim report a research plan designed to achieve as much of the objective of the present project as is possible with the remaining contract funds. Approval of the research plan by the NCHRP will be required prior to the initiation of remaining tasks.

Task 6—Conduct the approved research plan described in Task 5(b).

Task 7—Prepare the final report documenting work in all tasks. Conclusions and recommendations from the study should be directed toward the achievement of specifications for hot-mix asphaltic concrete that relate to acceptable limits of performance.

Project 10-27 FY '84

Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Robert Lytton
Effective Date: September 17, 1984
Completion Date: March 6, 1986
Funds: $200,000

An increasing responsibility of highway and transportation agencies is the maintenance, rehabilitation, and management of highways that have been built. Particularly with regard to asphaltic concrete pavements, this requires the use of efficient and economical methods for determining the structural properties of existing pavements. Use of nondestructive testing (NDT) data with associated analysis methods appears to have potential for determining these pavement structural properties. Several types of NDT equipment and analysis procedures are currently available for providing the desired information. Analysis procedures utilizing NDT data vary substantially in complexity, accuracy, and availability—making the selection of appropriate equipment and analysis methods for an individual agency's pavement management needs difficult.

Up-to-date information on the application and limitations of available analysis procedures for determining asphaltic concrete pavement structural properties using NDT data is urgently needed.

The objectives of this research are: (1) to provide methods and guidelines for calculating the structural properties of asphaltic concrete pavements, using nondestructive test data, for use in pavement analysis, design, rehabilitation, and other pavement management activities; and (2) to develop detailed procedures to verify the methods and to adjust the results for local conditions. It is anticipated that the objectives will be accomplished through the following tasks:

Task 1. Review existing literature on the theoretical, empirical, and rational analysis methods that are used to evaluate the structural capacity and strength of asphaltic concrete pavements (or layers) using NDT data. This review should consider concepts, assumptions, and limitations of each analysis method and should also be summarized in tabular form when possible.

Task 2. Evaluate existing methods of using NDT (deflection) data for analyzing asphaltic concrete pavement structures and designing resurfacing layers. The evaluation should address the ease of collection of required data inpnt, usefulness to structural property characterization, performance evaluation, pavement overlay design, cost-effectiveness, complexity, precision, adaptability, and correlation to different equipment and users. The degree to which the method can be used for a highway or street network level analysis versus project level analysis, deflection basin shape, and/or maximum pavement deflection analysis should be included.

Task 3. Regarding the methods evaluated in Task 2, conduct the following subtasks:

a. Establish appropriate criteria for considering the practicality and implementability of the methods.
b. Apply the criteria and select those methods consid-

ered suitable for immediate use by state highway and transportation agencies.

c. Provide detailed guidelines to use the selected methods, including NDT data and equipment requirements.

Task 4. Develop procedure(s) that can be used to verify the analysis method selected from those examined in this study. The procedure(s) shall outline those steps which can be taken to determine that (1) the selected analysis method is functioning mathematically as intended, (2) its output accurately represents the structural properties of the pavement (or layers) tested, and (3) when used to design pavement overlays, the thicknesses are properly adjusted for environmental and other local conditions.

Task 5. Review and summarize available correlations between data from different NDT devices.

Research is nearing completion. Existing NDT devices and concepts for analyzing asphalt concrete pavements have been identified and evaluated using utility theory. Generic categories of analysis methods for converting NDT deflection data to characteristics of pavement layers have been developed. The need for conversion of NDT deflection data to a standard load level has been recognized. A tentative field test program for verification of recommended procedures for using NDT deflection data in the pavement design process has been developed. The FY '86 program contains an allocation of $250,000 for conduct of the field verification program.

Project 10-28 FY '85

A Method to Determine Deteriorated Areas in Portland Cement Concrete Pavement

Research Agency:	Gulf Applied Research
Principal Invest.:	Dr. William J. Steinway
	Walter F. Horne
Effective Date:	November 1, 1985
Completion Date:	October 31, 1987
Funds:	$199,784

The maintenance of portland cement concrete pavements has increased tremendously over the last 10 years as these facilities have deteriorated from the effects of age and accumulated traffic loads. Accompanying the increased maintenance has come a need for a method to accurately and rapidly determine the location and extent of deteriorated concrete.

An accurate method enhances the preparation of plans for maintenance projects by permitting more precise calculations of quantities and boundary conditions. A rapid method is desirable for surveying several mile-long sections of pavements and minimizing the interference with traffic on heavily traveled roads. To further increase its utility, a method should be suitable for reinforced and nonreinforced concrete pavements with or without overlays.

Survey instruments employing a variety of technologies such as radar, sonics, infrared, and others have demonstrated to some degree the feasibility of rapid and accurate detection of distressed areas, but data reduction and interpretation are slow and require expertise not generally available in most state highway agencies. Furthermore, the data may not always be sufficient for determining quantities and exact locations and boundaries of the needed repairs at the project level. Existing instruments show promise; however, accuracy and speed of operation could be improved and the results more simply displayed and understandable.

The objective of this research is to modify, as necessary, existing nondestructive technologies and demonstrate a faster, more accurate method of determining the location, extent, and depth of surface and subsurface deterioration in concrete pavements. The development and testing under this project will require the accomplishment of the following tasks:

Task 1—Modify, as necessary, the selected technology to meet requirements for field calibration and operation. The technology must be capable of locating and determining the physical characteristics, degree, and extent of distress. The technology must be easily operated and the results clearly presented to allow application by personnel who do not have extensive specialized training in the technology.

Task 2—Develop aud execute a field testing program that verifies and documents the utility of the technique. The testing program must, at least, include: (a) the identification of boundaries of major types of distress such as poor quality materials, delaminations, "D" cracks, spalling, faulting, corner breakoffs, and voids; (b) the consideration of reinforced and nonreinforced concrete pavements with and without overlays; (c) the correlation of results from applying the technique with the actual in-place concrete condition; and (d) the limitations of the technique for accurately identifying and quantifying the types of distress investigated.

Task 3—Prepare the final report. The report should provide a detailed description of the instrument and method and provide guidelines, computer programs, and other pertinent information for implementing the technology. The estimated cost of implementation must also be included.

The technology to be investigated by the contract research agency will be a combination of ground penetrating radar and high resolution video.

Project 10-29 FY '86

Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders

Research Agency:	University of Texas at Austin
Principal Invest.:	Dr. John E. Breen

Effective Date:
Completion Date: 36 months
Funds: $240,000

The AASHTO Standard Specifications for Highway Bridges do not provide adequate guidance for designing reinforcement for tendon anchorage zones of post-tensioned concrete girders and slabs. Current designs can result in excessive cracking or congested reinforcing details. The wide variation of design practices currently in use suggests the need for research in this area.

Recent investigations at the University of Texas at Austin have developed design procedures for single tendons anchored in the webs of girders. However, additional information is needed for multiple tendons and other problems such as: influence of additional shear in support regions, bearing stresses for different types of anchorage systems, and the influence of diaphragms. Design criteria are needed for reinforcement details for inclined, sharply curved, and/or highly eccentric tendons, and for intermediate anchorages and coupling joints of tendons.

The objective of this research is to develop design procedures for end and intermediate anchorage zones for post-tensioned concrete girders and slabs. The research will include the following tasks:

Task 1—Review of relevant domestic and foreign research findings, available performance data, current domestic and foreign practice, and tendon-supplier recommendations. This information would be assembled from technical literature, unpublished experiences of engineers and tendon suppliers, insurance company records, and surveys of bridge and containment vessel owners, fabricators and designers. This review would include but not be limited to:

a. Procedures used for selecting and designing the different types of tendon anchorage systems and the factors affecting the reliability of these systems.

b. Procedures used for determining the placement and alignment of tendons, for proportioning the reinforcement surrounding the tendon anchorage, and for considering interaction effects for multiple tendons.

c. Procedures adopted for matching reinforcement requirements for anchorage zones with reinforcement requirements for shear, torsion, and continuity.

d. Procedures adopted for considering bearing effect and tendon curvature at anchorages.

e. Procedures to consider effects from factors such as highly skewed structures, diaphragms, and end blocks.

f. Procedures for intermediate anchorage zones including couplers.

g. Procedures to determine serviceability and failure behavior.

Task 2—On the basis of the information assembled in Task 1, evaluate the available design concepts for proportioning end aud intermediate anchorage zoue reinforcement. Identify the limitations to existiug knowledge and design concepts. Determine factors in need of detailed evaluation. Conduct preliminary analytical studies to evaluate trhe relative importance of these factors and to assist in the development of a detailed research plan, including laboratory and analytical studies, needed to accomplish the project objective.

Task 3—Within 12 months of contract initiation, submit the proposed research plan for NCHRP approval in the form of an interim report.

Task 4—After NCHRP review, modification, and approval of the detailed research plan developed under Task 2, conduct the laboratory and analytical programs.

Task 5—On the basis of the available information, experimental data, and analytical results, develop procedures to determine end and intermediate anchorage zone reinforcement for post-tensioned concrete girders and slabs.

Task 6—Prepare specification provisions to reflect accomplishment of the objectives in a format suitable for consideration for adoption by AASHTO. The recommended specifications shall be accompanied by a detailed commentary and design examples intended to facilitate their understanding and use.

Task 7—Identify areas in need of further investigation. Recommend priorities and estimate time and costs for needed research.

Task 8—Prepare a final report containing the research findings and proposed design procedures.

Project 10-30(1) FY '86

Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables

Research Agency: University of Manchester Institute of Science and Technology
Principal Invest.: Dr. D. G. John
Dr. C. E. Locke
Effective Date:
Completion Date: 7 months
Funds: $25,000

There is growing concern about corrosion, deteriorattiou, and structural integrity of steel components used in cable-stayed bridges and segmentally constructed concrete bridges when these components are placed in ducts or embeded in concrete and thereby not accessible for visual inspection and evaluation. To make informed decisions on maintenance and rehabilitation of bridge members, engineers need to know the rate at which deterioration or distress is occurring and the extent of damage that has already taken place. Various nondestructive inspection (NDI) methods (such as those described in the draft report of NCHRP Synthesis of Highway Practice Topic 15-03, "Detecting Defects and Deterioration in Highway Structures") that could be used to evaluate the condition of these steel components should

be assessed, and one or more practical systems for on-site inspection and evaluation of steel components in bridge members should be developed for field use.

The objectives of this project are: (1) to select the most promising NDI methods for determining corrosion activity and structural integrity of high strength steel rods and cables embedded in concrete or encased in ducts and (2) to experimentally evaluate these methods using realistic bridge components. The objectives will be accomplished in two phases:

Phase I. It is anticipated that research for Phase I will include at least the following tasks:

Task 1—Collect and review relevant domestic and foreign research findings, current practices, and performance data on promising NDI methods for determining corrosion activity and structural integrity of high strength steel rods and cables embedded in concrete or encased in ducts. Also, collect and review appropriate data and information on the mechanisms that caused in-service bridge problems that were associated with corrosion activity and loss of structural integrity of the steel components. The information on in-service problems should be collected from technical literature and from unpublished experiences of knowledgeable people.

Task 2—On the basis of the information gathered under Task 1, select the most promising NDI methods considering such factors as practicality for field use, cost of equipment, ease and cost of operation, and required level of operator skills.

Task 3—Prepare and submit an interim report covering Tasks 1 and 2 and containing a research plan for an experimental evaluation of selected NDI methods. NCHRP authorization will be required before commencing Phase II.

Phase II. It is anticipated that research for Phase II will include at least the following tasks:

Task 4—Assemble laboratory NDI equipment consisting basically of readily available components and conduct sufficient laboratory tests to establish a data base for determining optimum design concepts for prototype inspection systems. The NDI methods included in the inspection systems should be capable of determining section loss, defects, and corrosion activity of steel components embedded in concrete or encased in ducts. The test specimens shall include lengths of rods and of cables encased in ducts or embedded in concrete. Specimens taken from bridges shall be included.

Task 5—Prepare a final report documenting the findings of the research, including recommendations for the development of systems for the on-site inspection and evaluation of steel components used in cable stayed bridges and segmentally constructed concrete bridges.

During review of proposals for Project 10-30, it was decided to select 2 agencies to conduct Phase I including preparation and submittal of research plans for conduct of Phase II of the study. After completion of Phase I, consideration will be given to combining the remaining funds from Project 10-30 with funds allocated for Project 12-28(9) and conducting either or both of the proposed Phase II research plans.

Project 10-30(2) FY '86

Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables

Research Agency:	Southwest Research Institute
Principal Invest.:	Dr. R. E. Beissner Mr. C. E. McGinnis
Effective Date: *Completion Date:*	7 Months
Funds:	$25,000

There is growing concern about corrosion, deterioration, and structural integrity of steel components used in cable-stayed bridges and segmentally constructed concrete bridges when these components are placed in ducts or embedded in concrete and thereby not accessible for visual inspection and evaluation. To make informed decisions on maintenance and rehabilitation of bridge members, engineers need to know the rate at which deterioration or distress is occurring and the extent of damage that has already taken place. Various nondestructive inspection (NDI) methods (such as those described in the draft report of NCHRP Synthesis of Highway Practice Topic 15-03, "Detecting Defects and Deterioration in Highway Structures") that could be used to evaluate the condition of these steel components should be assessed, and one or more practical systems for on-site inspection and evaluation of steel components in bridge members should be developed for field use.

The objectives of this project are: (1) to select the most promising NDI methods for determining corrosion activity and structural integrity of high strength steel rods and cables embedded in concrete or encased in ducts and (2) to experimentally evaluate these methods using realistic bridge components. The objectives will be accomplished in two phases:

Phase I. It is anticipated that research for Phase I will include at least the following tasks:

Task 1—Collect and review relevant domestic and foreign research findings, current practices, and performance data on promising NDI methods for determining corrosion activity and structural integrity of high strength steel rods and cables embedded in concrete or encased in ducts. Also, collect and review appropriate data and information on the mechanisms that caused in-service bridge problems that were associated with corrosion activity and loss of structural integrity of the steel components. The information on in-service problems should be collected from technical literature and from unpublished experiences of knowledgeable people.

Task 2—On the basis of the information gathered under Task 1, select the most promising NDI methods considering such factors as practicality for field use, cost of equipment, ease and cost of operation, and required level of operator skills.

Task 3—Prepare and submit an interim report covering Tasks 1 and 2 and containing a research plan for an experimental evaluation of selected NDI methods. NCHRP authorization will be required before commencing Phase II.

Phase II. It is anticipated that research for Phase II will include at least the following tasks:

Task 4—Assemble laboratory NDI equipment consisting basically of readily available components and conduct sufficient laboratory tests to establish a data base for determining optimum design concepts for prototype inspection systems. The NDI methods included in the inspection systems should be capable of determining section loss, defects, and corrosion activity of steel components embedded in concrete or encased in ducts. The test specimens shall include lengths of rods and of cables encased in ducts or embedded in concrete. Specimens taken from bridges shall be included.

Task 5—Prepare a final report documenting the findings of the research, including recommendations for the development of systems for the on-site inspection and evaluation of steel components used in cable stayed bridges and segmentally constructed concrete bridges.

During review of proposals for Project 10-30, it was decided to select 2 agencies to conduct Phase I including preparation and submittal of research plans for conduct of Phase II of the study. After completion of Phase I, consideration will be given to combining the remaining funds from Project 10-30 with funds allocated for Project 12-28(9) and conducting either or both of the proposed Phase II research plans.

Project 10-31 FY '86

Acceptance Criteria for Steel Bridge Welds

Research Agency:	Materials Research Laboratory, Inc.
Principal Invest.:	Dr. P. B. Crosley Dr. E. J. Ripling
Effective Date: *Completion Date:*	36 months
Funds:	$348,350

Use of inaccurate methods of nondestructive evaluation and empirical acceptance criteria for bridge welds has resulted in unnecessary repair of welds and has permitted unsound welds to be incorporated in some bridges. Failure to apply accurate bridge weld quality acceptance criteria can significantly increase construction and maintenance costs or can lead to structural failures. Unnecessary weld repairs can generate harmful residual stresses and distortion and can often create new and more serious discontinuities.

Current empirical radiographic and ultrasonic weld quality acceptance standards had their origin in the boiler and pressure vessel industry. Use of these empirical standards has been justified by the inherent inaccuracy of nondestructive test methods. With improvements in the ability of nondestructive tests to accurately measure and characterize weld flaws, it is timely and appropriate to develop better weld quality acceptance criteria. The development of new criteria based on appropriate analytical methods and verification procedures will produce realistic bases for design and inspection decisions. New weld quality criteria will produce safer bridge welds while reducing unnecessary repairs.

The objective of this research is to develop improved acceptance criteria for bridge welds.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign codes of practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experience of designers, fabricators, and owners of steel bridges.

Task 2—Based on currently available information and the application of appropriate analytical techniques, develop rational, practical acceptance criteria for welds in steel bridges.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 12 months after the initiation of the study. The interim report shall present the criteria developed under Task 2 and the rationale for these criteria along with examples illustrating their application. The report shall also include comparisons between results produced by existing and proposed criteria. Finally, a detailed work plan for Task 4 shall be proposed in the interim report. NCHRP authorization will be required before commencing Task 4.

Task 4—Conduct additional analytical studies and laboratory tests for the purpose of further development and validation of proposed acceptance criteria for bridge welds.

Task 5—Revise the acceptance criteria, as necessary, based on the NCHRP review of the interim report and in consideration of additional insight gained from the findings of Task 4.

Task 6—Present the acceptance criteria in a format suitable for consideration by appropriate code-writing authorities. The recommended criteria shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate understanding and use of the criteria.

Task 7—Identify areas in need of further investigation. Recommend priorities and estimate the time and costs for the additional research.

Task 8—Prepare a final report.

Project 10-32 FY '86

Durability of In-Place Concrete Containing High-Range Water-Reducing Admixtures

Research Agency: Construction Technology Laboratories
Principal Invest.: Dr. David Whiting
Effective Date: January 6, 1986
Completion Date: July 5, 1987
Funds: $100,000

High-range water-reducing admixtures for concrete, also known as superplasticizers, were first introduced in Japan and West Germany in the 1960's, and more recently they were introduced in the United States. These admixtures can markedly increase the workability of concrete mixtnres. They also have the potential for producing very high strength, durable portland cement concrete by reducing the amount of water used while still allowing conventional placement methods.

Research indicates that these admixtures may affect entrained air void systems. Air void spacing factors below 0.008 in. seem to correlate with expected satisfactory laboratory "freeze-thaw" resistance. However, higher spacing factors often found in the concrete containing high-range water-reducing admixtures may or may not result in poor durability based on laboratory tests. Because the correlation betwecn air void characteristics and durability as measured in the laboratory under freeze-thaw conditions has not been well defined for concretes containing high-range water-reducing admixtures, further study is needed. There is also a perception that regardless of laboratory freeze-thaw testing, good field performance can be expected. Therefore, field performance should be studied to evaluate the relevance of the relationship between in-place durability and air void characteristics.

The objective of this research is to assess the relationship between the durability and the air void characteristics of concrete placed with high-range water-reducing admixtures. Existing structures that are subjected to freezing and thawing will be used for this assessment. Emphasis will be placed on older highway structures and structures that exhibit premature deterioration. To accomplish this objective, the following tasks shall be performed.

Task 1—Develop a list of candidate structures for evaluation, and establish criteria for selecting structures for further study. The criteria should include exposure to freezing and thawing in the presence of moisture; availability of materials data (e.g., mixture proportions, materials properties, freeze-thaw data, air void characteristics), construction data, and environmental data; and availability of owner agency assistance in obtaining core samples.

Task 2—Develop criteria for assessing the condition of structures based on factors that relate to freeze-thaw deterioration.

Task 3—Select an appropriate number of structures nsing the criteria developed in Task 1 and assess their condition using the criteria developed in Task 2.

Task 4—Obtain cores from the structures and measure the air void system characteristics including size distribntion of bubbles, specific surface area, and spacing factor. Any additional petrographic examinations should be conducted that would help assess the extent of freeze-thaw deterioration.

Task 5—Prepare a final report inclnding conclnsions and recommendations that can be drawn from the foregoing tasks.

Project 10-33 FY '86

Potential Benefits of Geosynthetics in Flexible Pavement Systems

Research Agency: Georgia Tech Research Corporation
Principal Invest.: Dr. Richard D. Barksdale
Effective Date: January 6, 1986
Completion Date: January 5, 1988
Funds: $100,000

Test results indicate that the tensile forces that can be developed in geotextiles and other geosynthetics, such as geomembranes and geogrids, hereinafter referred to collectively as geosynthetics, will increase the structural capacity and improve the performance potential of aggregate-surfaced roads placed over very weak subgrades (i.e., CBR less than 2). Techniques have been demonstrated whereby geosynthetics can be tensioned either by prestretching the geosynthetic or by loading and developing ruts in the geosynthetic-aggregate system, before placing additional (leveling) aggregatc basc.

The applicability of geosynthetics to higher type pavement systems incorporating unbound granular pavement layer(s) with an asphalt surface (flexible pavement systems) needs to be studied to determine whether the structural capacity and performance potential can be improved. Although geosynthetics have been used to some extent in the unbound granular layers of higher type pavements, their behavior and influence on pavement performance are not well understood. Consequently, a number of questions must be answered before the feasibility of widespread use of geosynthetics in flexible pavement systems can be determined, for example: (1) What types of geosynthetics should be used and what properties of these geosynthetics must be specified? (2) Is prestressing geosynthetics necessary and practical? (3) Under what conditions do geosynthetics influence flexible pavement systems? (4) Can the benefits of geosynthetics be documented?

The objective of this study is to determine the feasibility of including geosynthetics on the subgrade or in the unbound layers to improve the performance of flexible pavement systems or to provide alternative designs for equal

performance. To accomplish this objective, the following tasks are required:

Task 1—Select and/or develop analytical models or procedures to evaluate the behavior of flexible pavement systems incorporating geosynthetics.

Task 2—Analyze and identify the parameters that influence the behavior of the flexible pavement systems incorporating geosynthetics. The parameters to be examined should include but not be limited to: (a) properties of the geosynthetics, (b) location of the geosynthetics in the flexible pavement system, (c) installation methods for geosynthetics including prestressing and the removal of wrinkles, (d) properties of the aggregate, (e) characteristics of the subgrade, (f) environmental effects such as moisture and temperature, and (g) load magnitude and frequency. Appropriate ranges for significant parameters should be identified and the relative importance of these parameters established using theoretical models or procedures recommended by the investigators.

Task 3—Using a laboratory testing program, validate the model(s) and the appropriateness of the selected parameters. The laboratory testing program should be such that the geosynthetics and aggregate materials can be placed in a manner similar to normal roadway construction. It is anticipated that the validation testing will be done using an appropriate range of the most significant parameters. Relevant properties of each material incorporated in the laboratory test program should be determined using tests selected by the investigators and performed as part of this project.

Task 4—Establish the engineering feasibility of using geosynthetics in flexible pavement systems based on the findings from Tasks 1, 2, and 3. Properties of geosynthetics necessary for installation as well as long-term performance must be considered when establishing this feasibility. Potential benefits to be realized by incorporating geosynthetics in flexible pavement systems, such as improved performance or possible tradeoffs among components of flexible pavement systems, should be presented.

Task 5—Develop a framework for the design, implementation, and evaluation appropriate for full-scale field tests to validate the feasibility established in Task 4.

Project 10-34 FY '86

Transient Protection, Grounding, and Shielding of Electronic Traffic Control Equipment

Research Agency:	Georgia Tech Research Corp.
Principal Invest.:	Hugh W. Denny
Effective Date:	22 months
Completion Date:	
Funds:	$180,000

Electronic traffic control equipment is highly susceptible to disrupted operation and even permanent damage caused by electrical noise and transients (voltage spikes and surges) associated with connected service and signal lines. Lines providing electrical power and cables interconnecting equipment to sensors, communications systems, or peripheral hardware provide a direct path for the conduction of disruptive and damaging electrical transients from externally generated electrical noise. Lightning, switching transients, and other electromagnetic interference (EMI), including radio frequency interference (RFI), may be conducted on electrical and signal lines connected to traffic control equipment. Some disruptive noise may even originate from companion equipment located within the traffic control cabinet.

The problem of electrical transient damage to electronic control equipment may be minimized and in most cases eliminated by proper application of existing technology, i.e., currently available devices may be able to provide sufficient protection against equipment malfunction and deter damage. However, there are no widely accepted specifications or procedures for application of such devices to the control equipment cabinet, terminal blocks, and associated wiring. There is a need to develop such specifications and procedures and to make them available to operating agencies to obtain maximum benefit from the protection devices.

The objectives of this research are to: (1) review current practice and develop recommended procedures for the transient protection, grounding, shielding, and filtering of power and signal conductors, cabinets, and equipment associated with traffic control to assure the proper operation and extended life of the electronic equipment; (2) develop recommended performance specifications and test methods for protective devices; and (3) develop a user's handbook and a video-training tape. To achieve these objectives, the following tasks will be accomplished:

Task 1—Review all available research and technical literature to characterize the magnitude and waveform of transients on all input and output lines of equipment cabinets and to obtain related information for use in subsequent tasks.

Task 2—Identify and summarize current practice (performance specifications, test methods, and installation and maintenance procedures) of the traffic signal community.

Task 3—Develop preliminary draft procedures for providing transient protection of electronic traffic control equipment.

The procedures will address:

a. Ground rods and grounding networks.

b. Bonding and shielding of cabinets, equipment, wiring, and conduit.

c. Protection of cabinet power and signal circuits, including dress and respective location of all wires and harnesses.

d. Fuses and circuit breakers.

e. EMI/RFI filters.

f. Transient protection devices.
g. Test methods and procedures to verify the above.

Describe how the procedures can be applied to both new and existing installations. Also describe how they can be used to mitigate line transients from direct, near, and distant lightning strikes and from conducted and radiated EMI and RFI.

Task 4—Prepare and submit an interim report presenting the findings from Tasks 1 through 3 and also include a preliminary table of contents for the final report and user's handbook.

Task 5—Prepare final recommended procedures, performance specifications, test methods, and estimated hardware costs for transient protective devices for AC service and signal conductors, detector inputs, and communication lines (AC and DC).

Task 6—Prepare a final report and a user's handbook documenting the recommendations and specifications developed in Task 5. Include in the final report discussion of the rationale and implications of each recommendation along with applicable cautions. Describe in the user's handbook representative components, materials and assemblies, specifications, and procedures.

Task 7—Prepare a reproducible video-training tape in ½-inch VHS format in 30-minute segments keyed to the sections of the user's handbook. Prepare an instructor's gnide to supplement the user's handbook and training tapes.

Research should be initiated in early 1986.

AREA 11: LAW

PROJECT 11-1 FY '65

Rules of Compensability and Valuation in Highway Land Acquisition

Research Agency: University of Wisconsin
Principal Invest.: Dr. Richard U. Ratcliff
Effective Date: January 1, 1965
Completion Date: April 30, 1967
Funds: $84,840

Difficult problems of compensability and valuation of land acquisition for highway rights-of-way continue to plague courts, highway administrators, and appraisers. This project analyzed current legal rules and appraisal practices and suggests methods to eliminate inconsistencies, ambiguities, and inequities based on constitutional mandates, sound judicial analysis, and appraisal theory and practice.

The research was to express the parameters of indemnity representing the ideal based upon logical and acceptable criteria, identify deviations from the ideal basic principles found in statutes, operating rules, and court decisions, analyze the motivation for these deviations, aud suggest a workable compromise between the ideal and the practicalities in the application of the power of eminent domain.

The research included a sampling of reported highway condemnation cases involving evidentiary problems for 25 States covering a 16-year period. Cases of particular interest were cited to support the discussions about the specific rules of admissibility of various types of evidence.

The report contains information relative to the present law of evidence in eminent domain proceedings. Divergencies which appear in the law from State to State are identified and analyzed. The cause and extent of diversity are determined, and the connection between evidentiary law and the legal rules and standards of compensability and valuation is examined. The reasons the courts give as a basis for their decisions to admit or exclude various types of evidence are set forth and described.

The final report has been published as:

NCHRP Report 104, "Rules of Compensability and Valuation Evidence for Highway Land Acquisition."

Project 11-1(1) FY '68

Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation

Research Agency: Real Estate Research Corporation
Principal Invest.: Stanley F. Miller
Morris A. Lieberman
Effective Date: September 2, 1968
Completion Date: Febrnary 28, 1969
Funds: $5,000

Most frequently, the date of taking is the same as the date of valuation. However, especially in urban areas, valuation of property on such date frequently creates inequities to either the property owner or the State because of an enhancement or diminution in value of the surrounding or subject properties resulting from the public improvement or the announcement thereof. The diminution occurs when knowledge of the highway improvement depreciates the value of property to be taken prior to the date of taking. The enhancement occurs when such knowledge appreciates the value of the property.

The objectives of the research were to assemble and analyze whatever statutory and case law now exists on this subject. Valuation problems involved were also studied.

The research included a study of the general principles and techniques (both valuation and legal) that cause enhancement or diminution in the value of surrounding properties or those being taken by eminent domain as a result of the date of valuation or announcement thereof. Statutory laws of each of the 50 States were examined.

The final report covers a general discussion of valuation principles, including identification of factors which cause enhancement or diminution of value. The impact of date of valuation is discussed, and case studies of the effect of

time are presented. There is also a general discussion of the legal aspects and practices.

The final report has been published as:

NCHRP Report 114, "Effects of Proposed Highway Improvements on Property Values."

Project 11-1(2) FY '68

Recognition of Benefits to Remainder Property in Highway Valuation

Research Agency: Joseph M. Montano & Assoc.
Principal Invest.: Joseph M. Montano
Effective Date: October 1, 1968
Completion Date: March 31, 1969
Funds: $5,000

The subject of benefits is often discussed and casually considered, largely because it is a mandatory finding in many States, but rarely pursued with enthusiasm. Because of the need for more equitable treatement of the public interest, the practitioner, both legal and appraisal, needs to be more fully informed of the potential involved.

Actually there is a rather large and surprisingly liberal body of case law allowing a variety of benefits to offset or mitigate the amount of compensation that must be paid. These were collected, analyzed, and grouped, with emphasis on the most recent cases to ascertain trends. The desired end product was a trial memorandum that can be used by the practicing trial lawyer and appraised on a day-to-day basis. The research explored different approaches, both legal and appraisal, that would lead to greater recognition of benefits to offset or mitigate the amount of compensation which must be paid.

The final report gives a short and concise, but comprehensive, statement of what appellate courts have said about the trial aspects of benefits. It further contains an inventory of these appellate decisions, as well as a list of annotations, treatises, and legal periodicals. Moreover, the report gives some suggestions and ideas about what should be done and how to prove that benefits have resulted by virtue of the construction of public improvements.

The project report has been published as:

NCHRP Report 88, "Recognition of Benefits to Remainder Property in Highway Valuation Cases."

Project 11-1(3) FY '68

Taxation Aspects of Right-of-Way Acquisition

Research Agency: University of Tulsa
Principal Invest.: Dr. E. Dale Searcy
Effective Date: September 16, 1968
Completion Date: April 30, 1969
Funds: $2,250

Public land acquisition may have significant effects on landowners' tax status and liability, depending on alternative methods of valuation and payment of compensation. Such tax aspects should be considered, inasmuch as a full appreciation of the alternative methods of tax treatment of land acquisition can facilitate negotiations.

The objective of this research was to identify, analyze, and explain, with appropriate examples, the many elements of the taxation aspects of right-of-way acquisition. It included the Federal income and capital-gains tax elements, but also treated these elements from a state income and ad valorem tax point of view for purposes of illustration.

The research distinguished, for taxation purposes, between all of the different compensation elements involved (i.e., relocation payments, partial takes, etc.). It included these and other elements involved in the various interests or awards (negotiations vs. condemnation, etc.) and types of properties (residential, business, agricultural, investment properties, etc.).

A final report was not submitted; therefore the contract was terminated.

Project 11-1(4) FY '68

Compensation in the Nature of Additives to Market Value

Research Agency: Univ. of Oklahoma Research Inst.
Principal Invest.: J. Dwain Schmidt
Effective Date: December 1, 1968
Completion Date: May 31, 1969
Funds: $2,500

In recent years, the courts, Congress, and the State legislatures have been and are being pressed to allow reimbursement or damages to property owners in addition to payment of compensation under the traditional market value concept. These include payment of interest; property owner's litigation costs, including appraisal and attorney fees; moving or relocation expenses; percentage premiums above market value; hardship premiums; business discontinuation allowances; rent supplements; etc.

The objective of this study was to analyze statutes and cases on a Federal and State-by-State basis to ascertain the present state of the law of these issues and to measure the trend, if any.

The research examined some outstanding cases concerning additives to market value in highway condemnation cases and delved into recent legislation materially affecting the law of eminent domain as it relates to just compensation.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 11-1(5) FY '68

Rules of Discovery and Disclosure in Highway Condemnation Proceedings

Research Agency: Long, Mikkelborg, Wells & Fryer
Principal Invest.: Jeremiah Long
Effective Date: September 15, 1968
Completion Date: April 14, 1969
Funds: $2,500

A significantly large body of statute and case law is developing concerning the applicability of State and Federal rules of discovery to eminent domain actions and the rights of the parties to compel disclosure of the opposition's valuation and other testimony. Depending on the way such disclosure is permitted, advance possession of the other party's valuation evideuce, which is largely opinion, and the reasons therefor, may materially affect cross examination. The highway legal practitioner should be aware of the state of the law in this field.

Divergent conclusions and opinions relating to value are not based on the existence of differing facts but on individual interpretation of those facts in the expert's valuation of the property before and after acquisition. No amount of independent pre-trial effort on the part of opposing counsel or his client will reveal the conclusions and opinions of the opposing experts. Add to the uncertainties of preparation for cross-examination and rebuttal the primary importance of expert testimony in condemnation actions and the wide divergence in the contents of such opinion, and it is not surprising that the field of eminent domain has produced the most activity and the greatest diversity of legal opinion in the area of pre-trial discovery of the opinions and conclusions of value experts retained for negotiation and in anticipation of litigation.

The final project report discusses the existing Federal and State cases on the subject, the statutes, and rules adopted in various jurisdictions to resolve the uncertainties attending discovery of expert opinion.

The project report has been published as:

NCHRP Report 87, "Rules of Discovery and Disclosure in Highway Condemnation Proceedings."

Project 11-1(6) FY '68

Valuation and Condemnation Problems of Selected Special Purpose Properties

Research Agency: Edward E. Level
Principal Invest.: Edward E. Level
Effective Date: September 2, 1968
Completion Date: November 28, 1969
Funds: $7,500

Properties put to special uses are frequently required, in whole or in part, for highway right-of-way purposes. The rules of compensation and methods of valuation of such properties are inconsistent in their practical application, often with incongruous and varying results from State to State.

Research is needed to clarify the special-purpose-property field illustrated by the taking of cemeteries, parks, schools, and churches, or portions thereof. The research was to assemble and analyze the case law applicable to this class of property and the present state of appraisal practice in the field involving these special-use properties and to provide a clear exposition of the correct theory and practice in terms of a series of alternatives applicable to such properties.

Schools, churches, cemeteries, parks, utilities, and similar properties, due to the lack of sales data, cannot readily be valued by the usual appraisal methods or legally allowable proof. The project report considers what special appraisal techniques and legal rules are applied in valuing such properties.

Cases and appraisal methods are discussed as to just compensation, elements of the special-purpose properties, appraisal evidence and evidence allowed, and the competency of witnesses in trials concerning special-purpose properties. Specific discussions of appraisal techniques and legal rules applicable to cemeteries, churches, parks, schools, and other special properties are discussed.

The project report has been published as:

NCHRP Report 92, "Valuation and Condemnation of Special Purpose Properties."

Project 11-1(7) FY '68

Valuation and Compensability of Noise, Pollution, and Other Environmental Factors

Research Agency: Univ. of Oklahoma Research Inst.
Principal Invest.: J. Dwain Schmidt
Effective Date: October 1, 1968
Completion Date: March 31, 1969
Funds: $2,500

Highway departments today are confronted with some complicated takings, particularly in urban areas, wherein allegations are made claiming damages which arise from highway-oriented noise, air, and water pollution and other similar environmental factors.

The decided cases in this limited area were singled out and examined, with careful analysis given to the valuation and legal compensability problems.

The power to take private property for a public purpose by eminent domain is a basic right of government. However, in the United States, private property shall not be so taken without the payment of just compensation. The question researched in this project was whether highway-produced noise, air, and water pollution—and other similar environmental factors—are the type of injuries for which compensation must be paid.

The final report was not published in the NCHRP report series; however, microfiche of the report may be

purchased (see final page of this section for ordering information).

Project 11-1(8) FY '68

Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides

Research Agency: Harrison Lewis
Principal Invest.: Harrison Lewis
Effective Date: October 15, 1968
Completion Date: January 15, 1970
Funds: $7,500

During highway construction, or shortly thereafter, there are special types of damages relating to drainage, runoff, blasting, slides, etc., which sometimes result. Generally speaking, all damages which are the natural and probable result of involnntary takings are to be included and assessed in the condemnation proceedings, but the law and the appraisal practice relating to such special situations, litigated and negotiated, is far from clear and is not understood by many appraisers.

The purpose of the research was to identify and clarify these elements. The research included an assembly and analysis of case law from a majority of jurisdictions applicable to each of these special situations; an assembly and analysis of the best and prevailing appraisal principles applicable thereto; and a statement of the logical alternative methods of dealing with the valuation and damage problems involved, including the pros and cons of each such legal alternative.

The project report has been published as:

NCHRP Report 134, "Damages Due to Drainage, Runoff, Blasting, and Slides."

Project 11-1(9) FY '68

Valuation and Condemnation Problems Involving Trade Fixtures

Research Agency: Edward L. Snitzer
Principal Invest.: Edward L. Snitzer
Effective Date: March 15, 1969
Completion Date: December 1, 1969
Funds: $5,000

In the acquisition of commercial properties, questions and disputes often arise between condemnor and condemnee as to the obligation of the comdemning authority to take and pay for "trade fixtures." The condemning authority frequently takes the position that, as same are movable and, hence, not affixed to the freehold, they are personal property and, thus, may be removed by the condemnee. In this area, the courts have also recognized a different rule than exists between landlord and tenant and mortgagor and mortgagee in regard to such fixtures.

The objective of the research was to review all appellate cases in the trade fixture area and to cite and compare these with selected typical landlord-tenant and mortgagor-mortgagee cases to illustrate the different rules of law applicable. Appropriate jury instructions, based on the decided cases, were developed as to the acquisition and valuation criteria that have been judicially prescribed. Comments were made on the valuation techniques involved, particularly as to how they may differ, if they do, from conventional methods of fixture valuation. Existing legal and appraisal literature was reviewed and cited, particularly law review articles, *ALR* annotations, and *The Appraisal Journal.*

The project report has been published as:

NCHRP Report 94, "Valuation and Condemnation Problems Involving Trade Fixtures."

Project 11-1(10) FY '68

Compensability and Valuation Aspects of Residential Displacement in Highway Programs

Research Agency: Ross, Hardies, O'Keefe, Babcock, McDugald & Parsons
Principal Invest.: Fred P. Bosselman
Effective Date: March 15, 1969
Completion Date: September 15, 1969
Funds: $5,000

Serious practical problems arise when highway construction unavoidably necessitates substantial displacement of residential units both in urban and rural areas. Relocation of displaced residents is, in varying degrees, becoming a responsibility of public agencies. However, up to the present time, alternative means and procedures for performing this responsibility have been limited, and it is evident that new and greater efforts in this activity must be made. Significant legal and valuation problems must be solved if legislators and administrators are to have guidelines for development of new methods of improving relocation assistance and for decisions between alternatives in specific situations.

The research report contains discussions of the constitutional requirements and limitations and how the basic standards for the payment of compensation to persons whose property is taken for public nse are derived from such sources. The need for new compensation techniques is discussed and analyzed. Traditionally, "consequential damages" resulting from the taking of a man's property have been considered part of the burden of citizenship. The rapid increase of residential takings has caused great pressure on government to compensate more of these consequential damages. The various monetary and nonmonetary effects are outlined to indicate the wide range of losses that may result when residences are taken.

The project report has been published as:

NCHRP Report 107, "New Approaches to Compensation for Residential Takings."

Project 11-1(11) FY '68

Valuation Elements of Joint Development Projects, Including Air Rights

Research Agency: Real Estate Research Corp.
Principal Invest.: John M. Bohling
Effective Date: February 24, 1969
Completion Date: Angust 25, 1969
Funds: $5,000

Interest is increasing with respect to joint development projects involving highways and other kinds of public and private facilities. There is actually little information available, however, about the application of known appraisal concepts to such joint development projects. Additionally, a whole new valuation dimension has come into focus, involving the valnation of vertical planes of value (air rights). All of these aspects need to be explored.

The study briefly reviewed the legal factors covering the valuation of air rights and of joint development projects. An exploration was made of known appraisal concepts and valuation principles and their application to the valnation of multiple-use projects. The findings of this study will provide guidance for appraisal practitioners and public officials concerned with the valuation of joint development projects.

The study found that the current appraisal technique, as presented by the Keuhnle and White formulas, appears to present the best potential for the valuation of multiple-use projects, particularly as they apply to rights-of-way. These formulas present the value of the property interest to be disposed of (the air rights or tunnel easement) in order to approximate the difference between the value of the fee property before and after the specific property interest is conveyed. These formulas take into consideration other costs or benefits, such as (a) economic value loss because of reduction in functional utility due to construction, (b) added costs of constructing improvements in a different fashion than if erected on surface fee, (c) additional interest expense which would be incurred, (d) savings in excavation costs, (e) tenant relocation, (f) demolition.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 11-2 FY '65

Theory and Practice in Inverse Condemnation

Research Agency: Regional and Urban Planning Implementation
Principal Invest.: Mrs. Barbara Hering
Effective Date: February 1, 1965
Completion Date: June 30, 1966
Funds: $15,000

Legal procedures for determining the qnestion of liability of damage occurring during or after highway construction are neither clearly understood nor agreed upon. This project was intended to review case law covering inverse condemnation, review techniques to litigate inverse condemnation claims and defenses, analyze administrative techniques used in handling such claims, and compare judicial treatment and alternative statutory proposals applicable to State highway department problems.

An intensive review of legal cases has been conducted for five States having a substantial volume of such cases. Questionnaires supplemented by personal contact studied legal and administrative practice.

The project report has been published as:

NCHRP Report 72, "Theory and Practice in Inverse Condemnation for Five Representative States."

Project 11-3 FY '67

Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements

Research Agency: Donald T. Sutte, Jr., and Assoc.
Principal Invest.: Donald T. Sutte, Jr.
Prof. Roger A. Cunningham
Effective Date: November 1, 1966
Completion Date: December 15, 1967
Funds: $25,000

Because of the difficult problems that are emerging from the implementation of the Highway Beautification Act of 1965 and the scenic road programs, this project relates to the identification and application of legal and valuation principles for the acquisition of scenic, conservation, and roadside easements; outdoor advertising and junkyard activities; scenic enhancement interests; and the like.

All the available information was assembled pertaining to past experience in the use of scenic roadside easements and similar property interests in programs for scenic enhancement. An annotated bibliography of the relevant legal and appraisal literature has been prepared, and State and Federal highway agencies that have been active in acquisition of scenic easements were interviewed. The material was analyzed with regard to the statutory bases, the character of the easement, and the administrative and acquisition practices developed.

The researchers studied the steps for acquiring scenic easements, the advantages and disadvantages of scenic easements, and similar less-than-fee property interests. Model legislation was developed to deal with the legal problems identified.

The project report has been published as:

NCHRP Report 56, "Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures."

Project 11-3(1) FY '68

Public Control of Roadside Advertising Signs for Highway Beautification

Research Agency: Donald T. Sutte, Jr., and Assoc.
Principal Invest.: Donald T. Sutte, Jr.
Prof. Roger A. Cunningham
Effective Date: October 1, 1968
Completion Date: December 31, 1969
Funds: $20,000

The Highway Beautification Act of 1965 made several major changes in Federal policy regarding control of roadside advertising, which changes have affected State and local programs on such matters and require valuation and legal studies.

Based on the assumption that compensation must be paid for the elimination of those signs erected before October 1965 that must be removed, the legal research included a review of all the decided cases discussing all the various elements of compensation and, in particular, the taking from the owner of the sign, display, or device of all right, title, leasehold, and interest in such sign, display, or device and the taking from the owner of the real property on which the sign, display, or device is located, the right to erect and thereafter maintain such signs, displays, and devices thereon.

The valuation research included a general discussion of all applicable valuation principles and concepts considering the special-purpose nature of outdoor advertising signs; gave consideration to the explanation of the alternative methods of estimating compensation for all elements; gave separate treatment to the methods of measuring business losses; and recognized and separately treated the different types of outdoor advertising signs. Actual illustrations and case studies were ntilized.

The project report has been published as:

NCHRP Report 119, "Control of Highway Advertising Signs—Some Legal Problems."

Project 11-3(2) FY '68

Public Control of Junkyards for Highway Beautification

Research Agency: Real Estate Research Corp.
Principal Invest.: Stanley F. Miller
Morris A. Lieberman
Effective Date: September 2, 1968
Completion Date: February 28, 1970
Funds: $13,300

The Highway Beautification Act of 1965 made several major changes in Federal policy regarding control of junkyards, which changes have affected State and local programs on such matters and require valuation and legal studies.

Based on the assumption that compensation must be paid for the relocation, removal, or disposal of junkyards specified in the Highway Beautification Act of 1965, the legal research included an investigation of decided cases in five representative States. Furthermore, the statutory laws of the 50 States were examined as they pertained to the problem and the research objective.

The research included a general examination of valuation principles and concepts applicable to the valuation of junkyards. Careful and objective consideration was given to alternative methods of estimating compensation for all elements. The studies recognized and separately treated the different types of junkyard establishments.

The project report covers the basic principles of market value and compensation. Valuation practices and procedures are discussed, and factors that cause enhancement or diminution of value are identified. Case studies are included in the report to show examples of the effect of time on value and to show examples of remainder and specific parcels.

The project report has been published as:

NCHRP Report 112, "Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification."

Project 11-4 FY '68

Elimination of Wide Divergence in Right-of-Way Valuation

Research Agency: Amer. Inst. of Real Estate Appraisers
Principal Invest.: Frances Hokanson
Effective Date: July 1, 1969
Completion Date: February 28, 1971
Funds: $24,959

Wide variations in valuation have been reported in many States. These have most frequently occurred in instances (a) where two or more appraisers are so divergent that their testimony has little merit and (b) where appraisal of severance damage is shown by subsequent experience to be wholly unrealistic. Continued occurrence of such instances results in unnecessarily high awards and raises questions regarding validity of current valuation methods.

This research reviews, analyzes, and evaluates actual cases in which divergences existed. The reasons or bases for such divergences are identified. The research includes analyses of how divergencies relate to type of taking, type of use, level of government that acquires, and other factors. It also covers the extent to which appraisal divergencies reflect inadequacies in the appraisal process and techniques such as (a) misunderstanding of the facts of a particular appraisal, (b) lack of training and experience of appraisers, (c) conflicting legal and engineering premises, and (d) problems of severance damages. Alternative solutions are suggested to eliminate or diminish such divergences. The alternative solutions explored include possible changes in the law, presentation and admissibility

of valuation evidence, changes of appraisal concept, or methods of administration.

The project report has been published as:

NCHRP Report 126, "Divergencies in Right-of-Way Valuation."

Project 11-5 FY '71

Valuation of Air Space

Research Agency:	Daniel, Mann, Johnson, & Mendenhall
Principal Invest.:	Daniel J. McNichol
Effective Date:	October 1, 1970
Completion Date:	May 31, 1972
Funds:	$49,800

Use of air space over or under highways gives great promise as a major means of fitting highway transportation into the urban environment. However, difficulties in placing a proper valuation on rights in air space are hampering such developments in some areas. It is imperative that better methods for making such valuations be devised so that proper and orderly development can proceed without delay.

The objective of this study was to provide guidelines, procedures, and documentation for the right-of-way agent and lawyer in valuation, legal, and administrative problems as applied to air-space acquisition and planning. The primary emphasis was on developing applicable valuation theory and criteria.

The research included an inventory and review of before-and-after case-study material where air space had been bought, sold, or leased. An analysis was made in terms of factors common to all cases and of special factors relevant to various uses of air space and various types of highway structures.

The research also evaluated the adequacy of existing legislation and analyzed and reported on legal ramifications that influence the valuation process, taking into consideration legal constraints peculiar to air-space valuation. A basic theory for the evaluation of air rights was developed.

The variables and factors that influence air-space acquisition and the valuation processes were identified and analyzed. Matrices were developed to provide a comprehensive collection of relevant valuation factors, including economic feasibility analysis. The primary aim was to provide a clear and precise presentation of all factors considered in the valuation process and a basis for selecting the most desirable use.

The project report has been published as:

NCHRP Report 142, "Valuation of Air Space."

Project 11-6 FY '74

Valuation and Compensability of Noise Pollution

Research Agency:	Jack Faucett Associates
Principal Invest.:	Dr. E. J. Mosbaek
Effective Date:	April 1, 1974
Completion Date:	July 31, 1975
Funds:	$94,744

The view is widely held that highway noise has resulted in a deterioration in the quality of life along roadways. Although noise abatement procedures are being developed, their over-all effectiveness is still open to question, and they are not always applicable to all situations.

Therefore, highway administrations in the several states are confronted with the need to consider various ways of dealing with the impact of noise pollution resulting from highway traffic. Methods for measurement and prediction of noise produced by highway traffic are reasonably well developed, as are criteria for the interference of this noise with various human activities. However, criteria for determining compensability where excessive noise levels are anticipated do not exist. Consequently, it is desirable to develop measures of compensability for damages resulting from such noise. Such measures could be used, for example, in socio-economic environmental analyses or for assessing the comparative feasibility of abatement measures, as well as for establishing a basis for compensation.

The objective of this research was to identify and develop fair and equitable valuation methods and compensability criteria for the effect on adjacent areas of noise anticipated to be produced by traffic on proposed highway improvements. To accomplish these objectives, the research included the following tasks:

1. Review and summarize recent literature, including court decisions, pertaining to elements of damages arising from noise, and theories of compensation therefor, including methods of measurement and valuation of such damage.
2. Define measures and scales for quantifying the extent of potentially compensable damages resulting from exposure to highway traffic noise. Variables to be quantified should include such factors as impact on property values and interference with human activities.
3. Develop a compensation model or models that relate levels of compensation to varying levels of noise exposure and different land uses.
4. Apply and evaluate the use of the compensation models against a set of representative highway environments to assess the economic effects of noise compensation and revise the compensation models on the basis of the evaluation.
5. Prepare a guide for determining rates of compensation for damages resulting from exposure to highway traffic noise for practical application in planning and design of highways.

Research has been completed, and copies of the agency's final report have been distributed to NCHRP sponsors.

Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

AREA 12: BRIDGES

Project 12-1 FY '65

Deformation of Steel Beams Related to Permitted Highway Bridge Overloads

Research Agency: University of Missouri
Principal Invest.: Dr. Adrian Pauw
Dr. J. W. Baldwin, Jr.
Effective Date: February 1, 1965
Completion Date: June 30, 1967
Funds: $50,000

The bridge research in the AASHO Road Test demonstrated that permanent deformations can occur in steel beams due to a combination of load, fabrication, and environmental stresses which totally exceed the yield point of the steel. The current AASHTO specifications permit overloads on the typical highway bridges in service, and the possible occurrence of similar permanent deformations in these could foreseeably affect the useful life of the structure. This study was confined to simple-span composite and simple-span noncomposite steel-stringer highway bridges and is directed to a determination of (1) the causes and magnitudes of fabrication and environmental stresses, (2) the possible existence of permanent deformations in existing bridges due to current specifications, and (3) the effect from cycles of overloading.

This research was initiated to study the magnitude and effect of permanent deformations in simple-span composite and noncomposite steel-stringer highway bridges. Included in the work was a study of the causes and magnitudes of stress which, in addition to normal load stresses, lead to yielding of the steel stringer at load stresses with calculated magnitudes lower than the yield point of the material. Such factors as residual stress distribution due to rolling and welding, effects of thermal gradients, and the effects of creep and shrinkage of the slab on the stress in the steel were considered.

The final report has been included in the report for Project 12-6, which was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-2 FY '66

Distribution of Wheel Loads on Highway Bridges

Research Agency: Iowa State University
Principal Invest.: Dr. W. W. Sanders, Jr.
Effective Date: June 1, 1966
Completion Date: December 31, 1968
Funds: $79,512

The current AASHO specifications for the distribution of wheel loads to highway bridge floor systems are inadequate. This study correlated and evaluated the large amount of research conducted on this problem to date and made suitable recommendations for changes in the specifications covering wheel-load distribution factors for the various types of floor systems used in bridges. The major emphasis was on short- and medium-span bridges without skew. Included were floor slabs supported by steel, reinforced concrete, and prestressed concrete, as well as floor systems produced by adjacent box beams.

The final report has been published as:

NCHRP Report 83, "Distribution of Wheel Loads on Highway Bridges."

Project 12-3 FY '66

Development of Waterproof Roadway Joints for Bridges

Research Agency: Southwest Research Institute
Principal Invest.: Dr. E. W. Kiesling
J. E. Minor
Effective Date: December 15, 1965
Completion Date: March 14, 1969
Funds: $149,895

Difficult maintenance problems have resulted from bridge deck expansion joints as they are presently designed and constructed. These problems include corrosion and disintegration of structural elements due to the passage of water through the joints and curtailment of longitudinal movement due to the accumulation of foreign material in the joint. The problem is compounded by the range of longitudinal motion required for the proper functioning of the joint and the magnitude of skews of many joints. The research was directed toward the development of designs for economically feasible waterproof bridge expansion joints that adequately provide for thermal expansion and contraction and remain serviceable when installed normal or skewed to the line of traffic. Recommendations were made for the design, installation, and maintenance of the joints.

The research has been completed. The essential findings from the study have been reported in NCHRP Research Results Digest 14 (Oct. 1969). Because it contains proprietary information, the final report will not be published in the NCHRP report series and is available only to the sponsors of the Program.

Project 12-4 FY '66

Thermal Characteristics of Highway Bridges

Research Agency: Southwest Research Institute
Principal Invest.: Dr. Thein Wah
Effective Date: December 15, 1965
Completion Date: March 31, 1968
Funds: $102,400

Actual field studies on thermal behavior of bridges have shown that thermal forces can be of an appreciable magnitude and merit consideration. Inasmuch as present methods of design normally allow only for uniform thermal expansion of bridges, quantitative information is needed concerning all consequential ways in which temperature affects deformation and stresses in the structure. This study sought to determine the magnitude and significance of thermal gradients in girder-supported highway bridges and to develop an analytical method for predicting the resulting thermal stresses. Field tests were conducted to attempt to validate the analytical method.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-5 FY '67

Protection of Steel in Prestressed Concrete Bridges

Research Agency: University of Denver
Principal Invest.: Dr. W. C. Hagel
Effective Date: September 15, 1966
Completion Date: November 15, 1968
Funds: $173,255

This project sought to determine environmental conditions under which special protection is required and to develop effective protective systems under both pre- and post-tensioning configurations. Specifically, the objectives were (1) to conduct a thorough survey of available domestic and foreign data on corrosion and prevention of corrosion of prestressing steel in bridges, buildings, pavements, and other structures; (2) to review present practice to evaluate the effectiveness of prevention of corrosion and mechanical damage during manufacturing, shipping, and placing; (3) to identify the mechanisms of corrosion which attack prestressing tendons under various conditions, possibly including, but not limited to, the influence of concrete and grout composition, the presence of free water, electrolysis, and the presence or absence of cracking; (4) to devise an appropriate accelerated corrosion test or tests simulating the various service conditions surrounding prestressing tendons; (5) to evaluate various possible protective systems for prestressing tendons, including, but not limited to, metallic, plastic, or inhibitive coatings, grout substitutes or admixtures, cathodic protection, etc.; (6) to perform field and laboratory experiments to determine the effectiveness of present grouting methods for post-tensioned work and to snggest improvements in methods and/or materials; and (7) to evaluate the effectiveness of concrete cover over tendons.

The final report has been published as:

NCHRP Report 90, "Protection of Steel in Prestressed Concrete Bridges."

Project 12-6 FY '67

Prediction of Permanent Camber of Bridges

Research Agency: University of Missouri
Principal Invest.: Dr. James W. Baldwin, Jr.
Dr. Adrian Pauw
Effective Date: February 1, 1967
Completion Date: April 30, 1972
Funds: $82,253

The present construction practices used in providing camber in rolled beams result in an unpredictable loss of camber during the early life of the bridge. This loss of camber occurs under loads lower than those causing strains equal to the yield point of the material. There is a need for a determination of the causes of the loss of camber when the camber was produced by heat, strain, restraint, or a combination thereof. Toward fulfilling this need, the primary objective of this research was to recommend a means of predicting the permanent camber in rolled beams resulting from specific fabrication methods and to include (1) a thorough survey of available data on residual stresses in rolled beams; (2) a survey of existing methods of cambering beams and a classification of methods into different categories, if possible, with cambering by both mechanical and thermal means being studied; (3) the determination of the magnitude and distribution of residual stresses in beams as rolled and delivered to the fabricator without camber, with the beams studied being of sizes representative of typical highway bridges; (4) the determination of the effect of the cambering methods investigated on residual stresses; (5) the determination of permanent deformations in rolled beams without added camber when subjected to repeated loads at various levels with loads lower than those causing computed yield-point stresses (this does not presume to be fatigue loading, but the number of cycles applied would be equal to six-months service life of a bridge); (6) the determination of permanent deformations in rolled beams cambered by the methods investigated when subjected to repeated loads at various levels of loading lower than those causing computed yield-point stresses, the number of cycles applied being equal to six-months service life of a bridge; and (7) the formulation of a mathematical model (after the determination of objectives 5 and 6) for predicting the permanent camber.

The final report, which includes the findings of Project 12-1, was not published in the NCHRP report series;

however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-7 FY '67

Effects of Weldments on Fatigue Strength of Steel Beams

Research Agency:	Lehigh University	
Principal Invest.:	Dr. John W. Fisher	
Effective Date:	Oct. 1, 1966	July 1, 1970
Completion Date:	Jan. 31, 1970	Dec. 31, 1972
Funds:	$199,023	$200,000

The fatigue fractures observed in the coverplated steel beam bridges included in the AASHO Road Test, as well as those obtained in other similar structures, emphasize the important effect of welding and welded details on the life expectancy of highway beam or girder bridges. Also of great significance in these bridges are the loading history, the type of materials used, the design details, and the quality of fabrication. Among the more important design details are such factors as coverplates, stiffeners, attachments, and splices. Only approximate general mathematical design relationships have been possible on the basis of the limited existing experimental data. However, with the conduct of additional research, and an analysis and evaluation of the many interrelated fatigue parameters, suitable basic relationships can be developed to properly design welded bridges for a desired life expectancy.

The principal objective of Phase I of this research was to develop design relationships that define the basic behavior of welded coverplated beams under constant-amplitude fatigue loading. The results of the Phase I work have been reported in:

NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams."

The Phase II work had the objective of extending the basic knowledge obtained under Phase I into important design considerations, including stiffeners and/or lateral and transverse connections. Phase II included a continuing review of existing data and mathematical relationships defining the fatigue behavior of various details under constant-amplitude loading. It also included a statistically designed and controlled experiment that was intended to provide new information for the development of suitable mathematical relationships that can predict the fatigue behavior of welded beams with stiffeners and/or lateral and transverse connections. Variables studied included applied stresses, design details, and type of steel.

Phase II research has been completed, and the final report has been published as:

NCHRP Report 147, "Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments."

Project 12-8 FY '66

Bridge Rail Service Requirements as a Basis for Design Criteria

Research Agency:	Texas A & M University Research Foundation	
Principal Invest.:	Dr. Robert M. Olson	
Effective Date:	Mar. 1, 1968	Jan. 2, 1970
Completion Date:	Feb. 28, 1969	June 30, 1971
Funds:	$28,793	$69,753

Highway bridge railing systems have evolved through need and experience and with design information not fully substantiated by research. In recent years many full-scale crash tests on railings have been conducted providing much useful information, but still there is need for a better definition of service requirements. Of prime importance is a need for developing a fundamental concept of the purpose that railings are expected to serve under various site conditions with due consideration being given to a balance between safety, appearance, and economy. Design criteria, when established, can then be correlated with existing research data for development of specifications for the design of various railing configurations and materials.

The Phase I research effort to develop tentative service requirements has been completed, and the results have been published as:

NCHRP Report 86, "Tentative Service Requirements for Bridge Rail Systems."

The Phase II effort had as its objective the quantification of the service requirements to produce design criteria for bridge rail systems. This objective was to be pursued by further establishing the validity of a simple mathematical model developed under Phase I; by conducting parameter studies using the mathematical model to evaluate simulated vehicle-barrier collisions; by developing tables, curves, or nomographs for use by design engineers; and by refining the limits of tolerable deceleration on the basis of more recent information.

The agency devoted study to the trends of automobile weights and dimensions; the evaluation of accident causation factors that may have a significant influence on the frequency of bridge rail-vehicle collisions; the analysis of structural response and failure mechanisms of concrete parapets; the relationship between barrier strength and rigidity versus vehicle damage and accelerations transmitted to the passengers; the effects of barrier design on the dynamic response of a vehicle; the required barrier height for certain selected vehicles; and analysis of crash-tested bridge rail designs by a mathematical model for purposes of further validating the model and theoretically estimating the efficiency of the design.

Phase II research has been completed, and the final report has been published as:

NCHRP Report 149, "Bridge Rail Design—Factors, Trends and Guidelines."

Project 12-9 FY '67

Elastomeric Bearing Research

Research Agency: Battelle Memorial Institute
Principal Invest.: J. C. Minor
Effective Date: September 1, 1967
Completion Date: January 31, 1970
Funds: $84,800

The development of new elastomers and elastomeric bearing systems is proceeding at a rapid rate. The ability of these bearings and bearing systems to absorb the various loads and movements occurring in bridges in a more efficient manner and at a significantly lower cost than mechanical bearing systems justifies an effort to improve current designs. Toward this objective, this project contemplated research on elastomeric bearings and bearing systems using materials as defined in the AASHTO specifications for elastomeric bearing pads.

The major objectives of the project were to evaluate (1) effect of geometry on compressive strain, compressive set, shear modulus, and rotational modulus for hardness between 50 and 70 durometer and sizes from 50 to 200 sq in., and the effect of lamination on these values; (2) relative performance of glued laminated pads compared to fully vulcanized units, including an effective test of the adhesion between layers; (3) relative performance of molded pads versus pads sawed from larger sheets with an evaluation of the sawing process and determination of an acceptable cut surface; and (4) evaluation of the aging and low-temperature (to −40 F) characteristics of the various pads.

The research has been completed, and the final report has been published as:

NCHRP Report 109, "Elastomeric Bearing Research."

Project 12-10 FY '70

Analysis and Design of Bridge Bents

Research Agency: Portland Cement Association
Principal Invest.: Dr. James E. Carpenter
Effective Date: January 1, 1970
Completion Date: December 31, 1973
Funds: $297,900

The present strong emphasis on safe and aesthetic design of reinforced concrete highway bridges has resulted in substructure configurations that depart widely from the traditional footing-column-cap frame design. Aesthetic considerations often dictate the concealment of massive concrete caps and elimination of numerous vertical columns; however, design procedures in current use are not applicable to these new configurations. There is a general feeling that current procedures result in overdesigned structures containing much more steel than is necessary. Therefore, an urgent need exists for the development of appropriate design procedures.

Although the ultimate need is to establish valid design procedures that are applicable to many configurations of bridge bents, this project was limited to investigation of bent caps concealed in straight, continuous, reinforced concrete bridges.

Design procedures were developed by (1) constructing and testing adequately scaled reinforced concrete models of representative bents and (2) developing a mathematical model to correlate with the experimental results. The design procedures may be corroborated by data taken from full-size bridges instrumented during construction but not as a part of this project.

Research was based on prototypes representative of popular box-girder designs. The accomplishment of the research included: (1) reviewing the technical literature; (2) determining a design procedure for single- and multiple-column bents; (3) determining the cap design width by defining the extent of superstructure participating in supporting the cap loads; and (4) specifying changes required in the AASHTO specifications to permit use of the recommended design procedures.

To achieve the objectives of this research, a plan was developed that includes testing of ½-scale models of two reinforced concrete box girder bridges. These tests provided information on distribution of loads in the vicinity of the integrated bent cap. Five additional tests on model bent specimens provided further information on the location of critical sections and the effective width of the bent cap. These ½-scale specimens were intended to represent a transverse strip of bridge superstructure that is parallel to and includes the bent cap and columns. The reinforcement of the bent cap was varied in these models, as well as column flare and the thickening of the deck slab. Analytical studies of load distribution in the entire bridge and of stress distribution in the bent cap accompanied the experimental work.

Research has been completed, and the project report has been published as:

NCHRP Report 163, "Design of Bent Caps for Concrete Box Girder Bridges."

Project 12-11 FY '71

Waterproof Membranes for Protection of Concrete Bridge Decks

Research Agency:	Materials Research and Development	
Principal Invest.:	C. J. Van Til B. J. Carr	C. J. Van Til
Effective Date:	Aug. 1, 1970	July 15, 1973
Completion Date:	Mar. 31, 1973	September 30, 1978
Funds:	$206,025	$96,979

Many bridge decks suffer damage as a result of penetration of water and deicer solutions through the deck surface. One possibility for providing the protection necessary to alleviate this damage is to place an impermeable membrane over the entire deck surface. To be effective, such a membrane must maintain bond with the deck surface and must have sufficient extensibility to bridge active cracks without rupture through the range of temperature and loads to which the deck is subjected. It is likely that, in order to realize an acceptable degree of permanence, the membrane either will be protected by a wearing surface, such as asphaltic concrete, or will provide adequate wearing qualities within itself.

The objective of this research was to develop, or discover, one or more effective waterproofing membrane systems for use on concrete bridge decks.

The objective was approached in a two-phase study. Phase I, now complete, was devoted to preliminary evaluation of all available membranes, selection of the most promising for field evaluation and development of a field evaluation plan. Phase II was the field evaluation.

Phase I of the research consisted of conducting a detailed literature search; defining the service requirements for effective membrane systems; conducting sufficient field inspections to evaluate selected systems, including application techniques; conducting controlled laboratory studies to identify and define those properties that affect performance of membrane systems and devising qualifying tests relative to field performance; developing a procedure for determining cost-benefit ratios associated with the use of membrane systems and demonstrating the procedure by example cases; and devising an experimental program for evaluating the performance in the field of selected membrane systems under service conditions.

Of an iuitial group of 147 systems, 78 were selected for more detailed study. Characterization and performance data (from both laboratory and field) eventually produced five survivor systems that appeared to be the most promising candidates for further field evaluation. All of the survivors require a protective surfacing of asphaltic concrete to serve adequately, and all but one appear to require the application of an intermediate protective layer to avoid damage by construction operations subsequent to installation.

The results of Phase I have been reported in:

NCHRP Report 165, "Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase."

Under Phase II, the five systems selected as most promising were experimentally installed on new decks at each of four bridge sites in 1974 and 1975. Semiannual observations of performance of the installed systems were made. Research is completed, and the agency's final report has been distributed to the Program sponsors. Loan copies are available or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-12 FY '71

Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings

Research Agency:	United States Steel Corporation
Principal Invest.:	C. G. Schilling
	K. H. Klippstein
Effective Date:	October 1, 1970
Completion Date:	October 31, 1975
Funds:	$310,000

Highway bridges are subjected to a great variety of forces that range from constant dead load (through slowly changing forces due to creep of materials and temperature differentials) to an almost infinite variety of live loads caused by moving vehicles. Currently, most bridges are designed to carry a static load produced by a design truck with certain empirical allowances being made for dynamic effects. On the basis of these loads and an assumed frequency of occurrences, the design considers the static and fatigue properties of the material used. Not much is known about the actual service life of the bridge and the actual service loads.

The first major problem in predicting the life of highway bridges is to determine, from a heterogeneous spectrum of frequencies and amplitudes, the loading conditions to which the structure is subjected during its lifetime. Others have conducted field tests to develop this information.

This project was directed to the next major problem: to determine the behavior of welded highway bridge steels (specifically, A36 and A514) under variable-cycle fatigue loads and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The primary objective of this project was to develop information on the properties of welded steel bridge members under variable-cycle fatigue loadings and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The agency pursued the project objectives by: a study of pertinent past work with particular emphasis on field measurements of stresses in bridges under traffic; a theoretical study to predict from existing hypotheses the fatigue behavior of small specimens and beams that were tested later in the study; variable-amplitude fatigue tests of small specimens simulating certain beam details for the purpose of verifying the variable-amplitude load spectra selected and crack propagation threshold assumptions; variable-amplitude fatigue tests of relatively large beams of various steels with typical bridge details similar to those tested in NCHRP Project 12-7; and complete evaluation of the experimental results and development of methods of utilizing the results for design and specification purposes.

Research has been completed, and the final report has been published as:

NCHRP Report 188, "Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings."

Project 12-13 FY '73

Cathodic Protection for Reinforced Concrete Bridge Decks

Research Agency: USS Engineers and Consultants
Principal Invest.: J. B. Vrable
Effective Date: October 1, 1972
Completion Date: July 31, 1974
Funds: $174,601

Many reinforced concrete bridge decks experience damage because of corrosion of the reinforcing steel. One potential method for controlling this corrosion is the application of cathodic protection. Effective cathodic protection must provide proper current distribution and achieve protective polarization of the reinforcing steel. Therefore, there is a need to develop design criteria and optimum designs for cathodic protection systems that can arrest or control corrosion of reinforcing steel in concrete bridge decks, particularly in existing structures.

The objective of this research was to develop a technically and economically feasible cathodic protection system(s) for reinforced concrete bridge decks.

In this study, the two primary approaches to cathodic protection—the impressed current system and the sacrificial anode system—were investigated. Analog studies in the laboratory and prototype model studies were main features of the investigation. The feasibility of applying either approach to protecting bridge deck steel reinforcement against corrosion was demonstrated. A detailed work plan for a field evaluation of cathodic protection, applying the results of the study, was developed.

Research has been completed, and the project report has been published as:

NCHRP Report 180, "Cathodic Protection for Reinforced Concrete Bridge Decks—Laboratory Phase."

Project 12-13A FY '73

Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks

Research Agency: Portland Cement Association
Principal Invest.: Dr. David A. Whiting
Effective Date: August 1, 1975
Completion Date: May 15, 1981
Funds: $74,405

Many reinforced concrete bridge decks suffer damage caused by corrosion of reinforcing steel, especially those affected by deicing salts and marine environments. One method of controlling corrosion that has been successfnl in other applications is to apply cathodic protection to the potentially corrosive metal. Research under a previous NCHRP study, Project 12-13, had a primary objective of developing technically and economically feasible cathodic protection systems for the uppermost reinforcing steel in concrete bridge decks. The findings, published in NCHRP Report 180, "Cathodic Protection for Reinforced Concrete Bridge Decks—Laboratory Phase," demonstrated the potential of cathodic protection and recommended field demonstration programs. These recommendations included both forms of cathodic protection: impressed current cathodic protection and galvanic cathodic protection, i.e. the use of sacrificial anodes.

On completing Project 12-13, the NCHRP elected to pursue field evaluations of galvanic cathodic protection only. Impressed current cathodic protection was already receiving attention from several states.

Under NCHRP Project 12-13A, galvanic cathodic protection systems on an actual bridge deck were evalnated over a 3-year period. Ribbon anodes (as snggested by the previous research) using three different spacings and a perforated zinc sheet (suggested by the agency) were installed on a bridge deck under an Illinois Department of Transportation contract. The evaluations and related research are now complete.

Absolute judgments on galvanic cathodic protection of reinforced concrete bridge decks were not possible. However, the performance of two variations of protective systems, perforated zinc sheet anodes and closely spaced zinc ribbon anodes, provides encouragement for further research and field demonstrations of this relatively simple method of cathodic protection systems as a possible preservation technique for reinforced concrete bridge decks.

Research has been completed, and the project report has been published as:

NCHRP Report 234, "Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks—Field Evaluation."

Project 12-14 FY '73

Subcritical Crack Growth in Steel Bridge Members

Research Agency: United States Steel Corporation
Principal Invest.: Dr. John M. Barsom
Effective Date: October 1, 1972
Completion Date: June 30, 1974
Funds: $99,923

Highway bridges are subjected to a great variety of forces, ranging from constant dead load, through slowly changing forces due to material creep and temperature differentials, to an almost infinite variety of live loads caused by moving vehicles.

The life of a welded steel bridge member may be determined by the size of the largest actively growing crack in the member that was not detected or was considered acceptable by inspection at the time of fabrication; the effect of geometry of the welded details on the rate of stable fatigue crack growth (current work on both NCHRP Project 12-7 and Project 12-13 deals with fatigue and crack growth of welded details in a benign environment); the increase of fatigue crack growth rate due to an aggressive environment; and the crack size that can initiate a rapid crack extension when the combined residual and applied stresses, crack size, and fracture toughness provide a critical condition. Some steel bridges have failed prematurely over the last 35 years because one or more of these factors were not considered properly in design.

Fracture toughness of bridge steels and fatigue crack growth of welded details have been and are being studied by a number of research agencies. However, little has been published on the effects of aggressive environment on the rate of fatigue crack growth for bridge steels. In addition, at the time of initiation of this project, no requirements had been established for fracture toughness levels for bridge steels, nor had fracture mechanics and fracture toughness been applied to welded bridge details.

The long-range objective of this research, which may be achieved through several phases of work, is to develop information that will lead to prevention of unstable crack growth in welded steel bridge members. This objective includes the definition of material requirements and design specifications to avoid brittle fracture.

The main objectives of this project were:

1. To develop corrosion-fatigue data on bridge steels in distilled water and 3 percent sodium chloride solution under stress fluctuations such as occur in actual bridges.
2. To develop an analytical method for predicting the cyclic life of bridge components in distilled water and 3 percent sodium chloride solution under stress fluctuations such as occur in actual bridges.
3. To develop methods of utilizing the results for design and specifications purposes.

The steels studied were A36, A588 grades A and B, and A514 grades E and F. The test specimens were made from base metal of 1-in. plate material and were 1 in. thick.

The longitudinal and transverse tensile properties at room temperature were established for each grade of steel. Moreover, energy absorption, lateral expansion, and percent shear were determined in the temperature range between $-100°F$ and room temperature by using standard impact Charpy V-notch specimens.

Research has been completed, and the project report has been published as:

NCHRP Report 181, "Subcritical Crack Growth in Steel Bridge Members."

Project 12-15 FY '73

Detection and Repair of Fatigue Cracking in Highway Bridges

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: October 1, 1972
Completion Date: April 30, 1975
Funds: $100,000

Relatively large reductions in fatigue strength of many welded details occur when fatigue cracks initiate and grow from the small micro-size defects that exist at the weld periphery. This behavior has been well demonstrated by studies on coverplated beams and other comparable details and has been reported in NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams." Recently, fatigue cracking has been observed in the field where complete fracture of a tension flange was generated from fatigue crack growth at the toe of a transversely welded coverplate. In this instance, the bridge was only 13 years old. Subsequent inspection of 15 other coverplate ends revealed that the two beams adjacent to the cracked member were also cracked through about one-half the flange thickness. Smaller fatigue cracks were detected at several other coverplate ends.

When this research was initiated a review of available methods for the detection of fatigue cracks was needed. Typical details that are most susceptible to fatigue cracking needed also to be identified. In addition, methods were needed to improve the fatigue strength of severe notch-producing details of existing structures subjected to high volumes of heavy truck traffic.

The objectives of the study were to: (1) compile a state-of-the-art review of existing methods of nondestructive inspection and evaluate their reliability and adaptability in the detection of fatigue cracks in welded highway bridges; (2) compile a state-of-the-art review of typical existing and currently designed welded bridge details and evaluate those most susceptible to fatigue crack growth; (3) review and evaluate methods for improving the fatigue life and arresting the progress of fatigue damage that occurs at the weld toes of severe notch-producing details where the probability of failure is greatest. The methods were evaluated by tests of "as welded" and of fatigue-damaged coverplate beam specimens of A36 steel. These tests were comparable to and correlated with those conducted in NCHRP Project 12-7 and reported in NCHRP Reports 102 and 147. The experimental variables include crack size at the time of treatment, methods of improvement, stress range, and minimum stress; and (4) recommend methods for improving the fatigue life of, and arresting the progress of fatigue damage to, welded highway bridges.

Research has been completed, and loan copies of the agency's final report are available from the NCHRP upon

written request. The findings have been combined with those from Project 12-15(2) and published as:

NCHRP Report 206, "Detection and Repair of Fatigue Damage in Welded Highway Bridges."

Project 12-15(2) FY '75

Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: June 1, 1976
Completion Date: November 30, 1978
Funds: $150,000

Relatively large reductions in fatigue strength of many welded details occur when cracks initiate and grow from the micro-sized defects that exist at the weld periphery. This behavior had been demonstrated by studies on coverplated beams and other structural details, and has been reported in NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams," and NCHRP Report 147, "Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments." Recently fatigue cracking has been observed in the field at a number of different structural details. In one instance, complete fracture of a tension flange followed fatigue crack growth at the toe of a transversely welded cover plate in a 13-year-old bridge. Subsequent inspection of 15 other cover-plate ends revealed that the two beams adjacent to the cracked member were also cracked through about one-half the flange thickness. Smaller fatigue cracks were detected at several other cover-plate ends.

This study built on research completed earlier under NCHRP Project 12-15, "Detection and Repair of Fatigue Cracking in Highway Bridges." Project 12-15 demonstrated that peening the weld toe and applying a gas tungsten arc remelt process were successful in improving fatigue strength in the laboratory. The current study included further work on these methods and was concerned with three major areas related to the retrofit or repair of fatigue-damaged members.

Task 1 was intended as a pilot study to demonstrate the applicability of peening and gas tungsten arc remelting in the field.

Task 2 was intended to provide supplemental information on the low stress range behavior of full-size bridge beams. These beams were retrofitted and retested after various levels of fatigue crack growth.

Task 3 was intended to examine the fatigue strength of beams, with cracks at the ends of transverse stiffeners, that have subsequently been repaired by drilling holes at the crack tip. Five existing welded built-up beams were available for this study from an earlier test program.

Research is completed, and the final report, including findings from Project 12-15, has been published as:

NCHRP Report 206, "Detection and Repair of Fatigue Damage in Welded Highway Bridges."

Project 12-15(3) FY '78

Fatigue Behavior of Full-Scale Welded Bridge Attachments

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: February 1, 1978
Completion Date: July 31, 1980
Funds: $125,000

Fatigue problems have developed in a number of bridges with gusset plates welded to webs or flanges. Cracks have grown in the web gap between the end of the gusset weld and the transverse stiffener. This condition is complicated by the high residual stresses developed in these highly restrained configurations and also by out-of-plane movement caused by the lateral bracing. Information is needed on the fatigue strength of these details and on the efficacy of applicable retrofit measures.

The objective of this study was to examine the fatigue strength of beams with web and flange lateral attachment plates. In addition to providing a more comprehensive data base for this type of detail, the program was intended to examine the influence of lateral bracing members on the out-of-plane distortion of the lateral plate. Further work was also undertaken during the experimental studies on the effectiveness of peening and gas tungsten arc remelting the fatigue-damaged connections and on the ability of drilled holes to arrest crack growth.

A total of 18 beams, each with three welded gusset plate details, were tested in fatigue with stress ranges of 6 to 15 ksi. The results of these tests were used to assess the adequacy of applicable provisions of the AASHTO Specification. In addition, the influence of lateral bracing on the fatigue performance of the attachments was evaluated.

Research has been completed, and the final report has been published as:

NCHRP Report 227, "Fatigue Behavior of Full-Scale Welded Bridge Attachments."

Project 12-15(4) FY '79

Steel Bridge Members Under Variable-Amplitude, Long-Life Fatigue Loading

Research Agency: Lehigh University
Principal Invest.: Dr. John W. Fisher
Effective Date: April 1, 1980
Completion Date: September 30, 1983
Funds: $150,000

Fatigue cracks have developed at the ends of coverplates in beams that are only infrequently subjected to stress ranges exceeding the fatigue limit of AASHTO's Category E'. For example, in one particular structure,

small cracks have been detected in several beams where only 0.1 percent of the measured stress cycles exceeded the estimated fatigue limit. This field behavior suggests that more severe fatigue problems could result if bridges are subjected to heavier loads in the future, and the consequences of occasional overloads from permits and other sources may be more critical than previously assumed.

The objective of this study was to provide additional information on fatigue crack growth behavior of steel bridge members under randomly applied, variable amplitude loadings in the fatigue limit, extreme life region. Testing was carried out on center-crack specimens, cruciform specimens, and full scale welded beams.

The currently available test data in this region of behavior are very sparse and do not provide an adequate basis on which to assess this problem. The consequences of triggering fatigue crack growth in existing bridges as a result of increased loads could have a major impact on the life expectancy and safety of bridge on high volume arteries where large numbers of random variable stress cycles are expected.

Research has been completed, and the final report has been published as:

NCHRP Report 267, "Steel Bridge Members Under Variable-Amplitude Long-Life Fatigue Loadiug."

Project 12-15(5) FY '82

Fatigue Behavior of Variable Loaded Bridge Details Near the Fatigue Limit

Research Agency:	Lehigh University
Principal Invest.:	Dr. John W. Fisher
Effective Date:	September 1, 1983
Completion Date:	August 31, 1987
Funds:	$250,000

Fatigue cracks have developed at the ends of cover-plates in beams that are only infrequently subjected to stress ranges exceeding the fatigue limit of AASHTO's Category E'. For example, in one particular structure, small cracks have been detected in several beams where only 0.1 percent of the measured stress cycles exceeded the estimated fatigue limit. This observed field behavior suggests that more severe fatigue problems could result if bridges are subjected to heavier loads in the future, and the consequences of occasional overloads from permits and other sources may be more critical than previously assumed.

The objective of this study is to extend the findings of Project 12-15(4) by providing additional information on fatigue crack growth behavior of steel bridge members under randomly applied, variable-amplitude loadings in the fatigue limit, extreme life region. Testing will be carried out on eight full scale welded girders.

The currently available test data in this region of behavior are very sparse and do not provide an adequate basis on which to assess this problem. The consequences of triggering fatigue crack growth in existing bridges as a result of increased loads could have a major impact on the life expectancy and safety of bridges on high volume arteries where large numbers of random variable-stress cycles are expected.

In addition to the test program directed at the primary objective, a small portion of the total effort (less than 25 percent) will be expended on reassessment of fatigue specifications and evaluation of methods for arresting cracks caused by out-of-plane web distortion.

Through December 31, 1985, the fatigue testing is about 6 months behind schedule because of problems with the testing equipment. Two girders were tested to 50 million cycles with no detectable cracks present. The interim report was submitted to, and reviewed by, the project panel. It includes a comprehensive reassessment of current fatigue specifications and recommends minor revisions to the present AASHTO S-N curves.

Project 12-16 FY '75

Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel

Research Agency:	Battelle Columbus Laboratories
Principal Invest.:	Walter K. Boyd
Effective Date:	September 1, 1974
Completion Date:	November 30, 1977
Funds:	$214,912

This study was concerned with the problem of corrosion of reinforcing steel caused by chloride ions in bridge deck concrete. Research indicates that the alkaline environment in concrete prevents the corrosion of steel that normally occurs in the presence of moisture and oxygen. However, the introduction of chlorides to this otherwise protective environment allows the corrosion reaction to take place. Only a small amount of chloride is necessary to cause the reaction to start, and further addition of chlorides to the surface of concrete that has already shown distress may not be necessary for continued corrosion. Thus, application of a waterproof membrane and an overlay on a repaired bridge deck from which all chloride-contaminated concrete has not been removed may not solve the problem and, in some cases, may actually aggravate the condition because it prevents processes such as flushing and drying that might help to remove chlorides and also because it prevents visual examination of the deck.

Numerous techniques are currently used to arrest and repair the damage caused by corroding reinforcing steel in otherwise structurally sound concrete bridge decks. Repair techniques include removal of the concrete to or below the level of the top mat of reinforcing steel, a variety of treatments of the steel, and use of various materials to replace the concrete removed. In addition to replacement of the damaged concrete, the repair often includes ap-

plication of an overlay with or without a waterproofing membrane. The effect of these methods on subsequent corrosion has not been determined.

The over-all objective of this research was to determine the relative effectiveness of the various repair methods in arresting corrosion of the reinforcing steel, both within and outside the repaired areas, and whether some of these methods actually aggravate the corrosion problem.

The research included preliminary field snrvey, laboratory evaluation, and field investigation of repair methods used throughout the United States. The major emphasis of the project was on commonly used methods, but some methods that have been used experimentally in the field were also investigated.

The preliminary field survey sought to determine how well repair methods appear to be working and identify or "screen" methods for further study.

The laboratory evaluation was directed toward testing the observations and opinions obtained in the preliminary field survey and ranking the performance of the more successful repair methods. The evaluation included work on laboratory specimens that simulate or reproduce the corrosion phenomena and repair methods identified in the preliminary field survey as being worthy of investigation. Investigative techniques included electrical measurements, chloride analyses, and other corrosion detecting procedures.

The field investigation verified, under service conditions, the indications from the laboratory evaluations. Based on results of the laboratory evaluation, a limited number of selected decks were studied to provide examples of the most important findings.

Research has been completed. Copies of the agency report may be obtained on a loan basis upon written request to the NCHRP. A limited number of copies is available to NCHRP sponsors for permanent retention, and others may purchase microfiche of the report (see final page of this section for ordering information).

Project 12-17 FY '77

Evaluation of Repair Techniques for Damaged Steel Bridge Members

Research Agency: Battelle Columbus Laboratories
Principal Invest.: H. W. Mishler
Effective Date: November 15, 1976
Completion Date: April 30, 1978
Funds: $49,974

Steel bridge members often are subjected to damage due to accidental impact, mishandling, or fire. Methods used for repair of such members include: heat straightening, welding or bolting splices, replacement components, or reinforcement. The decision to repair a damaged member and the techniques used are determined on the basis of the inspector's or engineer's evaluation of the situation, with little sound engineering information available for guidance. To place this decision-making process on a more rational basis, it is necessary to assemble information concerning the effect of these repair techniques on the service life, safety, performance and maintenance of the structure. Decisions on method of repair must also consider the cost, user inconvenience, and esthetics of the repair technique.

A two-phase project is anticipated. Only Phase I has been carried out at this time.

The over-all objective of this project is to provide guidance for the assessment of accidental damage to steel bridge members and to identify, develop, and evaluate the effectiveness of repair techniques. The specific objective of Phase I was to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of Phase II is to evaluate the effect of the damage and the repair techniques identified in Phase I on the behavior of the structure, determine potential detrimental effects, and define the limits within which these repair techniques can be used. This is expected to be accomplished through application of selected techniques to damaged members and subsequent laboratory testing.

Phase I included the following tasks:

Task 1. Identify and categorize common types of structural damage and frequencies of their occurrence.

Task 2. Analyze the state of the art of present practice and equipment used for assessing damage and making repairs on highway bridges, railroad bridges, and other steel structures. Included in the topics to be considered are heating temperature, jacking methods, straightening tolerance, limitation of methods, degradation of steel's mechanical properties due to heating and straightening, speed of repairs, relative cost, and influence on the service life of the structure.

Task 3. Based on existing experimental and field performance data, evaluate techniques that have been applied or may have application in correcting structural damage.

Task 4. Prepare a report summarizing the work in Phase I and proposing a basic outline of research topics for Phase II.

Research has been completed. The project final report has been distributed to state highway agencies, and copies may be obtained on a loan basis upon written request to the NCHRP. A limited number of copies is available to NCHRP sponsors for permanent retention, and others may purchase microfiche of the report (see final page of this section for ordering information).

Project 12-17A FY '79

Guidelines for Evaluation and Repair of Damaged Steel Bridge Members

Research Agency: George O. Shanafelt and Willis B. Horn

Principal Invest.: W. B. Horn, G. O. Shanafelt
Effective Date: October 1, 1981
Completion Date: May 31, 1984
Funds: $99,950

Steel bridge members often are subjected to damage due to accidental impact, mishandling, or fire. Methods used for repair of such members include: heat straightening, and welding or bolting splices, replacement components, or reinforcement. The decision to repair a damaged member, and the techniques used, are determined on the basis of the inspector's or engineer's evaluation of the situation, with little sound engineering information available for guidance. To place this decision-making process on a more rational basis, it is necessary to assemble information concerning the effect of these repair techniques on the service life, safety, performance and maintenance of the structure. Decisions on method of repair must also consider the cost, user inconvenience, and esthetics of the repair technique.

The overall objective of this two-phase project was to provide guidance for the assessment of accidental damage of steel bridge members and to identify, develop, and evaluate the effectiveness of repair techniques. The specific objective of Phase I (Project 12-17) was to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of the second phase of research (Project 12-17A) was to extend the effort carried out under Project 12-17 and to develop a manual of recommended practice.

Research under Phase II produced a detailed procedure of assessment and evaluation of damage. Recommendations of repair techniques and the effects of those repairs were detailed to the extent possible using currently available information. These results were presented in a user's manual recommending procedures and specifications for steel bridge repair.

Research has been completed, and the final report has been published as:

NCHRP Report 271, "Guidelines for Evaluation and Repair of Damaged Steel Bridge Members."

Project 12-18 FY '77

Development of an Integrated Bridge Design System

Research Agency: Multisystems Inc.
Principal Invest.: Dr. Som P. S. Virk
Effective Date: September 6, 1977
Completion Date: December 31, 1982
Funds: $224,895

All highway agencies in the United States employ libraries of computer programs to perform individual tasks in the design of a bridge. This considerable array of software was developed at great cost and effort, much of which was expended in duplicate development. An obvious extension of the use of individual programs is to combine them into an integrated design system, a group of task oriented modules linked together through a common data structure.

The development of an integrated design system would:

1. Permit alternative approaches and solutions to bridge design problems.
2. Result in cost-effective engineering and optimal use of materials and personnel.
3. Save significant time in the total design process.
4. Permit changes in bridge design specifications to be incorporated with relative ease at strategic points in the design process.
5. Minimize duplication in computer program development.

The objective of this research was to initiate the development of an integrated, modular bridge design system encompassing current bridge design specifications and allowing the engineer a wide range of interaction with the computer in performing his design functions. Such a system should be able to accommodate a variety of typical bridges.

The project consisted of two phases. Phase I included a preliminary investigation with the most important products being an inventory of currently used bridge design software and the definition of a framework for an integrated bridge design system. The actual development of the system and its functional modules occurred in the second phase of research.

Phase I included the following tasks:

1. Contact State highway and transportation agencies by questionnaires supplemented by personal visits to review present bridge design practices.
2. Review existing bridge design systems and provide an assessment of their relative merits and limitations.
3. Define the framework of the integrated bridge design system that will be developed in Phase II.
4. Review existing programs and determine their applicability for use in an integrated bridge design system as defined in Task 3. A product of this investigation was an inventory of applicable bridge design software, structured so as to indicate the relevant characteristics of the programs.
5. Propose a plan for implementation of the system beyond Phase II, including training of user personnel, installation assistance to users, and maintenance of the system after its development.
6. Prepare a draft of an interim report presenting the findings of Phase I and proposing a detailed working plan for Phase II.

Phase II consisted of the following tasks:

1. Develop a system that will provide access to the modules in three modes:

(a) In an independent mode, each module, together

with pre- and post-processors, shall be directly usable as a stand-alone program.

(b) In a sequential mode, the pertinent modules shall be linked together into a single run.

(c) In a data-base mode, the modules shall communicate with each other through a data-base management system.

In the development of this system, consideration was given to the computer configurations available to the various state agencies. Although it is recognized that this system cannot be completely computer independent, it was made as simple as possible to install on various computer configurations. The system also includes user-oriented pre-processors and convenience-oriented report writing post-processors, with consideration given to graphic output.

2. Select or develop a comprehensive set of functional modules conforming to the over-all system design. Preference was given to well-tested modules from bridge design systems or programs identified in Phase I. Each module processes a distinct function of the design operation and has clearly defined input and output data structure. The modules were written in ANSI FORTRAN for maximum portability and lend themselves to easy modification to conform to new design specifications and desired local adjustments.

3. Prepare complete documentation and user instructions for the system modules and complete documentation, flow charts, and file specifications for the system.

4. Prepare detailed standards for the design, programming, testing, and documentation of future modules for the system.

5. Demonstrate the use of the system in the design of commonly used bridge structures. The demonstration combined structural analysis and member selection modules in a manner that illustrates the linking of modules. The demonstration used two different representative computer configurations.

Research has been completed. The objective of this research was not fully accomplished. A limited, follow-up study was carried out under NCHRP Project 12-18A to evaluate the current status and provide information for future activity in this area.

Project 12-18A FY '81

Assessment of an Integrated Bridge Design System

Research Agency: Engineering Computer Corporation
Principal Invest.: Roy A. Imbsen
Effective Date: February 1, 1984
Completion Date: January 3, 1985
Funds: $15,000

All highway agencies in the United States employ libraries of computer programs to perform individual tasks in the design of a bridge. This considerable array of software was developed at great cost and effort, much of which was expended in duplicate development. An obvious extension of the use of individual programs is to combine them into an integrated design system, a group of task-oriented modules linked together through a common data structure.

The objective of Project 12-18 was to initiate the development of an integrated, modular bridge design system encompassing current bridge design specifications and allowing the engineer a wide range of interaction with the computer in performing his design functions. Such a system should be able to accommodate a variety of typical bridges.

Project 12-18 did not reach its objective. A module for computation of bridge geometry was demonstrated to operate within the integrated system, but, for undetermined reasons, the superstructure design module did not function properly as part of the system.

Because of the limited success of Project 12-18, an independent assessment of the status of the integrated bridge design system was made. This study included the following tasks:

1. Evaluate Project 12-18 and identify its usable accomplishments.

2. Analyze the major problems that prevented the attainment of project objectives.

3. Reassess the validity of the original objectives of the project in light of current and projected future conditions.

4. Determine the prospect for successfully reaching all or some of the project objectives and estimate the level of effort involved for each of the necessary tasks.

5. Evaluate the possibility of merging this effort with developmental work on other systems (e.g. BRASS).

6. Summarize the state of current practice in solving common problems with representing and processing specification-dependent segments of bridge-design programs, and discuss practical techniques for isolating and updating these segments.

7. Consider the options available for additional research and recommend a specific course of action.

Research has been completed. The final report has been reviewed by the project panel.

The preliminary conclusions of the final report are as follows:

1. In the development work of NCHRP Project 12-18 for the integrated software system, too much emphasis was placed on the computer system aspect and not enough on the end-user needs.

2. The geometry module works well and is quite useful.

3. The superstructure module does not work properly.

4. Other systems, such as BRASS, are available with proven implementability that would be more attractive as a basis for development of an Integrated Bridge Design System.

Therefore, the final recommendation was that funds should not be spent on an additional phase of research for NCHRP Project 12-18.

Project 12-19 FY '78

Cathodic Protection of Concrete Bridge Structures

Research Agency: Corrosion Engineering & Research Co.
Principal Invest.: William J. Ellis
Effective Date: January 1, 1978
Completion Date: December 31, 1980
Funds: $250,000

Steel in concrete bridge members corrodes as a result of chlorides in the concrete. Continued corrosion of the steel causes the concrete to crack and spall. Cathodic protection has been demonstrated to be a reliable means of controlling corrosion in the top mat of reinforcement in bridge decks. Techniques and materials need to be developed and evaluated for controlling corrosion in other bridge members.

The primary objective of this study is to develop and evaluate one or more cathodic protection systems to control corrosion of steel in chloride-contaminated structural members (excluding top reinforcement in decks and steel in members below water or soil).

The cathodic protection system developed reflects consideration of: economic feasibility, including design, installation, operating, and maintenance costs; compatibility with the structure, including repaired areas; potential safety hazards; life expectancy; and resistance to various environments, such as freeze-thaw and marine conditions.

A secondary objective was to prepare a state-of-the-art report based on a thorough survey of methods, materials, and criteria that have been used to control corrosion in concrete bridge members other than the top portion of decks. The report describes both successful and unsuccessful experiences.

This project included the following tasks:

Task 1. Preparation of a state-of-the-art report in accordance with the previously stated secondary objective.

Task 2. Identification of current and potentially available methods, materials, and concepts that may hold promise for cathodic protection systems for applications other than the top surfaces of bridge decks.

Task 3. Preliminary analysis of methods, materials, and concepts identified in Task 2.

Task 4. Preparation of a report on candidate materials and technologies and an updated working plan for laboratory evaluation.

Task 5. Laboratory development and evaluation of candidate systems.

Task 6. Preparation of the final report on the findings of Tasks 2, 3, and 5, including recommendations for field evaluation of selected systems.

Research has been completed. The state-of-the-art report (Task 1) and the final report (Task 6) have been distributed to state highway agencies. Copies are available for loan upon written request to the NCHRP or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 12-19A FY '79

Concrete Sealers for Protection of Bridge Structures

Research Agency: Wiss, Janney, Elstner & Assoc., Inc.
Principal Invest.: Donald W. Pfeifer
Effective Date: August 1, 1979
Completion Date: December 1, 1981
Funds: $99,190

Considerable attention has been directed to deterioration of bridge decks caused by deicing salts. However, in a marine environment, chloride penetration can affect all bridge members, including piles, caps, girders, and diaphragms, as well as decks. Deterioration is also often caused by faulty bridge deck drainage that permits contamination of structural members by deicing salts.

Development of treatments to provide protection against intrusion of chlorides into bridge members would extend the life of structures subjected to this type of environment and not already contaminated beyond tolerable limits. Consequently, the objective of this study was to establish the efficacy of sealers used to protect reinforced concrete bridges exposed to chloride contamination and to provide guidance for their use on bridge members concentrating on structnral elements other than the top surface of the deck. Accordingly, a variety of testing procedures were developed and several candidate sealers were evaluated. The proprietary labelling of the sealers tested has only been made available to NCHRP sponsors. Of widespread interest, however, should be the testing procedures used.

The research has been completed, and the project report has been published as:

NCHRP Report 244, "Concrete Sealers for Protection of Bridge Structures."

Project 12-19B FY '81

Cathodic Protection of Concrete Bridge Structures

Research Agency: Wiss, Janney, Elstner Assoc., Inc.
Principal Invest.: William F. Perenchio
J. Robert Landgren
Effective Date: November 1, 1982
Completion Date: April 30, 1985
Funds: $150,000

Although the NCHRP project panel was generally pleased with the contents and presentation of the final report for Project 12-19, they agreed that the findings were not ready for widespread application. Consequently, a decision was made to pursue further the Project 12-19 objective of developing and evaluating one or more cathodic protection systems to control corrosion of steel in chloride contaminated structural elements (excluding top reinforcement in decks and steel in members below water or soil). Specifically Project 12-19B included: (1) laboratory investigations aimed at further development and evaluation of cathodic protection systems using conductive coatings as secondary anodes, and (2) field evaluations based on actual applications and monitoring.

Laboratory tests were performed on three conductive coatings. After optimizing the test results for the primary requirements of conductivity and durability, one coating was selected for further work. A cathodic protection system using the selected coating was applied to a laboratory-size concrete slab located at the Federal Highway Administration's Turner-Fairbank Highway Research Center and to an actual bridge pier in cooperation with the Illinois DOT. A bridge application in a coastal marine environment was also desired and anticipated, but the operating agency having responsibility for the bridge experienced delays in initiating the work.

Research has been completed, and the project report published as:

NCHRP Report 278, "Cathodic Protectiou of Concrete Bridge Substructures."

Project 12-20 FY '78 and FY '80

Bridges on Secondary Highways and Local Roads: Rehabilitation and Replacement

Research Agency:	University of Virginia	
Principal Invest.:	Henry L. Kinnier	
Effective Date:	March 1, 1978	June 1, 1980
Completion Date:	Feb. 29, 1980	Nov. 30, 1981
Funds:	$119,923	$49,955

Many bridges on secondary highways and local roads are in need of replacement or major structural repair. It has been estimated that more than 110,000 bridges in the U.S. are inadequate for heavy loads or in need of major repairs and that another 51,000 have narrow widths, poor clearances, and dangerous approaches. Furthermore, it has been reported that about 150 bridge failures occur in the United States each year. Under the severe fiscal constraints that currently exist at the local level, most of these bridges cannot be replaced in the foreseeable future. Until recently considerable effort had been devoted to the analysis and design of new structures, but little attention was given to problems associated with rehabilitation of older structures on the secondary and local road systems. Therefore, local agencies responsible for inspection, maintenance, and repair are required to make decisions without benefit of supporting information. Under these conditions, there exists an urgent need for research that will provide tools for engineers to reach and carry out cost-effective decisions. This project is intended to develop information that local highway agencies can apply immediately to the repair, improvement, or replacement of deficient bridges on secondary and local road systems.

The objective of the first phase of this project was to develop (1) procedures for accomplishing repair and strengthening operations for bridges on secondary highways and local roads, (2) standard replacement structures and components that could be mass produced, and (3) an economic process for determining the most cost-effective alternative available in a given situation.

Phase I has been completed, and the final report was published as:

NCHRP Report 222, "Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement." The primary content of this report consists of a manual of recommended practice comprising 34 repair procedures for common bridge deficiencies and 27 bridge replacement systems available for use in the United States.

The objective of the second phase of research was to expand the effort carried out under Phase I. Additional procedures for repair of the following types of bridge damage were studied: fatigue of steel members, scour, deck deterioration, fire, seismic, and accidental impact. Replacement systems based on the following concepts were considered: short-span segmental construction, sectional prestressing, modular construction aud precast concrete box culverts. These repair procedures and replacement systems were prepared in the format used in the manual developed in Phase I. Innovative concepts for bridge rehabilitation and replacement were also studied.

Phase II has been completed, and the final report has been published as:

NCHRP Report 243, "Rehabilitation and Replacement of Bridges on Secondary Highways and Local Roads."

Project 12-21 FY '79 and FY '82

Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members

Research Agency:	George O. Shanafelt and Willis B. Horn	
Principal Invest.:	W. B. Horn, G. O. Shanafelt	
Effective Date:	April 15, 1979	May 15, 1982
Completion Date:	Sept. 14, 1980	Jul. 8, 1985
Funds:	$58,520	$129,934

Prestressed concrete bridge members often are subjected to accidental damage due to vehicle impact, mishandling, or fire. Methods used or potentially available for repair of such members need to be identified and evaluated for various levels of damage. The decision to repair or replace a damaged member, and the techniques

used, are determined on the basis of the inspector's or engineer's evaluation of the situation, with little published information available for guidance. To place this decision-making process on a rational basis and to enable the determination of appropriate engineering solutions for the repair of prestressed concrete bridges, it was necessary to assemble and assess information concerning the effects of repair methods on the service life, safety, performance, and maintenance of the structure. Decisions on method of repair must also consider the cost, user inconvenience, and esthetics.

The over-all objective of this study was to provide guidance for the assessment of accidental damage to prestressed concrete bridge members and to identify, develop, and evaluate the effectiveness of repair and replacement techniques. The research was carried out in two phases.

The specific objective of Phase I was to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of Phase II was to develop and evaluate improved repair procedures for damaged prestressed concrete bridge members and to prepare a manual of recommended practice.

Phase II included an evaluation of the effect of damage and the positive and negative aspects of selected repair techniques on the behavior of the structure and of the limits within which these repair techniques can be used. This was being accomplished through application of selected techniques to damaged members and subsequent laboratory testing. A detailed procedure for assessment and evaluation of damage was produced. Recommendations of repair techniques and effects of those repairs were detailed. These results are presented in a user's manual recommending procedures and specifications for prestressed concrete bridge repair. Repair methods include: the metal sleeve (see NCHRP Report 226, Nos. 3 and 5), the internal splice (Nos. 7 and 8), and the external post-tensioning system (No. 2).

Research is complete and project reports for Phase I and Phase II have been published as:

NCHRP Report 226, "Damage Evaluation and Repair Methods for Prestressed Concrete Bridge Members," and

NCHRP Report 280, "Guidelines for Evaluation and Repair of Damaged Prestressed Concrete Bridge Members."

Project 12-22 FY '81

Thermal Effects in Concrete Bridge Superstructure

Research Agency:	Engineering Computer Corporation
Principal Invest.:	Roy A. Isabsen
Effective Date:	October 1, 1981
Completion Date:	January 31, 1984
Funds:	$100,000

Bridge design requires consideration of the effects produced by temperature ranges and thermal gradients in the structure. These effects are particularly significant in large concrete bridges but are covered only to a limited extent in the current AASHTO Standard Specifications for Highway Bridges. Modern methods of concrete bridge construction require more accurate information for design purposes.

An increasing number of long span concrete box girder bridges are being constructed in the United States. In large sections, commonly used for segmental or other modern concrete bridge superstructures, the effects of temperature gradients, either across the section or through the thickness of its elements, are important and should be considered in the design. According to some engineers, stresses caused by temperature gradients may exceed those calculated for design live loads. Some design codes used in other countries provide guidance on these effects, but they are not adequately addressed in the current AASHTO Specifications.

Accurate prediction of the thermal movement range in a bridge is necessary to design effective bearing assemblies and expansion joints. Although some field measurements indicate that actual bridge movements are less than theoretically predicted, in other cases failure of expansion devices and bearings has been attributed to inadequate allowance for thermal movements. The need for accurate prediction of thermal movement is intensified by the growing tendency for designers to reduce or eliminate the use of expansion joints in order to avoid the cost of their construction and maintenance.

A number of analytical and experimental studies have been conducted on thermal effects in bridges, and several others are currently underway. There is a need to analyze available information and provide engineers with more comprehensive specifications and design procedures.

The objective of this research was to develop recommended specifications and design procedures for consideration of thermally induced stresses and movements in concrete bridge superstructures. The project included the following tasks:

Task 1. Review current domestic and foreign codes of practice, research findings, and performance data. Although this review shall emphasize effects in concrete bridge superstructures, care should be taken to include all relevant aspects of thermal effects in other concrete structures.

Task 2. Analyze and evaluate the information generated in Task 1 to establish rationales for alternatives approaches to the development of design procedures for considering thermal effects in concrete bridge superstructures. This analysis and evaluation shall encompass thermal effects, in all types of concrete bridges, including stresses induced by thermal gradients in box type cross sections.

Task 3. Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 12 months after initiation of the study. The interim report shall in-

clude design examples illustrating the alternative approaches. NCHRP approval of the interim report will be required before commencing Task 4.

Task 4. Prepare specifications in a format suitable for consideration by AASHTO. The recommended specifications shall be accomplished by a detailed commentary and design examples intended to facilitate their understanding and use.

Task 5. Identify additional research that is needed for further development and refinement of design procedures for thermal effects.

Task 6. Prepare a final report.

The research has been completed. The final report and the recommended specifications have been reviewed and revised, as appropriate. The report and recommended specifications will be published as NCHRP Report 276.

Project 12-24 FY '83

Design of Multi-Beam Precast Bridge Superstructures

Research Agency:	University of Michigan
Principal Invest.:	Dr. A. H. Mattock
	Dr. J. F. Stanton
Effective Date:	August 1, 1983
Completion Date:	January 31, 1986
Funds:	$149,879

Because of their relative economy and the speed and ease of construction, the popularity of multi-beam bridge superstrucutres, including those with decks incorporated entirely within the precast units, is growing. The precast units are used in a variety of forms that include channel beams; box section beams; nonvoided rectangular beams; rectangular beams with circular voids; and single-, double-, and multiple-stem tees. More widespread use of these units is hampered by the fact that AASHTO Specifications do not provide adequate guidance in some areas. Specifically, Article 1.3.1(D) of the Standard Specifications for Highway Bridges includes only a brief, general statement that is of little help to engineers in designing connections to develop interaction between adjacent elements in this type of superstructure. Furthermore, although Article 1.3.1(D) provides factors for the lateral distribution of wheel loads for certain types of beams, it does not include factors for tees.

Decisions in this area have been based on judgment by individual engineers, and designs are frequently the result of trial and error. To place this design process on a more rational basis, it is necessary to research these problems and develop improved design procedures.

The objectives of this research are (1) to develop criteria for design of connections between adjacent precast elements in multi-beam bridge superstructures, and (2) to develop specification provisions for the lateral distribution of wheel loads in precast multi-beam bridge superstructures of single-, double-, and multiple-stem tee girders.

The scope of this study inclndes reinforced concrete as well as prestressed concrete elemcnts. The research includes the following tasks:

Task 1. Review relevant research findings and performance data. This information will bc assembled from both technical literature and unpublished experiences of producers and users of multi-beam elements.

Task 2. Based on currently available information, develop practical and easy-to-apply design criteria for both shear- and moment-connections between adjacent precast elements. Types of connections to be considered include but are not limited to: continuous shear keys, lateral bolts, welded ties, and cast-in-place reinforced concrete decks, as well as combinations thereof.

Task 3. Based on available information and application of existing analytical techniques, develop procedures to determine lateral load distribution factors for design of precast multi-beam superstructures of single-, double-, and multiple-stem tee girders. These procedures should be applicable to nonskewed and moderately skewed superstructures, within limits clearly defined by the research, and might be patterned after the provisions of Article 1.3.1(D) of AASHTO's Standard Specifications for Highway Bridges.

Task 4. Validate the findings of the analytical portion of this study relevant to the second objective by correlation with available experimental data on lateral load distribution, supplemented, as necessary, by limited static load tests on existing bridges.

Task 5. Prepare specification provisions to reflect accomplishment of both project objectives in a format suitable for consideration for adoption by AASHTO.

Task 6. Identify areas in need of further investigation. Recommend priorities and estimate time and costs for the needed research.

Task 7. Prepare a final report on the findings.

Research has been completed. The draft final report has been submitted and is presently being reviewed by the project panel.

Project 12-25 FY '83

Fatigue and Fracture Evaluation for Rating Riveted Steel Bridges

Research Agency:	Lehigh University
Principal Invest.:	Dr. John W. Fisher
Effective Date:	September 1, 1984
Completion Date:	March 31, 1987
Funds:	$199,957

Most highway agencies have a significant number of aged riveted steel bridges that must be inspected, evaluated, and rated on a periodic basis. The AASHTO *Manual for Maintenance Inspection of Bridges,* used for structural evaluation by most engineers, does not provide an effective means of establishing the safe load capacity of these struc-

tures when fatigue and fracture toughness are of primary concern. Engineers are left to evaluate these conditions with little sound information available for guidance.

Research on the problems of fatigue and brittle fracture of steel structures has led to the incorporation of the design provisions and material criteria, pertaining almost exclusively to welded steel structures, presently in the AASHTO *Standard Specifications for Highway Bridges.* The material criteria adopted by AASHTO require that steel used in certain members of new bridges have minimum specified Charpy V-notch impact-toughness values. However, this important parameter is not addressed in the *Manual for Maintenance Inspection of Bridges* for either old or new steels. Likewise, the manual does not provide adequate guidance for determining the effects of fatigue. Practical criteria and rating procedures are needed for incorporation into the manual.

Because fatigue and fracture criteria for design of new bridges are based on research on welded members, strength evaluation and rating of riveted structures using these criteria are questionable. Inasmuch as riveted members are usually built-up sections with internal component redundancy, it is expected that the findings of this study might permit the relaxation of stringent fracture toughness and fatigue criteria under some conditions and applications.

The objective of this research is to develop a rational framework and recommended procedures for engineering estimates of the fatigue and fracture resistance of riveted members for use in structural evaluation and rating of existing steel bridges. The research will include the following tasks:

Task 1. Review relevant research findings and performance data. This review shall place special emphasis on materials properties of steel and fabrication practices in use at various times of construction of riveted bridges.

Task 2. Based on the findings of Task 1 and stress analyses using AASHTO provisions for bridge rating, identify critical steels and riveted details, including built-up sections and connections.

Task 3. Prepare an interim report on the findings of Tasks 1 and 2. This report shall include a detailed work plan for the remainder of the study, and it shall be submitted not later than 9 months after initiation of the project. NCHRP approval of the work plan will be required before commencing Task 4.

Task 4. Conduct a laboratory test program, in accordance with the detailed plan presented in the interim report, for the purpose of evaluating the fatigue and brittle fracture behavior of selected riveted details and of steels having various materials properties.

Task 5. Prepare guidelines for consideration of fatigue and fracture in structural evaluation and rating of riveted steel bridges. The guidelines shall be in a format suitable for consideration by AASHTO and shall be accompanied by a detailed commentary and practical examples intended to facilitate their understanding and use.

Task 6. Prepare a final report documenting the findings of the research.

Through December 31, 1985, research on the first two tasks is completed. The interim report has been submitted and is presently being reviewed by the project panel.

Project 12-26 FY '85

Distribution of Wheel Loads on Highway Bridges

Research Agency:	Engineering Computer Corporation
Principal Invest.:	Roy A. Imbsen
Effective Date:	April 15, 1985
Completion Date:	July 15, 1987
Funds:	$300,000

Wheel load distribution on highway bridges is one of the key elements in determining member size and, consequently, strength and serviceability. It is, therefore, of critical importance both in the design of new bridges and in the evaluation of the load-carrying capacity of existing bridges.

Empirical distribution factors for stringers and longitudinal beams have been present in the *AASHTO Standard Specifications for Highway Bridges* with only minor changes since 1931. Recent additions to these specifications have included more rational load distribution factors for particular types of superstructures based on tests and mathematical analysis.

Research and analysis have produced a substantial amount of information on various bridge types indicating a need for revisions of the AASHTO Bridge Specifications. Methods of distributing wheel loads to individual supporting members, based on the latest information, are essential in evaluating existing bridges, and, with the trend to increasing truck and permit loads, the need for reliable criteria becomes more urgent.

Research should be undertaken to develop more realistic load distribution criteria applicable to all common types of bridges and materials. These procedures shall be applicable to simple-span and continuous, straight and curved and right-angle and skewed bridges within limits clearly defined by this research.

The objective of this research is to develop comprehensive specification provisions for distribution of wheel loads in highway bridges.

Research under NCHRP Project 12-26 should consider all variables affecting the distribution of wheel loads. The recommended provisions shall apply to both the Service Load and the Strength Design Methods as well as to structural evaluation of existing bridges.

Load distribution criteria developed in this study are expected to include: (1) simplified methods of analysis including code formulas and (2) analytical models that

are more comprehensive and exact and are intended for computer-based application.

The project will include the following tasks:

Task 1—Review current, domestic and foreign codes of practice, research findings, and physical test data.

Task 2—Analyze and evaluate the information generated in Task 1 to develop alternative approaches to the distribution of wheel loads. It is not intended that this study include extensive computer software development.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 18 months after initiation of the study. The interim report shall include design examples illustrating the application of alternative approaches. The report shall also include comparisons between the results produced by existing provisions and the various alternatives. The validity of these results shall be demonstrated by comparison with available experimental and analytical data. NCHRP approval of the interim report will be required before commencing Task 4.

Task 4—Prepare detailed specifications in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended specifications shall be accompanied by a detailed commentary and selected desigu examples intended to facilitate their understanding and use.

Task 5—Identify and comment on other sections of the AASHTO Bridge Specifications that are affected by the proposed changes in load distribution provisions.

Task 6—Recommend additional research that is needed for further development and refinement of load distribution criteria.

Task 7—Prepare a final report.

Through December 31, 1985, work is progressing on schedule on the first two tasks.

Project 12-27 FY '84

Welded Repair of Cracks in Steel Bridge Members

Research Agency:	The Welding Institute
Principal Invest.:	Mr. E. N. Gregory
Effective Date:	October 15, 1984
Completion Date:	October 14, 1987
Funds:	$374,575

Steel bridges are susceptible to fatigue cracking caused by numerous cycles of heavy truck loadings. Because reliable, practical methods of detection are not available for field use, small fatigue cracks are not usually found during routine inspection. In some cases, cracks grow undetected until they reach the point where the load carrying capacity of an individual member has been severely reduced. At the present time, many bridge engineers believe that bolted splices and member replacement are the only reliable methods of dealing with members with deep cracks. However, many members cannot tolerate the loss of section required for bolted splices. Where replacement is possible during a bridge rehabilitation or reconstruction project, long delays may be imposed on the contractor while waiting for fabrication of new members because cracks might not be discovered until the project is initiated. In many cases where cracking has progressed extensively, entire structures are being replaced with the cost of the replacement and detouring traffic running into millions of dollars.

There is a need to demonstrate the reliability of welded repairs and to provide guidance for effective methods of welded repair of fatigue cracks and brittle fractures in steel bridge members so that the economies of welding can be effectively realized.

The objective of this research is to identify and evaluate welding methods for repair of cracked steel bridge members to restore their load carrying capacity and fatigue life.

The research will include the following tasks:

Task 1—Review relevant domestic and foreign research findings, current practice, and performance data. This information shall be assembled from both technical literature and unpublished experiences of engineers, fabricators, and owners of steel bridges. This review shall include but not be limited to: (1) welding procedures including metallurgical aspects of repair, (2) mechanical aspects of repair welding in the field, (3) techniques for repair welding of members while uuder stress, and (4) problems and solutions for repair welding of members while under traffic loading. This review shall also be used to identify and categorize common types of service cracking problems in steel bridge members.

Task 2—On the basis of the information assembled under Task 1, evaluate the use of shielded metal-arc procedures for repair welding in the field. Consideration shall be given to degree of restraint, magnitude and variation of stress, sequence of welding, thickness and type of material, nature and extent of cracking, and effects of multiple repairs. Procedures shall be suitable for application in repair of partial and full thickness cracks in bridge members such as: flanges and webs of beams and girders and components of built-up welded and riveted members.

Task 3—Prepare an interim report on the findings of Tasks 1 and 2. This report shall include a summary and evaluation of current practice and a detailed work plan for the remainder of the study. It shall be submitted not later than 7 months after initiation of the project. NCHRP approval of the work plan will be required before commencing Task 4.

Task 4—Conduct a laboratory test program, in accordance with the detailed plan presented in the interim report, for the purpose of evaluating repair techniques and fatigue behavior of selected details repaired under

various conditions. (Since repair procedures will remove the original crack, a simulated crack will be suitable for the test program.)

Task 5—Prepare a final report documenting the findings of the research and propose guidelines for welded repair of cracked steel members in the form of a manual of recommended practice.

Through December 31, 1985, research is complete on the first three tasks and is progressing on Task 4.

Project 12-28(1) FY '85

Load Capacity Evaluation of Existing Bridges

Research Agency: Case Western Reserve University
Principal Invest.: Dr. Fred Moses
Effective Date: September 1, 1985
Completion Date: August 31, 1987
Funds: $225,000

The elements fundamental to the process of estimating the load capacity of existing structures are distinct from design elements that have been generalized for applicability to a wide range of structure types and service conditions. This generalization, when extended to the evaluation of existing bridges, often results in overly conservative estimates of load capacity and may result in unjustified actions such as the replacement of adequate structures. Refinements in assumptions concerning loading and resistance can be justified because the cost of evaluation is only a fraction of the bridge replacement cost. A more detailed and flexible methodology for the evaluation of the load capacity of existing bridges is required.

The load capacity of existing bridges can be determined most reliably and economically through a multilevel procedure. A large number of existing bridges is clearly capable of accommodating modern highway loads, and changes in the present rating procedures are not required in these cases. However, bridges found to be deficient under the present rating procedures should be reevaluated using higher level methods. This higher level rating system should permit selection of safety levels in a rational manner based on the effort expended on inspection, maintenance, and evaluation. This system should take into account the states of deterioration and distress of the bridge and permit the owner to make informed decisions about the pay-off in terms of higher load ratings resulting from such measures as additional load control, inspection, and calculation effort.

The higher level approach should combine probability theory and engineering judgment to account for uncertainties in load effects and resistances. The load and resistance factors incorporated in this approach should be determined by a procedure that would permit future improvements in knowledge to be incorporated conveniently. The concepts of operating and inventory ratings are unsuitable as the only method of bridge evaluation, but could be retained as a screening process for the application of the higher level rating system.

The final report on the first phase of NCHRP Project 10-15 "Strength Evaluation of Existing Reinforced Concrete Bridges" includes findings and recommendations related to methods of predicting structural capacity for load rating concrete highway bridges. The limit-state approach to bridge evaluation recommended in this report is considered to be appropriate. Nevertheless, some of the factors included in the report are not well documented, and the recommended approach is not yet ready for widespread application. The second phase of NCHRP Project 10-15 has as its objective further development of the limit-state approach to evaluating the structural capacity of reinforced concrete bridge superstructures.

Additional research is needed to apply this approach to other types of bridges.

The objective of this research is to extend the application of the limit-state approach to load capacity evaluation of various common bridge types.

Reinforced concrete superstructures are being covered in NCHRP Project 10-15, and, at a minimum, NCHRP Project 12-28(1) shall apply to common types of steel and prestressed concrete superstructures.

It is anticipated that the research will include at least the following tasks:

Task 1—Review relevant domestic and foreign practice and research findings. This information shall be assembled from both technical literature and unpublished experience of bridge owners and consultants.

Task 2—Analyze and evaluate the Task 1 data to determine the applicability of available information and identify the need for additional information for calibrating the load and resistance factors to be used in the limit-state approach.

Task 3—Select specific bridge types for inclusion in this study.

Task 4—Prepare an interim report presenting the findings of the first three tasks and proposing a detailed working plau for the remainder of the study. (The interim report shall be submitted within 9 months after the research begins. Research on the remaining tasks shall not be initiated until the proposed working plan has been approved by NCHRP.)

Task 5—Establish the effects of different levels of effort in such activities as maintenance, inspection, and analysis in modifying the load and resistance factors in the limit-state approach to evaluation.

Task 6—Calibrate the proposed method to a target safety level using available test data and other information.

Task 7—Apply the proposed method to selected examples of various bridge types and compare the results with results from currently used methods.

Task 8—Present the proposed method, its rationale, and the justification for its adoption at the regional meetings of the AASHTO Subcommittee on Bridges and Structures.

Task 9—Prepare a final report documenting the research findings and presenting the recommended method in a format suitable for adoption by AASHTO.

Through December 31, 1985, research is progressing on schedule on the first three tasks.

Project 12-28(2) FY '85

Bridge Management Systems

Research Agency: ARE Inc.
Principal Invest.: Dr. W. Ronald Hudson
Effective Date: June 24, 1985
Completion Date: June 23, 1987
Funds: $225,000

About one-half of the approximately 600,000 highway bridges in the United States were built before 1940. Most were designed for less traffic, smaller vehicles, slower speeds, and lighter loads. In addition, even in newer bridges, deterioration caused by service conditions and deferred maintenance is a growing problem. Almost 40 percent of the nation's bridges are classified, according to the Federal Highway Administration's (FHWA) criteria, as deficient and in need of rehabilitation or replacement. More than 100,000 of these are judged to be structurally deficient because of deterioration or distress, and another 100,000 are considered functionally obsolete or inadequate for current requirements. In recent years the Federal Highway Bridge Replacement and Rehabilitation Program has provided about $1 billion annually (scheduled to increase to $2 billion in FY '86) to cover the 80 percent Federal-aid share of the cost of work on deficient bridges. However, in 1983, the FHWA estimated the program's needs at almost $50 billion, and this estimate did not include future inflation or the cost of the additional needs that will develop while the presently identified, deficient bridges are being eliminated from the list.

It is obvious that available funds will not permit total rehabilitation or replacement of all deficient bridges, and the funds available must be carefully and correctly directed to bridges required by the public, industry, and emergency services to provide the most cost-effective treatment in each case.

Pavement management systems have proved to be an effective tool in dealing with roadway problems. Similar bridge management systems are urgently needed to assist state and local engineers and administrators in making cost-effective decisions regarding existing bridges. A framework is needed to incorporate: (1) inventory and inspection; (2) service classification and rating; (3) maintenance and rehabilitation needs for particular bridges; (4) cost-effective choices from among various options (i.e., closing, posting, preventive maintenance, repair, rehabilitation, and replacement); and (5) data on the cost effectiveness of various maintenance activities.

Several state highway agencies are presently working on some form of bridge management system, and many others are considering development of such systems. It is, therefore, appropriate and timely for a comprehensive effort to provide guidance for such development, based on, but not limited to, an evaluation of available information and the progress to date by agencies active in this area.

The objective of this research is to develop a model form of effective bridge management at the network level. At a minimum it will include:

1. Methods to assess present and future needs of existing bridges (inventory, inspection, capacity, maintenance, rehabilitation, replacement, and funding).
2. Guidelines for determining cost-effective alternatives both with and without financial constraints.
3. Priority treatment of needs through the use of generalized work activities (ranging from posting through preventive maintenance through replacement).
4. Flexibility to accommodate a variety of policy approaches.
5. Flexibility to accommodate future expansion to the project level.
6. Methods to ascertain standards of data reliability.

The research will include at least the following tasks:

Task 1—Review relevant domestic and foreign practice and research findings to codify current practice. This information shall be assembled from both technical literature and unpublished experiences of bridge owners.

Task 2—Analyze and evaluate the information generated in Task 1 to establish a rationale for the development of a bridge management system as a logical sequence of involved activities.

Task 3—Determine the needs and opportunities for application of automated data processing eqnipment and procedures in the bridge management system, and evaluate the feasibility of using both new and existing software on various types of computers to execute all or part of the system.

Task 4—Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 12 months after the initiation of the study. The interim report will outline the framework of the bridge management system to be developed under Task 5 and will include examples illustrating the application of the proposed system. The report will also include comparisons between results produced by alternative methods being considered for further development in Task 5.

Task 5—Develop a model bridge management system in a format suitable for adaptation by state highway agen-

cies and other bridge owners. The recommended system shall be accompanied by a detailed commentary and examples of specific realistic applications intended to facilitate the understanding and use of the system.

It is intended that this system will be developed in as much detail as permitted by existing information, but it is anticipated that a considerable amount of additional information will be needed. Such additional information, identified by the study, will be developed through future studies; therefore, the system will be designed such that the system can be continually upgraded as new information is obtained.

Task 6—Prepare a final report.

Progress to December 31, 1985, includes the completion of Task 1 and work begun on Tasks 2 and 3. Activities in Task 1 included:

1. The formation and start-up of a Technical Advisory Committee (TAC) representing five states to provide initial technical state-of-the-art information.
2. Site visits to each home state of TAC members.
3. A detailed literature survey.

In Task 2, research is in progress on establishaing maintainable components of the System; developing action thresholds; defining what is meant by workload for each maintainable component; identifying effectiveness of different maintenance/rehabilitation treatments; identifying life-cycle costing methods; developing a method to prioritize maintenance; rehabilitation, posting, closure, and/or replacement actions; and the determining of the formats and style of output from the System. Work has also been started on the investigation of the software and hardware needs of the System.

Project 12-28(3) FY '85

Fatigue Evaluation Procedures for Steel Bridges

Research Agency: Case Western Reserve University
Principal Invest.: Dr. Fred Moses
Dr. Charles Shilling
Effective Date: July 1, 1985
Completion Date: June 30, 1987
Funds: $200,000

The fatigue provisions in the current AASHTO Standard Specifications for Highway Bridges are based on approximations of actual conditions in steel bridges. These provisions combine an artificially high stress range with an artificially low number of stress cycles to produce a reasonable design. Furthermore, the current AASHTO provisions were intended for design applications and not for rating or assessing remaining fatigue life of existing steel bridges, especially those built before the present provisions were adopted.

In recent years, much information has been developed on (1) variable-amplitude fatigue behavior, (2) high-cycle (long-life) fatigue behavior, (3) actual traffic loadings, (4) load distribution for fatigue, (5) inspection and assessment of material properties and structural conditions, and (6) other pertinent parameters. This new information, together with the extensive information previously accumulated on the fatigue behavior of various details, is sufficient to permit the development of realistic procedures for the fatigue evaluation of bridges.

The objective of this research is to develop practical procedures that more accurately reflect the actual fatigue conditions in steel bridges, and that can be applied for fatigue evaluation of existing or new bridges. Specifically, the procedures shall permit determination of fatigue-load ratings and estimation of remaining life for existing bridges, shall be suitable for incorporation into AASHTO's Manual for Maintenance Inspection of Bridges and possibly for future bridge design specifications.

It is anticipated that the research will include at least the following tasks:

1. Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of designers and owners of steel bridges.
2. Analyze and evaluate the information generated in Task 1 to establish a rationale for the development of procedures for fatigue evaluation of steel bridges.
3. Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 12 months after the initiation of the study. The interim report shall outline the framework of the procedures to be developed under Task 4 and shall include examples illustrating the application of the proposed procedures. The report shall also include comparisons between results produced by existing and proposed methods. NCHRP approval of the interim report will be required before commencing Task 4.
4. Develop detailed procedures in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended procedures shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate the understanding and use of the procedures.
5. Prepare a final report.

Through December 31, 1985, research is progressing on schedule for the first two tasks.

Project 12-28(4) FY '85

Methods of Strengthening Existing Highway Bridges

Research Agency: Iowa State University
Principal Invest.: Dr. F. Wayne Klaiber
Effective Date: July 1, 1985
Completion Date: December 31, 1986
Funds: $149,986

About one-half of the approximately 600,000 highway bridges in the United States were built before 1940, and many have not been adequately maintained. Most of these bridges were designed for lower traffic volumes, smaller vehicles, slower speeds, and lighter loads than are common today. In addition, deterioration caused by environmental factors is a growing problem. According to the Federal Highway Administration (FHWA), almost 40 percent of the nation's bridges are classified as deficient and in need of rehabilitation or replacement. Many of these bridges are deficient because their load carrying capacity is inadequate to carry today's traffic. Strengthening can often be used as a cost-effective alternative to replacement or posting.

Many different methods are available for increasing the live-load capacity of various types of bridges such as: (1) adding members, (2) adding supports, (3) reducing dead load, (4) providing continuity, (5) providing composite action, (6) applying external post-tensioning, (7) increasing the cross section, (8) modifying load paths, and (9) adding lateral supports or stiffeners. Some methods have been widely used, but others are new and have not been fully developed. There is a need to compile, evaluate, and improve existing methods as well as to develop new procedures, equipment, and materials for increasing or restoring the load carrying capacity of existing bridges.

The work for this project will be accomplished in two phases. Phase I is described in this project write-up and includes preparation of the plan for Phase II as required by Task 5. The objectives of Phase I are to evaluate the feasibility and cost-effectiveness of present strengthening methods as applied to various types of bridges and to identify cost-effective innovative methods. Phase I objectives will require completion of the following tasks:

Task 1—Through review of available literature and contact with appropriate organizations, identify, describe, and categorize methods for strengthening existing highway bridges. New and innovative ideas as well as established methods shall be considered.

Task 2—Determine the types of structures which show the most need or broad cost-effective application of techniques for strengthening.

Task 3—Evaluate the cost-effectiveness of methods for strengthening bridge structures. Identify new materials and innovative techniques for further study.

Task 4—Prepare a manual for use by practicing engineers, describing the most effective techniques for strengthening existing highway bridges.

Task 5—Prepare a research plan for Phase II to improve and extend the application of current procedures and evaluate new procedures identified in Task 3. It is anticipated that Phase II will require laboratory and/or field testing and that cooperative arrangements with state highway agencies may be necessary.

Task 6—Prepare final report documenting all research. The Task 4 manual and Task 5 research plan shall be independent documents appended to the final report.

Work on Tasks 1, 2, and 3 is under way. Existing literature has been reviewed and analyzed, returns from an extensive survey are being examined, and criteria to evaluate cost-effectiveness in applying various techniques are under development.

Project 12-28(5) FY '85

Standard Methodology for Conducting Condition Surveys of Concrete Bridge Components

Research Agency: New Mexico State University
Principal Invest.: Dr. John Minor
Effective Date: August 1, 1985
Completion Date: January 31, 1987
Funds: $98,338

Although concrete structures have generally demonstrated good resistance to loss of load capacity and have only rarely been removed from service for this reason, determinations of bridge load capacities are often necessary to fully evaluate the effects of deterioration. Currently, work is progressing to develop methods to permit more accurate load capacity analysis; however, inspection and reporting methods need to be enhanced or refined and then standardized to help support this work.

In addition, more than one level of inspection should be available for structures with more severe damage. The current, federally mandated biennial inspections are expected to be adequate for the majority of structures; however, refinements and additional guidance would improve the uniformity of inspection and reporting. Structures where the initial inspection and available data indicate a reduced load capacity also should be reinspected using procedures that provide a higher level and quality of data of the structure's properties.

A research project is needed that will provide a standard framework for surveying and reporting the condition of reinforced and prestressed concrete structures. The framework must include more than one inspection level to improve the reliability of data when conditions warrant.

The objective of this research is to prepare a manual for conducting inspections of reinforced and prestressed concrete bridges to assess their condition and obtain material and cross-sectional properties needed to determine load ratings. The manual shall provide guidance to enable field inspectors to recognize various types of distress and to assess their significance on capacity. Techniques shall also be included to evaluate the strength and other physical properties of component materials. The manual shall describe the techniques used in routine biennial inspections, and the nondestructive and destructive testing techniques required to obtain more detailed information.

Accomplishment of the project objective will require completion of, at least, the following tasks:

Task 1—Through contacts with agencies and through review of available literature, identify, describe, and categorize those inspection techniques and guidelines that have been and/or are being used as input to the development of bridge capacity. Make follow-up contacts for additional information with those agencies where the initial contacts indicated favorable opportunities for further evaluations of promising methods. It is perceived that some agencies may have already developed manuals or procedures that, in many ways, cover the requirements of this project. Thus, part of this research may involve synthesizing and refining readily available information.

Task 2—Submit a detailed, comprehensive outline of the concrete bridge inspection manual with suggested format, for review by the NCHRP.

Task 3—Prepare final report documenting entire research effort, and the concrete bridge inspection manual. The manual shall be divided into at least two parts. Part I shall describe both the procedures for enhancing the conduct of routine bieunial inspections and the techniques for making preliminary assessments of the effect of deterioration on bridge capacity. Part II shall include methods for detailed investigations, including in-situ and laboratory testing, required to provide the necessary data for analyzing bridge capacity with a high degree of accuracy. The manual shall contain specific examples using photographs, diagrams, and other illustrations for guidance in conducting inspections and evaluating defects.

Task 4—Make a presentation to the AASHTO Subcommittee on Bridges and Structures at two regional meetings summarizing the project and resulting manual.

Present research involves activity under Task 1 which is designed to locate acceptable inspection techniques and general guidelines. Information that is acceptable will then be synthesized and enhanced to develop the manual required in subsequent tasks.

Project 12-28(6) FY '85

Distortion-Induced Fatigue Cracking in Steel Bridges

Research Agency:	Lehigh University
Principal Invest.:	Dr. John W. Fisher
Effective Date:	October 1, 1985
Completion Date:	September 30, 1988
Funds:	$250,000

Forces in various steel bridge members, such as cross bracing, can cause lateral (out-of-plane) distortions in webs and gusset plates that can eventually result in fatigue cracking. Such cracking is most likely to occur if the distortions must be accommodated in a short length of the web or gusset plate, for example, in the gap between the end of a stiffener and the flange. In fact, most of the fatigue cracks that have been observed in existing bridges have resulted from this cause. The distortions that contribute to this type of fatigue cracking are not calculated in normal design and rating procedures. Therefore, the usual AASHTO fatigue provisions can not be applied to this type of cracking. Instead, existing or proposed bridge designs must be systematically reviewed to identify and evaluate potential fatigue problems that might result from out-of-plane distortions. Although some preliminary guidelines have been developed (AISC Bridge Fatigue Guide—Design and Details) to assist in this type of review, more comprehensive guidelines and more detailed criteria are needed.

The objectives of this research are: (1) to categorize the kinds of fatigue cracks that have occurred because of out-of-plane distortions; (2) to develop comprehensive guidelines, including quantitative criteria, if possible, that define the conditions that are likely to cause fatigue cracking related to out-of-plaue distortions; and (3) to evaluate possible retrofitting techniques, such as drilling holes at the ends of the cracks, modifying attachment details to minimize lateral distortions, and increasing the gap between restraints. Laboratory fatigue tests of selected details that appear to be particularly susceptible to this type of fatigue cracking will be needed to accomplish these objectives. This testing should be correlated with an FHWA Regional Pooled Funds Study to be conducted at the University of Missouri and also with relevant present and planned field studies on actual bridges.

NCHRP Project 12-28(6) is intended to dove-tail with the Penn DOT-sponsored HP&R study entitled, "The Causes of Deformation Induced Cracking in Steel Bridges and Methods to Retrofit the Damage." The two studies are expected to be carried out concurrently and the research plans must be complementary. It is intended that the final report on NCHRP Project 12-28(6) should be self-sufficient.

By way of expanding on the scope of the Penn DOT-sponsored study, the following items will be considered under NCHRP Project 12-28(6).

- Fatigue cracking caused by live load-induced secondary stresses, both in-plane and out-of-plane.
- Common structural details not frequently encountered in Pennsylvania and, therefore, not included in the Penn DOT research.
- Structural details in multi-stringer bridges.
- Interaction between roadway-support stringers and underlying main structural members.
- Design guidelines for structural details that are less susceptible to distortion-induced fatigue cracking (e.g., NY DOT details for connection plates at cross frames).
- Guidance on retrofit and repair for use on a nationwide basis.

Project 12-28(7) FY '86

Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges

Research Agency:	Modjeski and Masters
Principal Invest.:	Dr. J. M. Kulicki
Effective Date:	33 months
Completion Date:	
Funds:	$300,000

Engineers normally assess the detrimental effects of corrosion on steel bridge components in terms of the increased static and fatigue stresses caused by the reduction in cross-sectional area of the components. Limited studies have shown that stress concentrations caused by corrosion in steel bridge members can resnlt in fatigue behavior equivalent to AASHTO Category E details or worse. However, corrosion can produce other severe effects such as (1) the "freezing" of pinned joints causing unintended bending moments; (2) the freezing of bearings causing unanticipated forces in piers, abutments, and bridge members; and (3) the build up of corrosion products causing local forces and distortions usually perpendicular to the plane of a plate element. Some of these detrimental effects are produced by nonuniform patterns of corrosion. Guidelines do not exist for bridge engineers to adequately identify and evaluate these effects of corrosion on critical details of steel bridges.

The objective of this research is to develop practical guidelines that can be used to assess the effects of corrosion on structural details in steel highway bridges. The guidelines shall apply to all of the steps involved in evaluating the effects of corrosion on the performance of existing bridges, and shall be suitable for incorporation into AASHTO's Manual for Maintenance Inspection of Bridges.

It is anticipated that the research will include at least the following tasks:

Task 1—Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of bridge engineers, consultants, and owners of steel bridges.

Task 2—Analyze and use the information generated in Task 1 to establish a framework for the development of procedures to evaluate corrosion effects in steel bridges.

Task 3—Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 8 months after the initiation of the study. The interim report shall contain a detailed research plan for Task 4 and a framework for the guidelines to be developed under Task 5. It shall also include examples illustrating application of the anticipated guidelines.

Task 4—Conduct laboratory tests, field investigations, and analytical studies in accordance with the detailed plan presented in the interim report. The purpose of this task is to provide insight for use in developing guidelines for evaluating the effects of corrosion on the structural behavior of steel bridges.

Task 5—Develop the detailed guidelines in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended guidelines shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate understanding and use of the guidelines.

Task 6—Prepare and submit a final report containing the research findings and proposed guidelines. Further research necessary for understanding the causes of the corrosion process on steel bridges and improving the ability to evaluate their effects should be identified and prioritized along with estimated costs.

Project 12-28(8) FY '86

Improving Bridge Load Capacity Estimates by Correlation with Test Data

Research Agency:	University of Tennessee, Transportation Center
Principal Invest.:	Dr. E. G. Burdette, Dr. D. W. Goodpasture
Effective Date:	24 months
Completion Date:	
Funds:	$199,994

A great deal of knowledge has been gained by physical testing of bridges and their components, much of it indicating that bridges resist loads in ways not always considered. Some causes of these differences in behavior are: unintended composite action, load distribution effects, participation of elements such as parapets and railings, two-way slab action where only one-way was assumed, participation of the floor system with chords of trusses, the difference between actual and assumed material properties, participation of bracing and secondary members, effectiveness of shear keys, confinement, support characteristics, and unintended continuity.

More realistic modeling of this behavior in existing structures will make it possible to better evaluate load capacity. With such refinements, more bridges will continue in service and provide adequate load capacity with or without modifications and repairs.

The objective of this research is to assemble domestic and foreign test data to identify, quantify, and report significant aspects of observed behavior that are not now considered in load capacity estimates.

The research will include the following tasks:

Task 1—Assemble and review relevant tests, research findings, experiences, and performance data, both published and unpublished. As a minimum the following types of bridges will be considered: (a) slab bridges; (b) beams and slab bridges, including concrete or timber decks on concrete, steel, or timber stringers; (c) T-beam

bridges; (d) multiple-box concrete bridges; (e) prestressed girders with composite slabs; (f) deck and pony trusses; (g) through trusses; and (h) rigid frames. Both simple and continuous spans, skewed and nonskewed alignments will be considered where appropriate.

Emphasis will be placed on structures that exist in large numbers for which more appropriate models of behavior will produce significant economic benefits.

Task 2—Determine which aspects of behavior demonstrated by the results of Task 1 can produce significant variations in load capacity with respect to that indicated by current load capacity estimates.

Task 3—The results of Tasks 1 and 2 will be reported to the NCHRP panel, in an interim report, for review and comments.

Task 4—Determine the assumptions that are appropriate for the analysis of various types of bridges and suggest their limitations. Indicate at what load levels these assumptions are valid. Identify areas where behavior has not been adequately investigated to permit application of the results.

Task 5—Prepare a final report.

Project 12-28(9) FY '86

Methods of Flaw Detection in Concrete Bridge Components

Research Agency:
Principal Invest.:
Effective Date:
Completion Date: Temporarily Deferred
Funds:

This project has been deferred because of overlap with another FY '86 NCHRP project, Project 10-30, "Nondestructive Methods for Field Inspection of Embedded or Encased High Strength Steel Rods and Cables." Once the initial phase of NCHRP Project 10-30 is completed, the resources available to NCHRP Project 12-28(9) will be used to assist in the completion of Project 10-30.

Project 12-28(10) FY '86

Guidelines for Determining Redundancy in Steel Bridges

Research Agency: Lehigh University
Principal Invest.: Dr. J. Hartley Daniels
Effective Date:
Completion Date: 30 months
Funds: $300,000

Redundancy in a bridge has been generally defined as the absence of critical components whose failure would cause collapse of the structure. To minimize the risk of collapse, fracture-critical members (FCMs) in existing bridges generally require more frequent and thorough inspections than other members, and, in new bridges, special design, fabrication, and material requirements apply to FCMs. However, there are considerable differences of opinion about which types of steel bridges can be safely classified as redundant.

Current AASHTO specifications define an FCM as a nonredundant tension member or other component whose failure would be expected to cause collapse of the bridge because a suitable alternative load path is not present. Nevertheless, specific criteria are not available to adequately define redundancy. Experience suggests that many bridge types have viable alternative load paths that are not easily identified. For example, longitudinal continuity, bracing, floor systems, and certain other structural conditions might have significant effects. Other considerations include the effects of failure of various individual components of built-up riveted girders and possible Vierendeel action due to partial joint fixity when diagonal members fracture in truss bridges.

Therefore, engineers need a better understanding of alternative load paths and specific criteria for redundancy. Furthermore, a classification of various types of steel bridges by degree of redundancy would be very useful in establishing bridge inspection and replacement priorities as well as in design of safe and economical bridges for new construction.

The objectives of this research are: (1) to develop a better understanding and definition of redundancy in various types of steel bridges; (2) to establish specific criteria for redundancy in such bridges, and (3) to develop guidelines for establishing redundancy classifications for various types of steel bridges.

The research will include the following tasks:

Task 1—Review relevant current domestic and foreign practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of bridge engineers and owners of steel bridges. Emphasis shall be placed on the performance of steel bridges in which failures of FCMs were observed.

Task 2—Analyze and evaluate the information generated in Task 1 and establish a general definition of redundancy in steel bridges. Consideration shall be given to load levels. New and innovative ideas as well as established practice shall be considered.

Task 3—Using the definition adopted in Task 2, develop a methodology for applying specific criteria for redundancy to various types of steel bridges.

Task 4—Present the findings of Tasks 1, 2, and 3 in an interim report to be submitted not later than 12 months after the initiation of the study. The interim report shall contain a detailed, updated working plan for Task 5 and shall describe the framework for the guidelines to be developed under Task 6. The report shall include examples illustrating the application of the methodology developed in Task 3 and comparisons between results

produced by existing and proposed methods. NCHRP approval of the interim report will be required before commencing the remaining tasks.

Task 5—Verify the methodology developed in Task 3 for selected types of steel bridges such as two-girder, simple- and continuous-span bridges, and other types of bridges that would be classified as nonredundant by the present AASHTO criteria. Implementation of this task may include analytical and experimental methods.

Task 6—Develop guidelines for establishing redundancy classifications for various types of steel bridges. These guidelines should be particularly useful in establishing bridge inspection and replacement priorities as well as in the design of safe and economical bridges for new construction. The recommended guidelines shall be in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. These guidelines shall be accompanied by a detailed commentary and examples of specific applications intended to facilitate the understanding and use of the methodology.

Task 7—Prepare a final report.

Project 12-29 FY '85

Design of Simple-Span Precast Prestressed Bridge Girders Made Continuous

Research Agency:	Construction Technology Corporation
Principal Invest.:	R. G. Oesterle
Effective Date:	August 26, 1985
Completion Date:	November 25, 1987
Funds:	$241,993

The design and construction of bridges composed of simple-span, pre-tensioned girders made continuous for composite dead loads and for live loads has become widespread. In general, the design of these structures has been based on the procedure outlined in "Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders," published by the Portland Cement Association in 1969. Although existing bridges designed by this procedure are generally performing well, it is believed that this method may not accurately predict the true behavior of these structures in light of new knowledge regarding material properties and behavior, new methods of analysis, and expansion of this concept to longer spans and wider girder spacings.

One of the major uncertainties in the design of these structures is the prediction of the positive and negative moments at the cast-in-place connections at the piers. This uncertainty is due to the different loading and construction stages, time-dependent effects, and the details used to make the connections. Because of these uncertainties and the lack of guidance in the AASHTO specification, widespread differences exist in applying the results of the PCA procedure for selecting the actual continuity moments used for the connections at the piers. Research is needed to resolve these uncertainties and to develop guidelines for more rational design and to take advantage of opportunities for more economical construction.

The objectives of this research are: (1) to investigate the behavior of precast prestressed bridge girders made continuous by connections using cast-in-place slabs and diaphragms at the piers, and (2) to develop design procedures and guide specifications that can be used to compute elastic, inelastic, time-dependent, and ultimate moments commensurate with the degree of continuity developed by the connections at the piers.

The research will include the following tasks:

Task 1—Review relevant current practice, performance data, and research findings. This information shall be assembled from both technical literature and unpublished experiences of designers and owners of structures of this type.

Task 2—Based on available information and the application of analytical techniques, develop improved procedures to determine the degree of continuity and the moments resulting from dead loads, live loads, and time-dependent effects.

Task 3—Based on available information and the application of analytical techniques, develop improved procedures to predict the inelastic redistribution of moments and the ultimate strength of the structure at all critical stages.

Task 4—Based on available information and the application of analytical techniques, develop improved procedures to determine the strength and serviceability requirements for the positive and negative moment connections at the piers, allowing for the use of either mild steel or prestressing steel for positive moment and mild steel for negative moment. The consequences of providing no positive moment connection shall also be investigated.

Task 5—The analytical portion of this study shall be verified by correlation with available experimental data that are relevant.

Task 6—Present the findings of Tasks 1 through 5 in an interim report to be submitted not later than 18 months after the initiation of the study. The interim report shall outline the framework of the specifications to be developed under Task 7 and shall include examples illustrating the application of the recommended procedures. The report shall also include comparisons between results produced by existing and proposed methods. NCHRP approval of the interim report will be required before commencing Task 7.

Task 7—Prepare detailed specifications in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended specifications shall be accompanied by a detailed commentary and selected design examples intended to facilitate their understanding and use.

Task 8—Identify areas in need of further investigation. Recommend priorities and estimate the time and costs for the additional research.

Task 9—Prepare a final report.

Through December 31, 1985, research is progressing on schedule on the first two tasks.

Project 12-30 FY '86

Fatigue of Cables in Cable-Stayed Bridges

Research Agency: Freeman Fox Ltd.
Principal Invest.: Jolyon A. Gill
Effective Date:
Completion Date: 21 months
Funds: $124,975

Cable-stayed bridges have become an advantageous and economical type of structure for medium- and long-span crossings in the United States. As of 1985, five cable-stayed bridges are in service, seven are under construction, and seven are in the design stage. The cable stays are vital components, and, because they are subjected to repeated loads, fatigue is an important design consideration. AASHTO Bridge Specifications do not include design or material requirements for cable stays; criteria and guidelines are needed. Information on fatigue design criteria for cable-stayed bridges is available in certain foreign codes, such as the German Specifications DIN-1073 and subsequent revisions. Those foreign codes presently in use, together with data available in the United States, should serve as a basis to develop design criteria and material requirements suited to American practice.

The objectives of this project are (1) to develop criteria and guidelines for fatigue design of cable stays and (2) to develop practical guidelines for material requirements and for testing wires, strands, and cable-stays.

The project will include the following tasks:

Task 1. Review performance history and data, current domestic and foreign codes of practice, and research findings. This information shall be assembled from both technical literature and unpublished experiences of designers and owners of cable-stayed bridges. Although this review shall emphasize fatigue behavior in cables of cable-stayed bridges, care should be taken to include all relevaut aspects of fatigue in other structural systems.

Task 2. Analyze and evaluate the information generated in Task 1 to establish rationales for alternative approaches to the development of design criteria and testing requirements for fatigue effects in cables. This evaluation will include consideration of the following: (1) intensity and frequency of fatigue loading; (2) number and position of lane loadings including their relationship to the number and location of stay planes; (3) multiple lane reduction factors; (4) spacing of cable stays; (5) local stresses in stay cables at saddles and anchorages; (6) assessment of fatigue strength of cables from tests on short lengths of individual wires or strands; (7) length similitude factors to relate tests of short cable specimens to full-length cables; and (8) quality control and quality assurance of wire and strand to maximize fatigue resistance.

Task 3. Present the findings of Tasks 1 and 2 in an interim report to be submitted not later than 12 months after initiation of the study. The interim report shall include design examples illustrating the alternative approaches. NCHRP approval of the interim report will be required before commencing Task 4.

Task 4. Prepare cable fatigue design provisions in a format suitable for consideration by the AASHTO Subcommittee on Bridges and Structures. The recommended provisions shall be accompanied by a commentary and design examples intended to facilitate their understanding and use.

Task 5. Prepare materials and testing requirements to supplement existing provisions in a format suitable for consideration by appropriate authorities.

Task 6. Identify additional research that is needed for further development and refinement of the recommended design criteria and materials requirements. Recommend priorities and estimate time and costs for the needed research.

Task 7. Prepare a final report.

Project 12-31 FY '86

Study of Impact Resistant Bridge Steels

Research Agency:
Principal Invest.: In Developmental Stage
Effective Date:
Completion Date:
Funds:

A survey of the variation to be expected in Charpy V-notch tests obtained from plates was conducted during 1973 and 1974 and reported by AISI. The survey was limited to three grades of steels as follows: (1) A-572—Grade 50 killed fine grain, as rolled, over ¾″ to 1-1½″; (2) A-517—Grade 70, normalized, 7/16″ to 2-½″; and (3) A-537—Class 2, quenched and tempered, 7/16″ to 2-½″. The survey of data consisted of longitudinal and transverse impact test values obtained from seven specified locations on each plate. The survey indicated that there exists a range of variability in CVN values and therefore it is prudent that users of plates that have impact testing specified familiarize themselves with the range of possible variability as well as percent of probability that CVN properties of the plates may vary from that ordered. Such variation can result in overall acceptable test values and cause inclusion of an inferior plate in bridge fabrication. Therefore, based on results of the AISI survey during the 1983 AASHTO meetings, it was recommended to reduce test temperatures for bridge steels to compensate for such possible variation. There exists no data to support the

adequacy of this recommendation. The proposed research is deemed essential to increase safety and life expectancy of bridges.

The objective of this project is to develop adequate Charpy V-notch test data to: (1) establish the limits of variation of CVN values within steel plates; (2) establish the CVN properties to insure a minimum CVN value within the plate; and (3) all common bridge steels covered in the AASHTO Bridge Specifications are to be investigated.

Project 12-32 FY '86

Evaluation of Bridge Deck Protective Strategies

Research Agency:	University of Washington
Principal Invest.:	Dr. N. M. Hawkins Mr. K. Babei
Effective Date: *Completion Date:*	36 months
Funds:	$300,000

During the 1960's and early 1970's, corrosion of steel reinforcement embedded in concrete contaminated by chloride deicing chemicals was determined to be a major cause of concrete bridge deck deterioration. As a result, various bridge deck protective strategies were developed such as epoxy-coated steel reinforcement, latex-modified concrete overlays, high density concrete overlays, interlayer membranes, and thicker concrete cover over steel reinforcement. Laboratory studies and early experience indicate that these strategies are effective in improving the performance of bridge decks. However, because of the large national investment in bridges and their importance in the efficient operation of highways, it is appropriate to examine the performance of these bridge deck protection strategies to see if original expectations are being attained and to determine whether unforeseen problems may occur.

A long-term objective of research in this problem area is to develop a guide for the design and construction of reinforced concrete bridge decks with a service life of 50 years or more. The specific objectives of this project are to (1) compile information on currently used bridge deck protective strategies, (2) evaluate the performance of bridge decks with more commonly used protective strategies, (3) identify further research needed to attain a bridge deck service life of 50 years or more, and (4) conduct the needed research.

It is anticipated that the research for Phase I will include at least the following tasks:

Task 1—Update the information in Appendix A of *NCHRP Synthesis 57*, "Durability of Concrete Bridge Decks," with regard to the use of protective strategies on *new deck construction and complete deck replacement*. The scope of this study will be limited to simple types of structures that represent the greatest number of bridges.

Task 2—Collect performance information on the following bridge deck protective strategies used independently or in combination over the past 10, or more, years: (1) epoxy-coated reinforcement, (2) high density concrete overlay, (3) latex-modified concrete overlay, (4) membranes, and (5) increased depth of cover over top reinforcement steel. Performance information may be obtained from reports, interviews, and site visits.

Task 3—Evaluate the information collected under Task 2 for any evidence that a 50-year deck life may not be attainable and that more than one protective strategy on a single deck is cost effective. Consideration should be given to such factors as: (a) adverse environments (e.g., deicers, marine environment, high temperature, freezing, wetting and drying), (b) simple versus continuous spans, (c) composite versus noncomposite spans, (d) sensitivity to construction quality, (e) monolithic versus two lift slabs, (f) deck stiffness, (g) traffic exposure, and (h) sensitivity to and compatibility with maintenance operations.

Task 4—Prepare an interim report on Tasks 1, 2, and 3, including a research plan for a detailed study of any problems identified under Task 3 and a detailed field study, as deemed appropriate, of a limited number of representative protective strategies to verify their satisfactory performance. The research plan would be for Phase II of the project and should include an estimate of time and funding consistent with the overall allocation of funds for the entire project.

Task 5—After NCHRP review, modification, and approval of the research plan developed under Task 4, conduct a detailed study of any problems identified and the proposed field studies.

Task 6—On the basis of the available information and results of the studies conducted under Task 5, prepare an assessment of the feasibility of attaining a bridge deck service life of 50 years or more.

Task 7—Prepare guidelines for the design and construction of reinforced concrete bridge decks including specification provisions suitable for consideration for adoption by AASHTO.

Task 8—Prepare a final report containing the research findings and proposed design and construction guidelines.

AREA 13: EQUIPMENT

Project 13-1 FY '65

Equipment Rental Rates

Research Agency:	Ernst & Ernst
Principal Invest.:	T. S. Dudick
Effective Date:	February 1, 1965
Completion Date:	January 31, 1966
Funds:	$22,800

This research dealt with the development of uniform methods and procedures for establishing construction

equipment rental rates. It included the establishment of the purposes for which rental rates are used; the feasibility of determining equipment rental rates by type, use, and region; a formula for equitable rental rates; and recommended procedures for obtaining and evaluating all information required for the various factors in the formula.

This research has been completed and the project report has been published as:

NCHRP Report 26, "Development of Uniform Procedures for Establishing Construction Equipment Rental Rates."

AREA 14: MAINTENANCE OF WAY AND STRUCTURES

Project 14-1 FY '65

Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: Dr. Bertram D. Tallamy
Effective Date: March 1, 1965
Completion Date: March 31, 1967
Funds: $205,128

This research involved an intensive study into typical maintenance operations on 28 Interstate test sections in several States for the purpose of satisfying the urgent need for a definitive system of determining maintenance requirements on a quantitative basis with due consideration being given to the requirements in terms of type, magnitude, and frequency. This system is applicable to Interstate highways within individual States and to comparable activities on the State highways. Attempts have been made to develop means for relating utilization of men, equipment, and material to production and maintenance operations and, further, to optimize efficiency in maintenance operations. The standards which were developed have been tested on a sample of maintenance operations on Interstate highways, and a unit maintenance cost index suitable for periodic updating was developed.

Research has been completed, and the project report has been published as:

NCHRP Report 42, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index."

Project 14-2 FY '71

Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities

Research Agency: Byrd, Tallamy, MacDonald, and Lewis
Principal Invest.: L. G. Byrd
Effective Date: October 1, 1970
Completion Date: March 31, 1973
Funds: $200,000

Highway maintenance activities often require occupancy of traffic lanes, structures, and shoulders of the roadway by men and equipment. This situation causes conflict between these activities and the traveling public, thus endangering both workmen and motorists and restricting the flow of traffic. The resulting development of hazardous situations and interference with the orderly flow of traffic is most pronounced where high-speed and/or high-denisty traffic conditions exist. There are several possible approaches to minimizing the problem and to providing a high level of safety, economy, and convenience for the highway user during required maintenance activities. At this time, utilization of techniques designed to reduce occupancy of the roadway by maintenance activities appears to offer potential for alleviation of the problem with least duplication of research efforts.

The objectives of this project were to identify and evaluate techniques that will significantly reduce the time of occupancy of the highway travel way and shoulders by maintenance forces for at least the following specific routine maintenance activities:

(a) Bridge deck repairing.
(b) Travel way patching.
(c) Crack and joint sealing.
(d) Mudjacking and subsealing.

Techniques for accomplishment of maintenance activities were intended to encompass the entire operation, including the necessary manpower, equipment, and materials. However, development of new materials or equipment was not considered to be within the scope of this study.

Research has been completed, and the project report has been published as:

NCHRP Report 161, "Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities."

Project 14-3 FY '73

Improved Pavement-Shoulder Joint Design

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. R. D. Barksdale
Effective Date: September 15, 1972
Completion Date: March 15, 1976
Funds: $100,838

The joint that results where portland cement concrete pavements and bituminous-surfaced shoulders interface has proved to be a prime contributor to pavement and shoulder distress and the need for costly maintenance. Leakage of surface water through the joint can lead to pumping, faulting at transverse joints, and shoulder cracking and settlement when in combination with other adversely contributing factors. Additionally, water

penetrating through leaky joints and reaching some kinds of base materials and subgrade soils can cause swelling and frost damage (in cold climates) with consequent pavement and shoulder damage.

Although the construction and maintenance of completely watertight pavement/shoulder joints for the life of the pavement is generally conceded to be impossible, it is believed that an effort should be made to minimize the passage of surface water throngh the joint. Therefore, some water is likely to enter throngh the joint at some time during the pavement life, and provisions should be made for subsurface drainage and/or treating the pavement layers to minimize the effects of the water. Consequently, there is need to develop reasonably adequate sealing systems for the joint and to identify suitable design and construction techniques, including snbsurface drainage, that will minimize the effects of the presence of some water.

Project objectives were accomplished with the development of a series of recommendations for pavement shoulder joint design and construction, sealant specifications, shoulder design, and underdrainage facilities intended to improve the performance of shoulders immediately adjacent to pavements. Guidelines are offered for a test program to evaluate several promising joint design and sealant systems developed by the project.

Research has been completed, and the project report has been published as:

NCHRP Report 202, "Improved Pavement-Shoulder Joint Design."

Project 14-4 FY '74

Reconditioning Heavy-Duty Freeways in Urban Areas

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Dr. William B. Ledbetter Dr. Alvin H. Meyer
Effective Date:	April 15, 1974
Completion Date:	March 24, 1976
Funds:	$99,665

In the next decade, considerable mileage of pavement on the most heavily traveled freeways in urban areas will reach a condition where structural rehabilitation will be required to keep the freeways operable. Some pavements already have reached this condition.

Today's commonly used repair methods of patching, removal and reconstruction, and the placing of thick overlays over the entire roadway are time consuming, disruptive of traffic flow due to blockage in the construction area, and generators of construction traffic for further interference. Patching rarely offers more than temporary relief. Removal for replacement has the disadvantage of wasting large quantities of existing pavement materials. Thick bituminous concrete and portland cement concrete overlays require wasteful coverage of the entire roadway although only a portion of the width may be structurally deficient. Vertical clearance requirements offer a further restraint in the use of thick overlays.

The duration and extent of interference to continuing use of the freeway facility during construction by current methods often create an impasse. Increased hazard to workmen and motorists makes timely, durable rehabilitation virtually impossible without closing or unacceptably restricting the freeway.

The over-all objective of this project was development of a new technology for reconstituting and/or replacing all or part of the pavement structure on a heavily traveled urban freeway so that the finished product has a design service life equal to or greater than that of the original pavement, including restoration of riding and nonskid characteristics. The capabilities of producing substantial lengths of new or reconstituted pavement during off-peak hours, minimal interference with traffic during construction, and full reopening during the hours of maximum traffic flow were required characteristics. The methods and procedures were evaluated in terms of economic feasibility for the rehabilitation of substantial segments of urban expressways. Lowest first cost per unit of repair or replacement is not a necessary limitation.

Research has been completed, and the project report has been published as:

NCHRP Report 196, "Reconditioning Hcavy-Duty Freeways in Urban Areas."

Project 14-5 FY '78

Maintenance Level-of-Service Guidelines

Research Agency:	Woodward-Clyde Consultants, Inc.
Principal Invest.:	Ram B. Kulkarni
Effective Date:	January 1, 1978
Completion Date:	April 30, 1980
Funds:	$204,200

A given road or system of roads provides varying levels of service to the road user. Maintenance levels of service influence the magnitude of the maintenance work (e.g., pavement patching, mowing, paint striping) and, therefore, the work scheduling requirements, work priorities, and resource allocations. Selection of a maintenance level of service is influenced by a number of considerations that inclnde safety, rideability, economics, environmental impact protection of investment, and aesthetics. To optimize the expenditure of maintenance resources, there has been a need to develop a systematic and objective method to establish maintenance levels of service guidelines for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, strncture, drainage ditches). Such a method, based on decision analysis theory, was successfully developed and demonstrated in two states for pavement edge drop-off and vegetation control. Users of the method find it useful in the following ways:

1. The method assists in determining a set of levels of service that maximizes highway user benefits subject to the constraints of available resources (dollars, personnel, etc.). This will assure the most efficient allocation of limited resources.

2. The method allows levels of service to be systematically adjusted for changes in available resources. The method also allows differing levels of service to be established for various road classifications.

3. The policy decisions to implement various levels of service will be defensible because the rationale can be well documented.

4. The method provides a mechanism for combining effects of alternative levels of service on multiple considerations (e.g., safety, user comfort, protection of investment, and aesthetics) in a logical and theoretically sound manner. The procedures will allow the agency to establish acceptable tradeoffs between different considerations based on collective inputs from a group of people that may include maintenance engineers, field supervisors, legislators, and highway users.

5. The method allows the decision-maker to establish explicit levels of service that clearly communicate to field personnel when maintenance of different highway elements should be scheduled. The explicit levels of service will also permit an objective evaluation of whether the intended levels of service are, in fact, being achieved in the field.

Application of the method requires six steps described in Chapter Two of the final report. The appendixes provide documentation of the method, comprehensive evaluations of existing practice, and guidelines for citizen participation in establishing maintenance levels of service. All appendixes except Appendix A, a user's manual for the computer program, are contained in the report. A computer program package including Appendix A is available on a loan basis, or may be purchased for $6.00, plus $1.00 for postage and handling, by writing to the NCHRP, and supplying an EBCDIC 9-track tape, or equivalent, with a density of 1600 BPI.

The final report has been published as:

NCHRP Report 223, "Maintenance Levels-of-Service Guidelines".

Research has been continued as Project 14-5(2).

Project 14-5(2) FY '81

Maintenance Levels-of-Service Guidelines

Research Agency:	Woodward-Clyde Consultants
Principal Invest.:	Ram B. Kulkarni
Effective Date:	September 15, 1981
Completion Date:	August 31, 1984
Funds:	$107,950

A formal and systematic methodology was developed in Phase I of NCHRP Project 14-5 to establish maintenance levels-of-service that maximize the user benefits subject to the constraints of available resources. A computer program was prepared to assist maintenance personnel in computational aspects of the methodology.

Although the development of the methodology was completed in Phase I, a need existed for a self-sufficient user's manual to instruct maintenance personnel on the implementation of the method. Techniques of decision analysis and operations research were used in the development of the method. Most maintenance engineers are unfamiliar with such techniques. It is, therefore, important to explain how to implement various steps of the method in terms that can be easily understood by potential users who have a limited knowledge of mathematical or analytical procedures.

The primary objective of this study was to develop a user's manual that can be used by transportation agenices in establishing maintenance levels-of-service. The manual is comprehensive, i.e., it describes all the steps involved in implementing the methodology; it is self-sufficient, i.e., transportation agencies are able to use the methodology without consultant assistance; and the manual is tested, i.e, 3 state Departments of Transportation have implemented the methodology for 11 to 57 maintenance conditions. Experience with the software indicated that maintenance conditions should be limited to 25 or less. Consequently those maintenance conditions on which a very small percentage of the budget is expended should be excluded from the system.

The manual is published as NCHRP Report 273, "Manual for the Selection of Optimal Maintenance Levels of Service."

Project 14-6 FY '82

Evaluating Deferred Maintenance Strategies

Research Agency:	ARE Inc.
Principal Invest.:	Bertell C. Butler Fred N. Finn
Effective Date:	June 1, 1982
Completion Date:	December 31, 1985
Funds:	$325,000

It had been documented in many studies that the nation's pavements and bridges were deteriorating at alarming rates. In part, this was due to the practice of highway agencies deferring maintenance activities because of decreased funding. Deferred maintenance was defined as the postponement of scheduled maintenance required to attain the planned serviceability for a facility over its design life, with projected traffic volumes. The full consequences of deferring maintenance were not known. However, one

consequence was thought to be much greater costs to the highway agency to reconstruct the system. Another effect was thought to be lower serviceability levels that generate manifold, higher user costs. A consequence for bridges was thought to be the replacement of bridge decks, with ensuing, extensive interruptions to traffic. Timely maintenance was thought to prolong pavement and bridge life, with resulting lower life cycle costs to the road agency and road user. A need existed to describe and quantify the trade-offs between deferred maintenance and the consequent agency and user costs in order to plan more effective maintenance expenditures in pavement and bridge management systems.

The general objective of this study was to develop procedures, guidelines, and criteria for state highway agencies to use in determining alternative maintenance strategies (involving timing and practice) for highway facilities. The results should have application by highway agencies to (1) budget preparation and financial planning, (2) legislative discussions and discussions with local governments, (3) maintenance work program preparation and use in maintenance management systems, and (4) work prioritization and assignment.

Research was completed. To the extent that the effectiveness of various maintenance treatments are known, maintenance managers have a powerful tool to assess the economic consequences of deferring pavement maintenance. Research on the consequences of deferring bridge maintenance was only partially successful. Use of the results awaits further research and consensus on what are the bridge-maintainable elements and the effectiveness of various maintenance treatments.

For rigid pavements, the highway cost-allocation models were used to develop the software program RIGID-AGENCY for application on microcompnters. AGENCY computes analyzed life-cycle pavement maintenance and rehabilitation cost for different maintenance strategies. Other programs are referred to as OCCUPY, VOC, IMPACT, and BLCCA. OCCUPY will determine the cost of delays to traffic for many different types of road closures. VOC, the acronym for vehicle operating cost, considers fuel and oil consumption, tire wear, maintenance and repair, depreciation, and emissions. IMPACT computes vehicle operating cost for the maintenance strategy, and BLCCA evaluates bridge maintenance strategies.

For flexible pavements, models developed by the World Bank have calibrated with data from the State of Nevada and used to develop FLEXIBLE-AGENCY for application on microcomputers. The other programs for costs of delay and vehicle operating costs are also appropriate for flexible pavements.

The models provide reasonable results and are recommended for trial use. Although the programs can be run without locally-derived, maintenance-performance relationships, such information would add greatly to confidence placed in the computer output results.

AREA 15: GENERAL DESIGN

Project 15-1 FY '66

Guardrail Design

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Raymond R. McHenry
Effective Date:	December 15, 1965
Completion Date:	June 14, 1966
Funds:	$19,723

Many factors are involved when the highway design engineer is faced with the decision of when to install a guardrail. The decision should be based on rational warrants for their use, and the system should be effective and compatible with these warrants. A number of agencies have conducted tests on various systems. The resulting data on design and warrants need to be evaluated in order to provide the engineer with a choice of effective systems. Phase I of the project was directed toward the search and evaluation of existing data on design and warrants, a critical analysis of past and current research, and defining additional needed research.

Research has been completed, and the project report has been published as:

NCHRP Report 36, "Highway Guardrails—A Review of Current Practice."

Project 15-1(2) FY '66 and FY '70

Guardrail Performance and Design

Research Agency:	Southwest Research Institute	
Principal Invest.:	J. D. Michie	
Effective Date:	July 1, 1967	May 1, 1970
Completion Date:	Aug. 31, 1970	Dec. 31, 1971
Funds:	$280,000	$100,000

Highway design engineers need a choice of effective guardrail systems. The considerable research already conducted on the more commonly used types (W-beam, standard cable, box beam) needed to be compared and analyzed critically for determination of further investigations necessary to refine structural details and to obtain more effective performance. A need for full-scale testing was apparent to fill in the gaps in previously concluded investigations. Accordingly, the objective of the Phase I research were: (1) to critically analyze existing data on guardrail performance and identify additional needed research; (2) to conduct additional full-scale performance tests; and (3) to evaluate performance of various guardrail systems considering vehicle response and damage as a measure of accident severity and rail repair.

The Phase I findings have been published as NCHRP Report 54, "Location, Selection, and Maintenance of

Highway Guardrails and Median Barriers," and NCHRP Report 115, "Guardrail Performance and Design." A 10-min sound film of the same title summarizes the Phase I research and is available on a loan basis from the TRB Audio-Visual Library for the cost of mailing and handling.

The Phase II work consisted of four major tasks. The first task was to repare a revision to NCHRP Report 54 that incorporates pertinent findings from the Phase I research and the findings from research conducted by others. Task 2 of the Phase II work was the preparation of a document to delineate warrants, service requirements, design criteria, and design procedures for all traffic barrier systems. For this purpose, traffic barrier systems were defined as including guardrail, median barrier, bridge rail, and energy attenuation devices. Task 3 included the formulation of new concepts for improved end treatments for longitudinal traffic barriers with some work devoted to improved transitions. Task 4 included the full-scale crash test evaluation of those promising concepts produced under Task 3.

The results of Phase II Tasks 1 and 2 have been published to NCHRP Report 118, "Location, Selection and Maintenance of Highway Traffic Barriers." The results of Phase II Tasks 3 and 4 have been published as NCHRP Report 129, "Guardrail Crash Test Evaluation—New Concepts and End Designs."

For administrative reasons, additional related research has been placed under Area 22, "Vehicle Barrier Systems." Details will be found under that heading.

Project 15-2 FY '66

Design to Control Erosion in Roadside Drainage Channels

Research Agency: University of Minnesota
Principal Invest.: Dr. Alvin G. Anderson
Effective Date: July 1, 1966
Completion Date: June 30, 1974
Funds: $97,300

The highway drainage engineer is required to provide designs to control erosion in roadside drainage channels over a wide range of conditions. Acceptable procedures have been developed for the design of channels for conditions where easily established grass cover will suffice and for conditions where paved linings are required. The objectives of this study were to establish criteria and extend existing procedures for conditions intermediate between these two. The major emphasis of the research will be placed on developing a procedure for the design of armored channels with investigations into the critical tractive force of gravel and crushed stone.

Research has been completed, and the project report covering development of design procedures for armored channels has been published as:

NCHRP Report 108, "Tentative Design Proceduure for Riprap-Lined Channels."

During an extension of the project, a limited field-evaluation of the tentative design procedure was undertaken. The performance of four channels, designed and built in accordance with the procedures, was observed. Two of the four channels have been subjected to discharges approaching the design discharge and appear to be stable after the floods.

The agency's final report for this latter phase was not published in the NCHRP report series; however, a copy of the report, "Tentative Design Procedure for Riprap-Lined Channels," may be purchased for $4.00 (see final page of this section for ordering information).

Project 15-3 FY '68

Rational Structural Analysis and Design of Pipe Culverts

Research Agency: Northwestern University
Principal Invest.: Dr. R. J. Krizek
Dr. R. A. Parmelee
Effective Date: October 1, 1967
Completion Date: December 31, 1968
Funds: $49,937

Various methods are currently being used in the design of pipe culverts, and considerable research is in progress that examines these methods. There is a general lack of agreement between theory and field experience. Current methods being used in design of culverts fail to reflect in a rational way many of the major aspects of behavior observed in the field.

The objective of this study was to evaluate previous research and current practice for the purpose of developing rational design methods for both rigid and flexible pipe culverts.

Research has been completed, and a project report has been received containing an extensive bibliography and synthesis of current knowledge on the design and installation of pipe culverts. It is apparent that information is not available at this time to develop a completely rational structural design procedure, due largely to lack of a generally accepted definition of pipe failure. However, several specific factors, such as installation practices, construction techniques, soil type, and safety factor, can be given greater consideration in design criteria.

The project report has been published as:

NCHRP Report 116, "Structural Analysis and Design of Pipe Culverts."

Project 15-4 FY '68

Estimating Runoff Rates from Small Rural Watersheds

Research Agency: The Travelers Research Center
Principal Invest.: Dr. Paul Bock
Isadore Enger
Effective Date: September 1, 1967
Completion Date: March 16, 1970
Funds: $299,902

A basic problem in designing highway bridges and culverts for stream crossings is the determination of the flow to be accommodated. This involves estimating the magnitude of peak flows at various frequencies for the drainage area under consideration. Most small rural watersheds are ungaged; thus, the engineer is required to estimate the design flow for these areas on the basis of limited topographic and climatic data.

Many State highway departments and other agencies are participating with the U.S. Geological Survey in programs to collect runoff information from small rural watersheds that is intended to provide a better understanding of the generation of runoff. With this background, it appeared possible to develop improved procedures for estimating the magnitude and frequency of peak flows for small rural watersheds (approximately 20 sq mi or less). The objective of this project was to develop such procedures that (1) require only data readily obtainable by designers, (2) use parameters that are logically justified, (3) take cognizance of differences due to geographic characteristics, and (4) present the results in readily usable form.

The objectives have been partially met in that methods for estimating the magnitude and frequency of runoff from small rural ungaged watersheds have been developed. The question of whether they provide better estimates of runoff than currently used methods for a given watershed is not easily answered. Indications are that they may provide better estimates in some cases. Of probably greater significance is the compilation of information for 493 rural watersheds with an area of 25 square miles or less and at least 12 years of surface runoff data that can be used by others to develop better methods of prediction for a particular locality.

The research has been completed, and the project report has been published as:

NCHRP Report 136, "Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds."

Project 15-5 FY '68

Dynamic Characteristics of Heavy Highway Vehicles

Research Agency: General Motors Corporation
Principal Invest.: D. E. Pollack
Effective Date: August 15, 1967
Completion Date: January 10, 1969
Funds: $135,000

The dynamic loading of bridges and pavements by heavy highway vehicles influences the life expectancy of these highway structures by an unknown amount. Increasing permissible vehicle loads and speeds may increase the dynamic loading and shorten the life of these structures.

Dynamic pavement loading is influenced by the pavement roughness characteristics and by certain characteristics of the vehicle. It is necessary to consider these factors in order to predict the loads that will be produced.

With the foregoing in mind, information was gathered on those vehicles characteristics that make a significant contribution to the dynamic forces. Equipment for measuring these characteristics was constructed, and the characteristics of representative types of heavy vehicles were determined.

The research has been completed, and the final report has been published as:

NCHRP Report 105, "Dynamic Pavement Loads of Heavy Highway Vehicles."

15-6 FY '68

Development of Criteria for Safer Luminaire Supports

Research Agency: Texas A & M University
Research Foundation
Principal Invest.: Dr. T. C. Edwards
Effective Date: September 1, 1967
Completion Date: August 31, 1968
Funds: $147,254

Conventional luminaire support poles are, of necessity, mounted close to the traveled roadway. In these locations, they constitute a severe roadside hazard and are frequently struck by vehicles that are out of control, with attendant severe vehicle damage and injury or death to occupants.

The purpose of this study was the development of luminaire support design criteria to minimize the hazard described. Consideration was given to the hazard presented to both the striking vehicle and to nearby traffic.

Five classifications of safety devices for luminaire supports, as presently being specified by state highway departments or industry, were investigated. These are: (1) frangible bases for use with aluminum or steel shafts, (2) the progressive failure-shear base, (3) a stainless-steel shaft with integral transition base, (4) an aluminum shaft on a cast-aluminum shoe base, (5) the multidirectional slip base.

The research has been completed, and the final report has been published as:

NCHRP Report 77, "Development of Design Criteria for Safer Luminaire Supports."

A 20-minute film, "Lights Out," is available on a loan

basis from the TRB Audio-Visual Library (see final page of this section for ordering information).

Project 15-7 FY '80

Flow Modifications by Storage Loss Through Flood Plain Encroachment

Research Agency: Dames & Moore:
Principal Invest.: Dr. Donald L. Chery, Jr.
Effective Date: May 1, 1980
Completion Date: January 31, 1982
Funds: $99,730

With the continuing redndion of undeveloped land, highways and other developments often encroach on the flood plains of rivers and streams. The loss of floodwater storage space occasioned by the highway encroachment may contribute to changes in discharge and water-surface elevations for varions floods. These changed conditions may influence flood behavior within an affected reach of the river or stream. Current environmental impact statements require an assessment of such loss of flood-plain storage and the associated changes in flow patterns for various design floods. Various flood-routing procedures are available for assessing the changes in water-surface elevation upstream and downstream due to encroachments on the flood plain; however, they are detailed, costly, and time consuming. There is a need for simple procedures, or means to short-cut complicated procedures, so that they are reasonable, reliable, and easily applied by engineers and technicians. Further, there is a need for the derived procedures to apply to both large and small watersheds.

The objective of this project was to provide simple and reliable procednres to compute the changes in flow and water surfaces affected by encroachments on flood plains. Hydrologic information outside the affected reach, such as input hydrographs and inflows, was assumed to be available to the user. The products of this investigation were intended for use in general assessment and preliminary planning rather than for detailed design.

Research is complete. The agency has submitted a final report with an appended user's manual. Both reports are available on a loan basis or microfiche of the report may be purchased (see final page of this section for ordering information).

Project 15-8 FY '82

Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics

Research Agency: University of Michigan Transportation Research Institute
Principal Invest.: Dr. Paul L. Olson
Effective Date: May 1, 1982
Completion Date: May 31, 1984
Funds: $274,970

Sight distance is one of the basic criteria in highway design. It not only determines safe stopping and passing distances, but also has a pronounced effect on the required lengths of horizontal and vertical curves. Significant changes have taken place in the driver and vehicle parameters on which sight distance is based. Because sight distance is a major factor in the cost and safety aspects of highway geometric design as well as traffic operations, there is a need to evaluate the importance of all significant parameters related to current roadway, vehicle, and driver characteristics. There is also a need to update vehicle performance data related to acceleration and deceleration rates; the cnrrent highway design criteria are based on vehicle fleet characteristics over 10 years old.

The primary objective of this research was to evaluate those parameters affecting stopping sight distance including: (1) perception and reaction time; (2) driver eye height; (3) height of an object in the roadway; and (4) braking distance as affected by tire performance, brake system performance, pavement skid resistance, and grades. A second objective of this research was to update vehicle acceleration and deceleration rates to be representative of the current vehicle fleet.

Design values for driver height of eye and height of object on the roadway were determined. Criteria contained in the draft report from NCHRP Project 20-7, Task 14, "A Policy on Geometric Design of Highways and Streets," were evaluated in view of changes in vehicle mix and driving population. The sensitivity (i.e., effect on stopping sight distance) of incremental changes in each parameter was determined over a range of design speeds.

Recommendatious for driver perception time related to a hazardous object in the roadway and for reaction time were developed. The research considered: (1) contrast between the object and its background; (2) driver expectancy—e.g., urban vs. rural conditions and land use type; and (3) driving population characteristics including age, vision, driving experience, and the like. Field and laboratory tests were conducted to supplement existing information.

The specific performance characteristics of tires and brakes for the current vehicle fleet, including autos and trucks (loaded and unloaded), were determined. Effects of changes in vehicle mix, tread and brake wear, pavement skid resistance, and grades on stopping sight distances were also considered.

In addition, acceleration and deceleration characteristics for the current vehicle fleet were determined. This phase of the research was limited to a literature review and an evaluation of the results of the braking distance study described above.

The final report has been published as:

NCHRP Report 270, "Parameters Affecting Stopping Sight Distance."

Project 15-9 FY '85

Encasement of Pipelines Through Highway Roadbeds

Research Agency:	Byrd, Tallamy, MacDonald, and Lewis
Principal Invest.:	R. A. Koenig, Jr.
Effective Date:	12 months
Completion Date:	
Funds:	$30,000

Many states and railroads, to varying degrees, require the encasement of pipelines through their roadbeds. This policy is predicated on the premises that the pipeliue is protected from the associated loading, that the pipeline can be removed and reinstalled from the casing in the event of failure, and that liquids would be discharged out the ends of the casing in the event of rupture, thereby protecting the integrity of the roadbeds. The pipeline owners contend that the pipe designs and strengths available today can accept loadings without casing, that welds on road crossings are x-rayed, that the casing may interfere with cathodic protection systems, and that casing installation/maintenance is costly and unnecessary. Existing policies are extremely varied in that requirements for casing may be based on soil type, method of installation, products being transported, and/or operating pressures of the system. In many cases the validity of current policy is unknown leading to excessive or insufficient protection as the case may be. A study under NCHRP 20-7, Task 22 entitled "Encasement of Pipelines Through Highway Roadbeds," completed a review of the present state of the art of pipeline encasement on a national basis. Research findings show that states have developed and maintained their own utility accommodation policy within AASHTO policy and Federal Pipeline Safety Regulations. Pipeline operators, utility companies, and railroads have developed their own guidelines and policies; however, no comprehensive national standards exist for the encasements or for conditions warranting encasement or nonencasement. The study concluded that each crossing should be evaluated as to its uniqueness and that all methods available to provide protection, including use of casing pipes, should be considered. The study also concluded that research is needed to compile failure and maintenance rates for both transmission and distribution pipelines of all types and an evaluation of the effect of such failures and highway facilities so that a more quantitative assessment of the need and effectiveness of pipeline protection can be made. Accordingly, this research is intended to update present criteria and/or develop new criteria for encasements or equivalent alternates and to develop guidelines for encasement or nonencasement.

Project 15-10 FY '85

Development of a Design/Graphics Interface System

Research Agency:	C.W. Beilfuss & Associates, Inc.
Principal Invest.:	Charles W. Beilfuss
	Roy R. Guess
Effective Date:	August 1, 1985
Completion Date:	July 31, 1988
Funds:	$500,000

Transportation organizations are currently faced with the problem of handling an accelerated design workload caused in part by the recent increase in federal funding levels to upgrade the nation's transportation network. Most of these organizations use computer-aided design systems, such as the Roadway Design System, COGO-ROADS, and other systems developed by individual states. These design systems, while providing productivity gains, make limited use of the latest technology available in computer-aided graphics.

A number of proprietary interactive graphics drafting systems have been developed that provide drafting productivity increases from 3:1 to 6:1. Some of the interactive roadway design systems use features from proprietary interactive graphics drafting systems. These systems have shown productivity gains to the designer on the same or higher order than those obtained in the drafting field. The interactive graphics roadway design systems use only minimal features of the drafting software. However, they must rely on expensive terminals and support computers that are required for the drafting functions, but are not necessary for design.

Consequently, there is a need to develop an interface system that will allow interactive compatibility between existing design systems and graphics systems having varying degrees of complexity and costs. Such an interface system will provide flexibility in the types of hardware and software used and at the same time provide a standardization for computerized communication within, and between, state highway departments and consultants in the design of highway facilities. This interface system will permit the designers and draftpersons to interact in much the same way traditional, manual highway design is handled.

The objective of the project is to provide a nonproprietary interface between highway facilities design systems and generally accepted graphics systems. The interface shall include all requirements to allow transfer of the highway facilities design graphics files to and from a standard graphics file that can be processed by available graphics systems. Additionally, the interface should allow for the inherent performance characteristics of the interfaced graphics devices to be used. Accomplishment of the objective requires the following tasks:

Task 1—Conduct a review of design systems in use or under development by transportation organizations that

will influence the design of the proposed interface system. The review must include the Interactive Graphics Roadway Design System (developed by Texas) and COGO-ROADS. Computer-aided drafting systems in nse shall be reviewed to establish the graphics interface requirements. Available hardware, such as microcomputers and terminals including possible combinations of microcomputers and mini or mainframe computers, must be considered to provide the basic requirements of the interface system at minimum costs. A general design of the interface system based on studies of these reviews shall be furnished NCHRP for approval. Advantage, where possible, should be taken of existing nonproprietary software that could be enhanced to provide the needed capabilities. NCHRP approval of the general design will be required before initiation of subsequent tasks.

Task 2—Develop a detailed design document of the proposed interface system incorporating any revisions resulting from the NCHRP Task 1 review. The detailed design document shall include graphics input/output system requirements, data formats, and system flow, and it shall be of sufficient detail to allow an analysis of the system structure for the design and graphics interface. An interface specification shall be described in sufficient detail to provide a basis for a state transportation agency graphics interface standard. NCHRP approval of the detailed design will be required before initiation of subsequent tasks.

Task 3—Develop, install, and successfully demonstrate the interface system on computers in two cooperating transportation organizations that have significantly different computer environments and are acceptable to the NCHRP. ANSI Standard Fortran X3.9-1978 will be the accepted program language.

Task 4—Prepare a final report documenting the interface system in conformance with all elements of FIPS-PUB-38 titled, "Guidelines for Documentation of Computer Programs and Automated Data Systems," level 4. This documentation shall include a programmer's guide, a recommended graphics interface standard for state transportation agencies, and an instruction manual for interfacing graphics systems. An outline of the final documentation shall be submitted with the Task 2 detailed design document for approval by the NCHRP.

Research under Task 1 has commenced. A general design of the interface specification is expected in early 1986.

AREA 16. ROADSIDE DEVELOPMENT

Project 16-1 FY '66

Effects of Deicing Compounds on Vegetation and Water Supplies

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. E. Blaser
Effective Date: March 1, 1966
Completion Date: April 30, 1972
Funds: $217,300

The rapidly increasing use of deicing salts to maintain roadways relatively free of ice and snow during the winter season has raised questions concerning the extent of certain detrimental effects attributed to their use. Several research projects have considered alternative (such as additives to the salts, nonchemical methods, and different compounds) to the use of sodium chloride and calcium chlorides for deicing roadways. At present, it does not appear likely that reliable and economical alternate methods will come into common use in the foreseeable future. The objectives of this study were to identify the detrimental effects of deicing salts on roadside vegetation and water supplies and to seek means for counteracting these detrimental effects.

The first phase of the study was an extensive literature review and survey of experience with regard to deicing salt use on roadways and the effects of this use on roadside vegetation, water, and wildlife. It also included identification of research needs in this problem area. This was followed by an experimental program covering the actual effects of deicing salts on specific types and species of vegetation and on soils along highways. Efforts were made to evaluate methods of counteracting certain detrimental effects.

Research has been completed, and the results of the first phase of the study have been published as:

NCHRP Report 91, "Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research."

The results of the experimental phase have been published as:

NCHRP Report 170, "Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase."

Project 16-2 FY '68

Evaluation of Research on Roadside Development

Research Agency: Western States Landscape Association
Principal Invest.: Wayne O. Earley
Effective Date: October 1, 1967
Completion Date: March 31, 1969
Funds: $100,000

The objective of this project was to review, interpret, and evaluate past and present research on roadside development, describe areas where additional or continued research is needed, and recommend procedures for resolving these needs. The study included, but was not limited to, consideration of the relationship of roadside development and (1) highway location and design; (2) vegetation (planning, establishment, and management by

plant growth zones is consideration of erosion control and roadside plantings); (3) resource conservation; (4) rest areas, scenic turnouts, and overlooks; (5) safety; and (6) right-of-way, scenic areas, and adjacent land use. Recognition was given to research under way or accomplished in legal authority, but it was not evalnated in this project.

The research has been completed, and the project report has been published as:

NCHRP Report 137, "Evaluation of Research on Roadside Development."

Project 16-3 FY '73

Erosion Control During Highway Construction

Research Agency:	Utah State University	
Principal Invest.:	Dr. Calvin G. Clyde	
	Dr. C. Earl Israelsen	
	Paul E. Packer	
Effective Date:	Nov. 1, 1973	Mar. 1, 1978
Completion Date:	June 30, 1976	Nov. 30, 1979
Funds:	$179,224	$70,776

Uncontrolled water and wind erosion resulting from constrnction activities causes significant damage to the environment. The sediment produced pollutes surface water, restricts drainage, fills reservoirs, damages adjacent land, and destroys the natural ecology of lakes and streams. Besides harming the environment, soil erosion during construction increases costs and causes extensive delays and repairs.

Research is needed to develop more effective techniques, devices, and materials to control erosion during construction activities. This need was documented in NCHRP Synthesis 18, "Erosion Control on Highway Construction."

The synthesis stndy, while focusing attention on the need for a major research effort, also uncovered a large quantity of information, often fragmented or undereval-uated, on known erosion control measures likely to have application in highway construction. Because of the existence of this information, the urgency of the problem, and research funding limitations, a logical first step in the eventual solution of the total problem was the development of recommendations for an interim set of specific guidelines for erosion control based on existing information.

Research has been completed, and project objectives have been accomplished. The Universal Soil Loss Equation was used as the basis for estimating soil loss. Existing maps that divide the country into areas of varying soil erosion potential were updated for use in application of the equation. An experimental program was planned and conducted for verifying the applicability of the equation for estimating soil loss from a construction site and for limited testing of erosion control products. An erosion control manual has been prepared for use by highway and transportation agencies and others for estimating soil loss from a specific construction site and assessing the effectiveness of erosion control procedures.

The project report has been published in 2 volnmes as:

NCHRP Report 220, "Erosion Control During Highway Construction—Research Report"; and NCHRP Report 221, "Erosion control During Highway Constrnction—Manual on Principles and Practices."

AREA 17: SAFETY

Project 17-1 FY '66

Development of Improved Methods for Reduction of Traffic Accidents

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	John W. Garrett
Effective Date:	February 1, 1966
Completion Date:	May 31, 1968
Funds:	$247,847

The objective of this research was to develop motor vehicle accident investigation procedures, records, and statistics, which will more accurately reveal accident cansation than the current accident record system. An extensive review of the state of the art revealed that the current data collection forms and procedures do not meet research requirements; few statisitcally trained personnel are employed for data analysis. Also, safety findings are assimilated slowly by the agencies responsible for the design, maintenance, and operation of the highway system. Long-term recommendations included an improved centralized accident record system in which accident data were integrated with appropriate nonaccident data. Also proposed was a multilevel accident reporting scheme providing minimum data on all accidents, intensive investigative data on a small percentage of accidents, and special study data collected for a statistical sample of accidents. Improved cooperation between operating agencies with similar objectives was regarded as essential. Short-term recommendations included increased dissemination and utilization of current safety knowledge; utilization of modern technology at all levels of the system through the initiation of continuing education seminars and a safety review board; use of trained statistical personnel and techniques for better utilization of data; and use of accurate accident location methods. Location methods were reviewed and evaluated for guidance. Demonstration studies were performed to illustrate the feasibility of the proposed system and the techniques required. The study demonstrated the use of police to gather factual data in a study where they were provided with special report forms, written instructions, special training, and equipment. Utilization of intensive accident investigation procedures and the use of both accident and nonaccident data in a study also were demonstrated.

The project has been published as:

NCHRP Report 79, "Development of Improved Methods for Reduction of Traffic Accidents."

Project 17-2 FY '72

Methods for Evaluating Highway Safety Improvements

Research Agency: Operations Research Incorporated
Principal Invest.: Harry Denning
Effective Date: January 10, 1972
Completion Date: June 20, 1972
Funds: $29,973

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for before-and-after and parallel studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do studies, a single document has not existed that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research was to provide a detailed technique in the form of guidelines from which calculations could be made that would allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

Activities prior to the contract's termination included detailed planning for the project and preparation of a detailed working plan. This research was resumed under Project 17-2A.

Project 17-2A FY '72

Methods for Evaluating Highway Safety Improvements

Research Agency: Roy Jorgensen Associates
Principal Invest.: John C. Laughland
Effective Date: February 1, 1973
Completion Date: July 31, 1974
Funds: $98,403

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for before-and-after and parallel studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do studies, a single document has not existed that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research was to provide a detailed technique in the form of guidelines from which calculations can be made that will allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

The research has been completed, and the final report has been published as:

NCHRP Report 162, "Methods for Evaluating Highway Safety Improvements."

Project 17-3 FY '78

Application of Traffic Conflicts Analysis at Intersections

Research Agency: Midwest Research Institute
Principal Invest.: Dr. William D. Glauz
Effective Date: December 15, 1977
Completion Date: October 31, 1979
Funds: $190,000

There is a need for a reliable and inexpensive tool to be used in lieu of or in addition to accident data to diagnose safety and operational deficiencies and permit evaluation of improvements within a short period of time. Traffic conflicts analysis shows promise of providing such a tool, and several highway agencies are using the techniques as part of their standard operating procedures. However, conflict definitions and sampling procedures vary significantly.

The objective of this research was to develop a procedure for collecting and using traffic conflicts data to diagnose safety and operational deficiencies and to evaluate the effectiveness of improvements at intersections. This objective was achieved through an examination of present use of traffic conflicts analysis, development of new procedures, and field testing.

The final report was published as:

NCHRP Report 219, "Application of Traffic Conflict Analysis at Intersections." Examples that illustrate the methods of data collection, data analysis, and application of the traffic conflicts technique are presented.

Project 17-4 FY '78

Evaluation of Traffic Controls for Street and Highway Work Zones

Research Agency: BioTechnology, Inc.
Principal Invest.: Dr. Hugh W. McGee
Effective Date: January 2, 1978
Completion Date: June 30, 1979
Funds: $200,000

The objective of this project was to determine the effectiveness of selected work-zone traffic control devices and to determine how these devices should be designed and used. The research was restricted to stationary work zones and did not consider moving operations.

An extensive literature review was completed covering the effectiveness of control devices, methods of use, accident experience, and driver performance measures. Present and alternative markings for barricades, cones, drums, and vertical panels were tested using a slide presentation in a laboratory study. Rail width, width and arrangement

of stripes, and color ratio were investigated. A controlled field test of various devices and layout configurations was conducted, followed by further field testing at actual construction sites. The effectiveness of the devices when used collectively was evaluated in situations similar to those depicted in the typical MUTCD layouts. The field sites included rural two-lane and rural expressway locations.

Research has been completed; the findings were combined with the results of NCHRP Project 17-4(2) and published as:

NCHRP Report 236, "Evaluation of Traffic Controls for Highway Work Zones."

Project 17-4(2) FY '80

Evaluation of Traffic Cones and Tubes for Street and Highway Work Zones

Research Agency: BioTechnology, Inc.
Principal Invest.: Dr. Richard F. Pain
Effective Date: April 23, 1980
Completion Date: September 30, 1981
Funds: $125,000

The first phase of this research (NCHRP Project 17-4) investigated the effectiveness of selected traffic channelizing devices and device markings in stimulating driver awareness of work-zone situations. Because of limited funding, Phase I did not cover the full range of device types and applications. Therefore, additional research was needed to extend the evaluation to other device types and applications and to determine the usefulness of each type under various work zone situations.

The objective of this continuation phase was to evaluate various types of cones and tubes and to determine the effects of size, spacing, reflectorization, and illumination on driver performance. The research was restricted to stationary zones and did not consider moving operations.

The current use of cones and tubes and the methods by which they are reflectorized or illuminated were reviewed. A limited survey of device manufacturers and operating agencies was conducted to determine the degree of use of each type of device and to identify the types that should be evaluated in this research.

Controlled day and night field tests of various types, sizes, spacings, and levels of reflectorization and illumination of cones and tubes were conducted. The testing was carried out at a closed site (i.e., an unopened section of the Richmond I-295 bypass) rather than at an actual construction site.

Research has been completed, and the combined findings from Projects 17-4 and 17-4(2) have been published as:

NCHRP Report 236, "Evaluation of Traffic Controls for Highway Work Zones."

Project 17-5 FY '80

Effectiveness of Clear Recovery Zones

Research Agency: Midwest Research Institute
Principal Invest.: Jerry L. Graham
Effective Date: April 1, 1980
Completion Date: April 30, 1982
Funds: $200,000

Although significant improvements have been accomplished in many areas of highway safety, the current annual statistics of 45,000 deaths, 3 million injuries, 20 million accidents, and the resulting $15 billion in accident costs are clear proof that the problem is far from solved. The safety problem is compounded by the financial situation of highway agencies; i.e., funding is not available to build all needed improvements. As a result, there is a critical need to evaluate the cost-effectiveness of the design standards that are currently in use.

If standards contain adequate flexibility, each design can be tailored to gain maximum cost-effectiveness. The total safety benefit will be increased by building each improvement in the most cost-effective way rather than attempting to use a rigid set of standards for all projects, regardless of cost.

The objective of this research was to investigate and quantify the effectiveness of clear recovery zones of differing slopes and widths in reducing the number and severity of run-off-the-road accidents. The frequency and severity of run-off-the-road accidents were compared on highways with and without clear zones. Highway sections in Missouri, Illinois, and Minnesota served as the primary data base, supplemented with data collected previously by MRI for a skid-reduction study. Highway sections compared had similar characteristics, (e.g., traffic volume and composition, functional classification, and alignment). Included in the sample were freeways and non-freeways aud both left- (including median) and right-side encroachments. Excluded from the study were low-volume roadways (less than 750 ADT), intersections, interchanges, and urban facilities.

Research has been completed. The final report, including illustrative examples describing potential applications of the clear area safety relationships in design practice, has been published as:

NCHRP Report 247, "Effectiveness of Clear Recovery Zones."

Project 17-6 FY '80 and FY '83

Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones—Phase I

Research Agency: BioTechnology, Inc.
Principol Invest.: Dr. Richard F. Pain
Effective Date: November 1, 1982
Completion Date: July 24, 1984
Funds: $100,000

Construction and maintenance work on or adjacent to the highway has been recognized as presenting special hazards both to the motorist and to workers. Most of the research to date has been directed at traffic control measures for nse in relatively long-term work zones that generally involve extensive control treatments. Service vehicles moving slowly or stopped temporarily on or adjacent to the travel lanes also present a serious driving hazard, as evidenced by the substantial number of accidents involving such equipment. However, installing and removing an elaborate traffic control layout for these situations may be more hazardous than performing the service operation with a simpler system.

Uniform and comprehensive guidelines are not available for signal lighting systems on service vehicles or for traffic control measures in short-term and moving operations. Research is needed to develop and evaluate such systems and measures that will be effective and efficient. The number of possible situations is too great to define a specific treatment for each; nonetheless, there is a need to provide information regarding the types of treatment that have been or promise to be successful for typical situations. These guidelines would be used by state and local agencies, as well as utility companies, to determine the best treatments for their specific activities.

The objective of this project is to develop guidelines for warning systems on service vehicles and for traffic control in short-term, intermittent moving, and continuously moving work zones. In addition to considering the basic traffic and safety requirements, the guidelines will also place emphasis on the operational efficiency and cost-effectiveness of each treatment.

The state of the art was determined through a literature review and a review of current practice. Existing literature was reviewed to identify currently recommended standards, actual practice, and potential improvements. The MUTCD, the FHWA utilities handbook, ITE publications, SAE Handbook, representative state and local manuals, utilities operating practices, and research reports related to vehicle signal lighting and traffic control systems were reviewed. Selected organizations were contacted to obtain more detailed information on the most promising techniques, problems with current practice, and the feasibility and desirability of developing standards.

Typical situations were identified for which service vehicle warning and traffic control systems are needed, and those situations having similar traffic control requirements were combined to reduce the number of alternative treatments to be developed. Short-term, intermittent moving, and continuous moving activities were included. Some of the variables considered included: type of facility; roadway width, number of lanes, shoulder characteristics; nrban or rural; traffic volume and speed; physical sight restriction; adverse visibility; activity period (e.g., day or night, peak or off-peak); duration of activity; length of work zones; extent of lane encroachment; lane blockage; and speed of operation.

Service vehicle warning and traffic control systems were developed for each work-type situation. For signal lighting, consideration was given to the effects of color, flash characteristics, number, size, and intensity, as well as the environment in which the vehicle is operating. Other vehicle warning devices such as arrow boards, flags, and vehicle paint schemes were also considered. The traffic control systems include the use, as appropriate, of flagmen, vehicles (e.g., barrier, shadow), and traffic control devices (e.g., signs, channelizing devices, arrow panels). Spacing and size of devices, as well as the placement and number of all elements, are included. In development of the alternatives, consideration was given to the information needs of the motorist, equipment availability, characteristics of service vehicles, cost-effectiveness, portability, traffic operations, and motorist and worker safety (including the added hazard due to the placement and removal of devices).

The above activities complete the Phase I effort. Because of staff changes at the research agency, this contract had to be terminated at this point. Phase II is being conducted under a new contract as NCHRP Project 17-6A. The research findings from both phases will be published together at the end of Project 17-6A.

Project 17-6A FY '80 aud FY '83

Service Vehicle Lighting and Traffic Control Systems for Short-Term and Moving Work Zones (Phase II)

Research Agency:	Transportation Research Corp.
Principal Invest.:	Fred R. Hanscom
Effective Date:	October 15, 1984
Completion Date:	April 15, 1986
Funds:	$225,000

Construction and maintenance work on or adjacent to the highway has been recognized as presenting special hazards both to the motorist and to workers. Most of the research to date has been directed at traffic control measures for use in relatively long-term work zones that generally involve extensive control treatments. Service vehicles moving slowly or stopped temporarily on or adjacent to the travel lanes also present a serious driving hazard, as evidenced by the substantial number of accidents involving such equipment. However, installing and removing an elaborate traffic control layout for these situations may be more hazardous than performing the service operation with a simpler system.

Uniform and comprehensive guidelines are not available for signal lighting systems on service vehicles or for traffic control measures in short-term and moving operations. Research is needed to develop and evaluate such systems and measures that will be effective and efficient. The number of possible situations is too great to define

a specific treatment for each; nonetheless, there is a need to provide information regarding the types of treatment that have been or promise to be successful for typical situations. These guidelines would be used by state and local agencies, as well as utility companies, to determine the best treatments for their specific activities.

The objective of this project is to develop guidelines for warning systems on service vehicles and for traffic control in short-term, intermittent moving, and continuously moving work zones. In addition to considering the basic traffic and safety requirements, the guidelines will also place emphasis on the operational efficiency and cost-effectiveness of each treatment.

This research consists of two phases—Project 17-6 and Project 17-6A. Please refer to the Project 17-6 description for details regarding Phase I.

In Phase II, indoor laboratory studies were condncted to evaluate and optimize the vehicle warning and traffic control systems. Closed field studies were conducted in Maryland to further test the most promising systems. Field tests will be conducted in early 1986, nnder actual highway conditions, using real or simulated work activities, in New York and Louisiana as a final validation of each system.

A final report and an operations guide will be prepared describing recommended vehicle warning and traffic control systems developed under this project. This guide will be designed to facilitate direct incorporation into state and local mannals used by service personnel in short-term and moving work zones.

Work to date has been limited to the development of a detailed study design for the lab study and the location of a suitable field site.

Project 17-7 FY '86

Guidelines for Converting STOP to YIELD Control at Intersections

Research Agency:	Bellomo-McGee, Inc.
Principal Invest.:	Dr. Hugh W. McGee
Effective Date:	42 months
Completion Date:	
Funds:	$200,000

Recent research indicates there could be large savings in fuel consumption, vehicle operating costs, motorist delay, and vehicle emissions if YIELD control were substituted for STOP control at appropriate locations. These user savings may offset increased accident costs, if there are more accidents, where intersections are converted from STOP to YIELD control. This potential for cost savings and improved operations sets the stage for possible large-scale conversions of many STOP-controlled intersections to YIELD control.

Studies of low-volume intersections have concluded that control type has no appreciable effect on accident experience. These studies indicate YIELD control is more economical than STOP control because of the redneed delay and road user costs. For higher traffic volume intersections, however, insufficient accident data have been collected to demonstrate the relative safety of STOP versus YIELD control.

The extent of noncompliance with STOP signs at certain locations also suggests that YIELD control may be more appropriate. Research has shown that a very high percentage of motorists do not comply with STOP signs where they perceive a full stop is not needed for safe entry into the intersection.

The objectives of this research are (1) to determine the accident experience when STOP-controlled intersections are converted to YIELD control, and (2) to develop guidelines for converting STOP control to YIELD control. The research will include both four-leg and T-type intersections and will cover the full range of applicable traffic volumes.

In order to meet these objectives, the following tasks will be performed:

Task 1—Determine the current traffic engineering practice and safety experience at STOP- and YIELD-controlled intersections through a review of the technical literature and contacts with State and local highway agencies. Conduct a survey of all 50 States and approximately 100 local jurisdictions providing a good geographical distribution to determine where STOP control has been converted to YIELD control and whether accident data exist. Obtain criteria for instituting such a change and the traffic and geometric characteristics of the intersections where these conversions occnrred.

Task 2—Prepare a study design to determine the safety consequences of converting STOP control to YIELD control for the full range of applicable volumes. Depending on the survey findings, the study approach may include collection and analysis of existing data and/or new field studies. The study design will include data collection, sample size, and statistical analysis requirements.

Record accidents by type (e.g., right angle, rear end, etc.) and by severity (PDO, injury, and fatal). Include a fnll range of intersection conditions (e.g., approach speeds, sight distance, number of approach lanes, etc.).

Submit an interim report on the findings of Task 1 and the study design developed in Task 2.

Task 3—Collect existing accident data and/or conduct new field stndies to carry out the approved study design.

Task 4—Analyze the accident data according to the approved study design. Relate the accident findings to intersection and operating characteristics, and provide tables and charts to effectively illustrate the results. Interpret the results to explain the meanings associated with the statistical findings.

Task 5—Obtain the results from previous studies of user costs and benefits related to STOP and YIELD control. Update these costs to current dollars. Integrate the

safety results obtained from this project and develop criteria for converting from STOP control to YIELD control. Develop improved warrants for STOP and YIELD control.

Task 6—Prepare a final report including the guidelines for converting STOP control to YIELD control and suggested wording for improved STOP and YIELD control warrants for potential inclusion in the MUTCD.

Research should be initiated in early 1986.

AREA 18: CONCRETE MATERIALS

Project 18-1 FY '68

Revibration of Retarded Concrete for Continuous Bridge Decks

Research Agency: University of Illinois
Principal Invest.: Dr. H. K. Hilsdorf
Effective Date: September 1, 1967
Completion Date: December 1, 1969
Funds: $103,895

Transverse and longitudinal cracking of continuous concrete bridge decks can be caused by changes in deflection and rotation over supports during construction in addition to the possible effect of restraint to subsidence (bleeding) afforded by the top reinforcing steel. Such cracking is of significance with respect to the development of spalling. Revibration of retarded concrete may be useful in eliminating such occurrences in continuous bridge decks placed in one operation; therefore, this research had the objectives of (1) conducting a survey to determine the extent to which either delayed vibration or revibration has been used in placing bridge deck concrete, including the purpose, conditions, and results; (2) determining by laboratory and/or field tests if transverse and longitudinal cracking can be significantly reduced by revibration after retarded concrete has been placed over the entire deck of a continuous bridge or a complete segment of several spans supported by a continuous girder system; (3) determining the effect of revibration and subsequent finishing on the durability of bridge deck surfaces exposed to deicing chemicals; and (4) determining the most effective and practical means of revibration in the field.

The research has been completed, and the final report has been published as:

NCHRP Report 106, "Revibration of Retarded Concrete for Continuous Bridge Decks."

Project 18-2 FY '73

Use of Polymers in Highway Concrete

Research Agency: Lehigh University
Principal Invest.: Dr. John A. Manson
Effective Date: October 1, 1972
Completion Date: September 30, 1975
Funds: $300,000

Deterioration of concrete bridge decks, reduction of skid resistance on concrete surfaces, unacceptable concrete wear rates, and a need for thinner and stronger concrete slabs are problems that confront every State highway department. Among the major deficiencies of some of the concrete presently used are high permeability, low strength, cracking, low wearing ability, and spalling. The mechanisms causing deterioration include frost action, differential expansion and contraction, reinforcement corrosion, chemical attack, traffic loads, and wear.

Polymer-impregnated concrete reportedly provides significant increases in strength and durability. However, present developments and techniques have not progressed to the extent that they are adequate for field use; therefore, more work in this area is required.

The over-all objective of this project was to develop the technology for the economical use of polymers to improve the serviceability of concrete in highways. The immediate goal concerned economically feasible methods for polymer impregnation of concrete bridge decks in place.

The program was conducted jointly by Lehigh University and The Pennsylvania State University.

The study included a state-of-the-art survey, laboratory development of engineering data on the penetration of candidate materials, testing of drying techniques and prototype impregnation equipment, durability studies, and experimental impregnations of two bridge decks. Final work centered on the use of methyl methacrylate and trimethylolpropane trimethacrylate (MMA/TMPTMA) as the monomer system. Two methods of drying (propane-fired infrared and propane torch units), two methods of monomer application (soaking and pressure), and two methods of polymerization (hot water and steam) were used. Polymer penetration to depths of more than 4 in. was achieved. Extreme dryness was found to be the key to deep penetration. This was obtained with temperatures of about 250 F at 4-in. depths. The first successful penetrations of a bridge deck were achieved with equipment covering areas of only a few square feet. Field equipment was enlarged and up-graded, and successful impregnations were achieved over several 36-sq ft areas on two bridge decks—one a test-track deck and the other a deck in regular service. A field manual describing the techniques that were developed and including suggested safety precautions and acceptance criteria is included in the final report.

Research has been completed, and the final report has been published as:

NCHRP Report 190, "Use of Polymers in Highway Concrete."

Project 18-2(2) FY '78

Polymer Concrete in Highway Bridge Decks

Research Agency: Lehigh University

Principal Invest.: Dr. John A. Manson
Effective Date: January 1, 1978
Completion Date: March 15, 1979
Funds: $30,000

NCHRP Project 18-2 demonstrated the feasibility of polymer impregnation of salt-contaminated, but structurally sound, bridge decks to depths sufficient to encase the upper layer of steel reinforcement (about 4 in.) as a possible means of arresting or preventing corrosion. It was concluded that additional research and development work will be needed to refine the method and to extend its applicability beyond the range of variables of the completed investigation. Polymer impregnation includes a high-temperature drying process whose effects on the durability and structural integrity of the deck concrete are not now understood. It has been noted that the process causes fine cracks to appear in the concrete, but little else is known. The authors of NCHRP Report 190 concluded that research is needed to (1) measure the extent of this problem and provide a solution if required; (2) provide additional information on the long-term effectiveness of the impregnation process in preventing or arresting corrosion: and (3) determine the economics of the use of polymer impregnation. Determination of long-term effectiveness and economics will require consideration of the relative merits of various processes for impregnation as well as other methods of prevention and repair of bridge deck corrosion problems. Research is also needed to determine whether corrosion in a contaminated deck can be controlled by sealing with a shallow polymer impregnation, or complete encapsulation of the top reinforcement is necessary.

NCHRP Report 18-2(2) was not intended to provide answers to all of these specific questions. Its objective was more general: to clarify the state of knowledge with regard to polymer concrete in bridge decks. It did not involve extensive investigations to develop new research findings but was intended to outline what is already known, what additional information is needed, and what new research needs to be undertaken. The final report provides guidance for decisions on future research in this area.

Research has been completed. Copies of the agency's report may be obtained on a loan basis upon written request to the NCHRP. A limited number of copies are available to NCHRP sponsors for permanent retention, and others may purchase microfiche of the report (see final page of this section for ordering information).

Project 18-2(3) FY '78

Long-Term Rehabilitation of Salt-Contaminated Bridge Decks

Research Agency: Lehigh University
Principal Invest.: Dr. John A. Manson
Effective Date: May 1, 1980
Completion Date: April 29, 1983
Funds: $199,900

A critical review and experimental work were conducted on methods for the rehabilitation of salt-contaminated bridge decks. Emphasis was given to improving techniques for the impregnation of concrete with poly(methyl methacrylate) and to the concept of scarification to remove the top layer of concrete, followed by impregnation with a polymer or corrosion inhibitor, and overlaying with a low-permeability concrete. Exploratory research with electrochemical removal of salt was also conducted.

Resistance to freezing and thawing and to corrosion was determined for several combinations of substrate treatment and overlay (latex-modified concrete, low-slump dense concrete, and polymer concrete) after scarification was simulated. Treatments of the concrete with methyl methacrylate consistently gave superior performance with respect to durability and corrosion resistance provided the concrete was dry prior to impregnation. Two impregnated inhibitors (calcium nitrite and a commercial rust inhibitor) and a hydrophobic silane improved corrosion resistance, but durability under freezing and thawing conditions was decreased. Sulfur gave variable or poor results. A new technique for impregnation was also developed, based on deeply grooving the concrete to facilitate drying and the impregnation process.

Research has been completed, and the final report has been published as:

NCHRP Report 257, "Long-Term Rehabilitation of Salt-Contaminated Bridge Decks." The published report contains an appendix detailing the deep grooving technique as a means to facilitate deep polymer impregnation, i.e., impregnation to a depth to include the encapsulation of the top reinforcing steel in bridge decks. An agency "Supplement to NCHRP 257" containing several additional appendixes was distributed to NCHRP sponsors only. It is available to others on a loan basis or a purchase basis for the cost of reproduction (see final page of this section for ordering information). The appendixes in the supplemental report detail the laboratory investigations and present the development and use of an economic model for comparing cost-effectiveness of various alternatives.

AREA 19: FINANCE

Project 19-1 FY '68

Budgeting for State Highway Departments

Research Agency: Ernst & Ernst
Principal Invest.: F. W. Hinck, Jr.
Effective Date: September 5, 1967
Completion Date: September 4, 1968
Funds: $45,000

Effective budgeting is interwoven with and is basic to the whole management and decision-making process. In seeking its fullest benefit, budgeting needs to be applied to all potential uses. The modern concept of the total budget process views budgeting as an integral part of planning, administration, and policy making.

Althongh budget plans of varying effectiveness now exist in the several State highway departments, there is no indication that highway administration recognizes and utilizes the budget process to its full potential.

Research is needed with the long-range objective of devising a concisely defined framework of budget systems, together with detailed documentation for implementing policies and procedures. To meet this need, the researchers analyzed the organization plans and funding arrangements controlling State highway departments. They determined in detail the prerequisites which must be satisfied and the problems requiring resolution for effective State highway budgetary systems to be instituted. Documented recommendations were developed for devising a concise universal State highway budgeting system with detailed aids for implementing appropriate policies and procedures.

Research has been completed. The project report will not be published in the regular NCHRP report series, but the essential findings from the report have been published in NCHRP Research Results Digest 20.

Project 19-2(1) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Booz • Allen & Hamilton
Principal Invest.: H. L. Wilsey
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to Project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(2) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Ernst & Ernst
Principal Invest.: F. W. Hinck, Jr.
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(3) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Roy Jorgensen & Associates
Principal Invest.: J. L. Garner
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to Project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(4) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Roy Jorgensen & Associates
Principal Invest.: Roy E. Jorgensen
J. L. Garner
Effective Date: February 1, 1969
Completion Date: November 30, 1971
Funds: $220,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

Performance budgeting represents a method by which budgeting can be an effective management tool. The de-

velopment of a performance budgeting system for highway maintenance must be based on at least the following factors: the work load; the criteria for establishment of maintenance levels; the levels of maintenance desired for various functions; resource requirements necessary to provide the selected levels of maintenance; records and reports required to serve the budget system; and procedures for management planning, evaluation, and control.

The objectives of this project were to develop a model highway maintenance performance budgeting system and to pilot test the installation of the system in a State highway department.

The objectives have been accomplished in terms of the development of a model system that can be adapted for use by a State highway department to make most effective use of available maintenance funds and to assist in the process of highway budget and management planning. Pilot installation of the model system in cooperation with the State Highway Department of Georgia indicates that implementation is feasible.

The research has been completed, and the project report has been published as:

NCHRP Report 131, "Performance Budgeting System for Highway Maintenance Management."

Project 19-3 FY '71

Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways

Research Agency: Wilbur Smith and Associates
Principal Invest.: R. E. Whiteside
Effective Date: September 15, 1970
Completion Date: June 14, 1972
Funds: $96,728

The Congress and State legislatures have the continuing responsibility for considering legislation respecting legal maximum limits of motor vehicle weights and dimensions. When laws are changed, highway designers must take into consideration the effects of the new legal limits on such things as vehicle design, vehicle use of the highways, axle configurations, road axle-weight distribution and frequency, and trucking practices. These factors, among others, affect management decisions relative to pavement design, bridge design, and highway geometric design; over-all highway maintenance policies and procedures; methods of upgrading existing highways and bridges; and budget for highway construction, betterments, and maintenance. Also affected are road-user tax incomes and highway cost allocations. However, absence of a clear definition of such things as the interrelationship between changes in the law and axle weights on the highway contributes to uncertainty and makes legislation and management decisions difficult. A further difficulty is that knowledge helpful to the making of decisions on the many factors involved is relatively scarce and widely scattered throughout the literature and the disciplines. A synthesis of the knowledge and a development of guidelines for evaluating the effects of such legislative changes are needed to make this knowledge more readily usble to State highway departments and others making decisions relative to the consequences of changes in the legal limits of vehicle weights and dimensions.

The objectives of this research were: (1) to critically review past and current research and methodologies relating to the consequences of possible changes in legal vehicle weight; (2) to evaluate methodologies and procedures identified in the review as to their reliability, adequacy, ease of application, and other attributes; (3) to assemble from existing knowledge a recommended methodology or methodologies identifying all decision points involved in reaching a conclusion regarding costs and benefits associated with changes in legal weights and dimension limits for vehicles; and (4) to recommend additional research and development as may be found necessary to fill gaps in present knowledge.

The research has been completed, and the project report has been published as:

NCHRP Report 141, "Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways."

AREA 20: SPECIAL PROJECTS

Project 20-1 FY '65, FY '66, and FY '67

Highway Reserch Information Service

Research Agency: Highway Research Board
Principal Invest.: Dr. Paul E. Irick
Effective Date: March 16, 1964
Completion Date: October 31, 1967
Funds: $455,000

The objectives of the Highway Research Information Service were: (1) to select and store input information from current and past highway research that will be of value to users of highway information, (2) to disseminate current information to users, and (3) to retrieve relevant information on request.

All storage and retrieval procedures are now operational. The service, available to anyone interested, includes abstracts of publications, new reports on research in progress, and the updating of previonsly stored reports for ongoing research.

Project 20-2 FY '66

Research Needs in Highway Transportation

Research Agency: Bertram D. Tallamy Associates
Wilbur Smith and Associates
Principal Invest.: Lloyd G. Byrd
Paul E. Conrad

Effective Date:	April 1, 1966
Completion Date:	December 31, 1967
Funds:	$98,760

This project developed a coordinated framework of needed short- and long-range research in the field of highway transportation. Major areas of needed research were identified and arranged in the general framework. Technical priorities of need and an estimate of the appropriate level of funding for each are included. The framework was designed in such a manner as to permit updating with minimal effort.

The project report gives method or concept for structuring research as developed by the research, which includes a method for assigning priorities and costs to proposed research. The methods developed under this research were applied to 900 proposed research project statements considered in the study to formulate an example research program.

The final report has been published as:

NCHRP Report 55, "Research Needs in Highway Transportation."

Project 20-3 FY '67 and FY '68

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

Research Agency:	Texas A & M University Research Foundation	
Principal Invest.:	Dr. J. A. Wattleworth Kenneth G. Courage	
Effective Date:	Dec. 15, 1966	Jan. 1, 1967
Completion Date:	Jan. 31, 1969	Dec. 31, 1968
Funds:	$394,016	$200,540*

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Practical measures for increasing operational efficiency by judicious application of traffic surveillance, communication, and control were studied for the heavily traveled corridor of the John C. Lodge Freeway in Detroit.

The initial research program included an evaluation of the effectiveness of the existing National Proving Ground surveillance, communication, and control system, and its individual components. Methods were determined for increasing the effectiveness of the freeway and surface street system, and equipment configurations were recommended to improve the system based on a cost-effectiveness study.

A technical report, "An Evaluation of Two Types of Freeway Control Systems," covering the 1967 research work was submitted and accepted. The report includes an evaluation of the initial NPG television and advisory speed and lane-control signs and a description and evaluation of the ramp-metering system. Six additional reports were prepared covering the 1967 research work.

The major work items proposed for completion in 1968 were a pilot study of a freeway-frontage road driver information system, further freeway operations studies using improved detection and refined control techniques, environmental effects studies, pilot equipment studies for traffic-responsive signal control throughout the corridor, and a preliminary design for a more extensive driver-communication system to include the surface streets within the corridor. The project report for the 1968 work, "A Freeway Corridor Surveillance, Information, and Control System," was accepted but not published. A summary of the work has been provided in the report prepared under Project 20-3C.

At the end of 1968 the research agency requested, due to extensive other research commitments, to be relieved of further work. A continuation proposal was requested from the University of Michigan. The research was continued under Project 20-3A.

Project 20-3A FY '69 and FY '70

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

Research Agency:	University of Michigan	
Principal Invest.:	Dr. Donald E. Cleveland	
Effective Date:	Nov. 20, 1968	Jan. 1, 1969
Completion Date:	May 31, 1971	Dec. 31, 1969
Funds:	$505,631	$20,000†

This project was a continuation of the 1967 and 1968 research conducted by the Texas Transportation Institute under Project 20-3.

The basic tasks and their respective components of the 1969 research work were designed to develop information required for the ultimate synthesis of a traffic surveillance, driver information, and control system capable of real-time control of traffic throughout an entire network of arterial streets and freeways. The topics included (1) detection of capacity-reducing incidents, (2) improved ramp control techniques and environmental effects, (3) pilot studies of freeway-frontage road informational system, (4) an experiment in traffic routing within the freeway corridor, and (5) observation of freeway operations. Draft reports on the topics of the 1969 research work have been accepted by the project committee.

The 1970 research had the general objective of improving the combined level-of-service on the Freeway and the supporting street network. The work was divided into

*NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.

†NCHRP funds obligated under the $70,000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.

four principal tasks, all of which were completed: (1) improvement of ramp metering and freeway corridor flow; (2) improvement of Davison-Lodge interchange operation; (3) determination of the effect of weather on freeway corridor operations; and (4) long-term motorist response to the information system.

Draft final reports on the results from the work under the tasks were accepted and are available on a loan basis upon written request to the NCHRP. They, along with the 1969 reports, have not been published, but are summarized in the report prepared under Project 20-3C.

Project 20-3B FY '70

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting

Research Agency: Patrick J. Athol
Principal Invest: Patrick J. Athol
Effective Date: July 1, 1972
Termination Date: September 27, 1974
Funds: $31,116

Because a substantial body of knowledge relative to more efficient operation of systems made up of freeways and adjacent streets has been acquired through NCHRP Projects 20-3, 20-3A, and studies under other programs, Project 20-3B was established with the following objectives:

1. Preparation of a report summarizing the main findings of freeway surveillance and control on the John C. Lodge Freeway in Detroit. The end product of this synthesis was to have been one report that summarized all historic and technical activities of the research conducted by the State of Michigan and under the NPG and NCHRP Projects 20-3 and 20-3A. The major emphasis was to be placed on reporting on usable results that have been found to be practical on the Lodge project.
2. Preparation of a report in the vein of "Getting the Most Service from Freeways," using published research reports and the experience available from past and ongoing freeway traffic operations projects.

Objective 1 was advanced only to the point of a preliminary report that was submitted to the NCHRP project panel for an acceptance review. Based on this review, extensive revisions were required. They were begun but were never completed; therefore, a revised report was never submitted. Some work was carried out toward Objective 2, but, although the original completion date had been overrun by a year, it was not substantial and never progressed to the point of a preliminary report. Still another extension was imminent; however, the contractor chose to quit without fulfilling the objectives set forth in his proposal. By mutual agreement, the project was terminated. This research was resumed under Project 20-3C.

Project 20-3C FY '70

Summary of the Lodge Freeway Research

Research Agency: Asriel Taragin
Principal Invest.: Asriel Taragin
Effective Date: November 15, 1975
Completion Date: July 15, 1976
Funds: $10,183

This project was initiated to prepare a summary report outlining the main findings from a long series of freeway surveillance and control studies on the John C. Lodge Freeway in Detroit. The historical research has been completed, and a report has been submitted. It covers the objectives, organization, and data, as well as the results, conclusions, and recommendations associated with each stage of the traffic research studies. References to all published and unpublished reports as well as file documents pertinent to the background of the studies have been appropriately identified.

The agency's final report has been distributed to the sponsoring agencies; microfiche of the report may be purchased (see final page of this section for ordering information).

Project 20-3D FY '70

Summary of All Freeway Surveillance, Communication and Control Experience

Research Agency: Alan M. Voorhees & Associates
Principal Invest.: Dr. Donald G. Capelle
Effective Date: May 15, 1977
Completion Date: December 31, 1978
Funds: $40,000

This project complements Project 20-3C. It was established to prepare a summary report of all experience with the surveillance, communications, and traffic control aspects of freeway operations. Published reports and other experience available from relevant research projects were reviewed. The final report provides a synthesis of past and present practices to aid highway administrators in decisions related to freeway operation problems.

Research has been completed. Because the final report is of a nontechnical nature and is directed to top-level administrators, it was published as a special publication rather than in the regular NCHRP series. The report, "Freeway Traffic Management," is available for $5.00 (see final page of this section for ordering information).

Project 20-4 FY '68

Public Preference for Future Individual Transportation

Research Agency: Chilton Research Services (CRS)
National Analysts (NA)
Principal Invest.: Robert K. McMillan
James M. Marshall
Effective Date: May 2, 1967

Completion Date: January 21, 1969 (CRS)
January 2, 1968 (NA)
Funds: $279,171

Reliable information is needed on public attitudes and behavior relating to transportation and the factors that influence these to permit more effective planning for the allocation of resources for transportation purposes. The objective of this research was to determine the attitudes and behavior of the public related to transportation and identify the factors that influence such attitude and behavior.

To determine the foregoing, two independent national samples of 2,500 interviews each were surveyed in May 1967 by the two separate agencies. The surveys used the same questionnaire, so that after an initial statistical evaluation between the two surveys the results could be combined for a more detailed analysis. The survey was designed to determine what people think about the importance of various transportation modes and the sources and distribution of transportation financing. Attitudes were related to people characteristics, transportation and community values, transportation needs, and recorded behavior. This project presents a valid national description of transportation attitude and behavior patterns with determination of differences in social, economic, demographic, and geographic subgroups.

A first-phase report was published in 1968 as:

NCHRP Report 49, "National Survey of Transportation Attitudes and Behvior—Phase I Summary Report."

This report presents a preliminary analysis of the nationwide survey data. It includes a comparison of household and individual characteristics for both survey samples and a question-by-question analysis of the total sample.

A second-phase report has been published as:

NCHRP Report 82, "National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report."

This report presents results of a more advanced statistical analysis of the data. This analysis is multi-variant in nature; that is, it considers many variables simultaneously to obtain a comprehensive view of transportation attitudes, their relation to behavior and demographic characteristics, and profiles of people holding these views.

The report includes 16 charts that indicate attitudes, according to eight demographic variables, toward spending for roadways and highways and public transportation. The report deals comprehensively with data by describing the methodology, statistical methods used, and the detailed findings.

Project 20-5 FY '68 and continuing

Synthesis of Information Related to Highway Problems

Research Agency: Transportation Research Board
Principal Invest.: T. L. Copas
H. A. Pennock

Effective Date: December 15, 1967
Completion Date: Continuing
Funds:

$100,000 annually,	FY '68-'71
$200,000 annually,	FY '72-'75
$300,000 annually,	FY '76-'77
$330,000	FY '78
$360,000 annually,	FY '79-'83
$380,000	FY '84
$650,000	FY '85
$575,000	FY '86

Administrators, practicing engineers, and researchers are continually faced with highway problems on which much information exists, either in documented form or in terms of undocumented experience and practice. Unfortunately this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not brought to bear on its solution. Costly research findings may be unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

In this project, particular highway problems, or sets of closely related problems, will be designated as topics for information synthesis.

For each topic the objectives are:

1. To locate and assemble documented information.
2. To learn what engineering practice has been used for solving or alleviating the problem.
3. To identify all ongoing research.
4. To learn what problems remain largely unsolved.
5. To organize, evaluate, synthesize, and document the useful information that is acquired.
6. To evaluate the effectiveness of the synthesis after it has been in the hands of its users for a period of time.

The 123 published syntheses of highway practice that have been prepared under this project are listed in Table 7. Additional information on the project may be found in Research Results Digest 148.

Studies are in progress on the following topics: "Welding and Inspection Practices in Bridge Fabrication," "Methods of Cost-Effectiveness Analysis for Highway Projects," "Storm Water Management for Transportation Facilities," "Durability of Prestressed Concrete Highway Structures," "Effects of Permit and Illegal Overloads on Pavements," "Protective Coatings for Bridge Steel," "Traffic Data Collection and Analysis: Methods and Procedures," "Bridge Inspection Equipment, Staffing, and Safety," "Use of Weight-In-Motion Systems for Data Collection and Enforcement," "Maintenance Management of Street and Highway Signs," "Freezing and Thawing Resistance of High-Strength Concrete," "Wet Pavement Safety Programs," "Use of Fly Ash in Concrete," "Traffic-Safe and Hydraulically Efficient Roadside Drainage Practices," "Scheduling Urban

Freeway Maintenance," and "Bridge Expansion Devices, "System-Wide Safety Improvements," "Integrated Highway Information Systems," "Effectiveness of Quality Assurance Procedures for Highway Construction and Materials," "Design, Construction, and Maintenance of PCC Pavement Joints," "Recycling of Portland Cement Concrete Pavement," "Durability of Drainage Pipe," "D-Cracking of Concrete Pavements," "Cracking/Breaking and Seating Concrete Pavements," "Pavement Management Practices," "Pedestrians and Traffic Control Measures," "Staffing Considerations for Construction Engineering Management."

Project 20-6 FY '69 and continuing

Legal Problems Arising out of Highway Programs

Research Agency: Transportation Research Board
Principal Invest.: Robert W. Cunliffe
Effective Date: November 1, 1968
Completion Date: Continuing
Funds:

$200,000 FY '69-'71	$100,000 Ann. FY '78-'79
$125,000 FY '72	$150,000 Ann. FY '80-'81
$50,000 FY '73	$100,000 FY '82
$185,000 FY '74	$150,000 FY '83
$125,000 FY '75	$200,000 FY '84
$85,000 FY '76	$280,000 FY '85
$75,000 FY '77	$200,000 FY '86

A major and continuing need of State highway departments involves the assembly, analysis, and evaluation of operating practices and the legal elements of special problems involving right-of-way acquisition and control and highway law in general. Individual State experiences need to be compared and made available for possible application nationally. Need exists with respect to both immediate and longer-range right-of-way and legal problems.

In spite of this critical need, there has been no present mechanism that is capable of responding in time to be of practical assistance to State highway departments. The Right-of-Way and Legal Affairs Committee of the American Association of State Highway Officials has tried all of the known channels in an effort to initiate such research, but the response has been negative for one reason or another.

Accordingly, State highway officials have agreed that an appropriate mechanism be initiated under which needed research of the type suggested can be undertaken and with dispatch. Prototypes of such a device may be found in the various AASHO and HRB road-test projects that have been undertaken and, perhaps more closely related, in the 1956-60 special HRB Highway Laws Project.

NCHRP Project 20-6 has been established to meet the aforementioned need and is a continuing effort involving research on a priority listing of topics selected by the cognizant NCHRP project committee. The topics of concern to date are:

Study No. 1— Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act (Research Results Digest No. 3)
Study No. 2— Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administration Discretion in Route Location of Federal-Aid Highways (Research Results Digest No. 6)
Study No. 3— Valuation Changes Resulting From Influence of Public Improvements (Research Results Digest No. 11)
Study No. 4— Advance Acquisition Under the 1968 Federal-Aid Highway Act (Research Results Digest No. 19)
Study No. 5— Valuation in Eminent Domain as Affected by Zoning (Research Results Digest No. 22)
Study No. 6— Federal Environmental Legislation and Regulations as Affecting Highways (Research Results Digest No. 25)
Study No. 7— Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (Research Results Digest No. 32)
Study No. 8— Proposed Legislation to Authorize Joint Development of Highway Rights-of-Ways (Research Results Digest No. 31)
Study No. 9— Legal Effect of Representations as to Subsurface Conditions (Research Results Digest No. 39)**
Study No. 11— Personal Liability of State Highway Department Officers and Employees (Reserch Results Digest No. 79)**
Study No. 12— Tort Liability of Highway Departments Arising Out of Skidding Accidents (Research Results Digest Nos. 83 and 95)**
Study No. 13— Appeal Bodies for Relocation Assistance (Research Results Digest No. 40)
Study No. 15— Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases (Research Results Digest No. 41)
Study No. 16— Supplemental Condemnation: A Discussion of the Principles of Excess and Substitnte Condemnation (Research Results Digest No. 42)
Study No. 17— Liability of State Highway Departments for Design, Construction, and Maintenance Defects (Research Results Digest No. 80)**

Study No. 23— Exclusion of Valuation Changes Resulting from Influence of Public Improvement: A Study of the Provisions of 42 U.S.C. 4651 (3) (Research Results Digest No. 45)
Study No. 24— Eminent Domain: An Overview*
Study No. 25— Where Does Police Power End and Eminent Domain Begin?*
Study No. 26— Just Compensation and the Doctrine of Damnum Absque Injuria*
Study No. 27— The Meaning of Highway Purpose (Research Results Digest No. 68)*
Study No. 28— Valuation of Outdoor Advertising Rights*
Study No. 30— Liability for Drainage Damage*
Study No. 31— Trial Strategy and Techniques Using the Income Approach to Valuation (Research Results Digest No. 54)*
Study No. 32— Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation (Research Results Digest No. 47)*
Study No. 33— Trial Strategy and Techniques Using the Reproduction Cost Less Depreciation Approach to Valuation*
Study No. 34— Trial Aids in Highway Condemnation Cases* (Research Results Digest No. 111)
Study No. 35— Model Airspace Act: A Vehicle for Joint Development*
Study No. 36— Formation of the Contract** (Research Results Digest No. 109)
Study No. 37— Effect of Mistakes in Bids, Plans and Specifications**
Study No. 38— Legal Problems Arising from Changes, Change Clauses and Changed Conditions**
Study No. 39— Contract Completion Time: Damages for Delay; Liquidated Damages; Work Stoppage Under Court Order**
Study No. 40— Administrative Settlement and Disposition of Claims**
Study No. 41— Trial Strategy and Techniques in Contract Litigation** (Research Results Digest No. 108)
Study No. 42— Environmental Litigation: Rights and Remedies**
Study No. 43— Trial Strategy and Techniques in Environmental Litigation**
Study No. 44— Legal Interrelationship of the Federal and State Governments**
Study No. 45— Review of the One-Offer System of Right-of-Way Acquisition (Completed)
Study No. 46— Liability of Governmental Agencies for Improper Traffic Control Devices, Signs, and Pavement Markings** (Research Results Digest No. 110)
Study No. 47— Supplementation of Studies 15, 31, 32 and 33, and Project 11-1(2)***
Study No. 48— Supplementation of Studies, 3, 4, and 5.***
Study No. 49— Inverse Condemnation***
Study No. 50— Payment of Attorney Fees and Other Costs in Condemnation and Environmental Litigation*** (Research Results Digest No. 103)
Study No. 51— Appraisal of Property Damages Due to Highway Noise*** (Research Results Digest No. 99)
Study No. 54— Outdoor Advertising Control and Acquisitiou (Completed)
Study No. 57— Legal Aspects of Access Control on Unlimited-Access Highways*** (Research Results Digest No. 112)
Study No. 60— Relocation of Public Utilities† (Research Results Digest No. 116)
Study No. 61— Right to Compensation in Eminent Domain for Abrogation of Restrictive Covenants*** (Research Results Digest No. 113)
Topic No. 2-03 —Condemnation Blight† (Research Results Digest 119)
Topic No. 2-04 —Legal Aspects of Historic Preservation in Highway Programs†† (Research Results Digest 138)
Topic No. 2-05 —Local Land-Use Regulations in Relation to Highway Programs (Completed)††
Topic No. 2-08 —"State Highway Programs Versus the Spending Powers of Congress"†† (Research Results Digest 136)
Topic No. 2-09 —Procedural Aspects of Inverse Condemnation Actions (Completed)††
Topic No. 2-10 —The Effect of Federal and State Public Information Acts on Highway and Transportation Department Activities†† (Research Results Digest 137)
Topic No. 2-13 —Update of Five Tort Liability Papers in Chapter VIII, SSHL†
Topic No. 2-14 —Update of "Legal Effect of Representations as to Subsurface Conditions"†
Topic No. 2-15 —Update of "Valuation and Condemnation of Special Purpose Properties" (Completed)††
Topic No. 2-16 —Update of "Environmental Litigation: Rights and Remedies" (Completed)††
Topic No. 2-17 —Update of "Damnum Absque Injuria

*Published in *Selected Studies in Highway Law*, Vols. 1 and 2.
**Published in *Selected Studies in Highway Law*, Vol. 3.
***Published in first addendum to *SSHL*.
†Published in second addendum to *SSHL*.
††Published in third addendum to *SSHL*.

and the Concept of Just Compensation in Eminent Domain"†

Topic No. 2-18 —Update of "Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation"†

Topic No. 2-19 —Update of "Liability for Delay in Completion of Highway Construction Contracts"†

Topic No. 2-21 —Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines†† (Research Results Digest 129)

Topic No. 2-22 —Update of "Legal Problems Arising from Changes, Changed Conditions, and Disputes Clauses in Highway Construction Contracts"†

Topic No. 2-23 —Update of "Where Does Police Power End and Eminent Domain Begin"†

Topic No. 2-24 —Update of "The Meaning of Highway Purpose"†

Topic No. 2-25 —Update of "Liability of the State for Highway Traffic Noise"†

Topic No. 2-26 —Update of "Right of Compensation in Eminent Domain for Abrogation of Restrictive Covenants"†

Topic No. 2-27 —Update of "Liability for Highway Drainage Damage"†

Topic No. 2-28 —Update of "Valuation nd Condemnation Problems Involving Trade Fixtures (Completed)††

Topic No. 2-29 —Update of "Valuation and Condemnation of Advertising Signs and Related Property Interests Under the Highway Beautification Act" (Completed)††

Topic No. 2-30 —Update of "Payment of Attorney Fees in Eminent Domain and Environmental Litigation" (Completed)††

Topic No. 2-31 —Update of "Rules of Discovery and Disclosure in Highway Condemnation Proceedings" (Completed)††

Topic No. 2-32 —Update of "Legal Implications of Control of Access to Uncontrolled-Access Highways" (Completed)††

Topic No. 2-33 —Liability of the State for Injury Producing Defects in Highway Surface†† (Research Results Digest 135)

Topic No. 2-34 —Liability of Highway Agencies for Unsafe Construction Zones (In Progress)

Topic No. 2-35 —Liability of Highway Agencies for Failure to Provide or Maintain Highway Barriers, Guardrails, and Similar Safety Devices (In Progress)

Topic No. 2-36 —Liability of Highway Agencies for Defects in Design, Construction, and Maintenance of Bridges†† (Research Results Digest 141)

Topic No. 2-37 —Liability of Highway Agencies for Failure to Remove Obstructions In or Near the Highway (Completed)†††

Topic No. 3-01 —Disposition of Minerals on Highway Rights-of-Way (Research Results Digest 147)†††

Topic No. 3-02 —Legal and Procedural Issues Related to Relocation Assistance (In Progress)†††

Topic No. 3-03 —Antitrust Violations in Highway Construction Contracting (Deleted)†††

Topic No. 3-04 —First Amendment Aspects of Control of Outdoor Advertising (Research Results Digest 145)†††

Topic No. 3-05 —Liability of a Public Agency for Precondemnatiou Activity: The "De Facto" Taking (Completed)†††

Topic No. 3-06 —Exaction of Right-of-Way by the Exercise of Police Power (Completed)†††

Topic No. 3-07 —Trial Strategy and Techniques in Handling Tort Claims Arising Out of Highway Operations (In Progress)

Topic No. 3-08 —Tort Liability and Reduced Levels of Service or Maintenance (Deleted)

Topic No. 3-09 —Trial Strategies and Techuiques in Establishing Violations of Size and Weight Laws (In Progress)

Topic No. 3-10 —Enforceability of the Requirement of Notice in Highway Construction Contracts (Completed)†††

Topic No. 3-11 —Alternative Right-of-Way Acquisition Plans and Opportunities Stemming from Reduced Federal and State Budget for Highway Improvements (In Progress)

Topic No. 3-12 —Acquisition of Uneconomic Remnants Under 23 U.S.C. 109(f) (In Progress)

Topic No. 3-13 —Liability of Public Agencies Arising Out of Rejection of Low Bids, Misaward of Contracts, and Local Preference Laws (Pending)

Topic No. 3-14 —Use of Guarantee or Warranty Clauses in Highway Construction Contracts (In Progress)

Topic No. 3-15 —Impact on Right-of-Way Acquisition in the States of Federal Deregulation of Specified Items Involving Right-of-Way (Pending)

Topic No. 3-16 —Enhancement of Damages in Eminent Domain Cases (Pending)

Topic No. 3-17 —Seminar Program Package: Enforcing Antitrust Laws in Highway Construction Programs (Pending)

Topic No. 3-18 —Barriers to Exehange of Motor Carrier Accident Information Among the States and Between the States and Federal Agencies (Pending)

Topic No. 3-19 —Minority Business or Enterprise Requirements in Public Contracts (Research Results Digest 146)†††

Topic No. 3-20 —Update of Five Papers on Contract Law (In Progress)

Topic No. 3-21 —Update of "Payment to Public Utilities for Relocation of Facilities in Highway Rights-of-Way" (Pending)

Topic No. 3-22 —Update of "Liability of State and Local Governments for Negligence Arising Out of the Installation and Maintenance of Warning Signs, Traffic Lights, and Pavement Markings" (Pending)

Studies completed under this project are published as NCHRP Research Results Digests (see Table 9). In addition, most recently completed studies have also been included in the text, *Selected Studies in Highway Law.* Volumes 1 and 2, dealing primarily with the law of eminent domain, were published in 1976, and Volume 3, dealing with contracts, torts, environmental and other areas of highway law, was published in early 1978. All three volumes have been distributed on a limited basis to selected state and federal offices. Information on obtaining copies of this text may be found in NCHRP Research Results Digest 128 or by contacting the Transportation Research Board Publications Office.

The first addendum to Selected Studies in Highway Law, consisting of five new papers and supplements to eight existing papers, was issued during 1979. A second addendum with two new papers and 15 supplements was distributed early in 1981. A third addendum consisting of eight new papers, seven supplements, and an expandable binder for Volume 4 was distributed during the first half of 1983. The four volumes now total more than 2,300 pages comprising 56 papers, some 30 of which have been supplemented during the past 3 years.

Copies of the final reports on Studies 45 and 54 have been distributed to NCHRP sponsors, and loan copies are available from the NCHRP upon written request. Microfiche of the reports may be purchased (see final page of this section for ordering information).

Because right-of-way issues are of somewhat less concern than when the project was initiated, the AASHTO Select Committee on Research deleted "right-of-way" from the project title in 1984. Right-of-way topics needing research will still be conducted, but not as the major research area. Through December 31, 1985, research continues on new topics of current interest in the legal field. Updating and supplementing the text book will also be continued.

†Published in second addendum to *SSHL*.
††Published in third addendum to *SSHL*.
†††To be published in fourth addendum to *SSHL*.

Project 20-7 FY '69 and continuing

Research for AASHTO Standing Committee on Highways

Research Agency:
Principal Invest.: Open
Effective Date: December 2, 1968
Completion Date: Continuing
Funds: $100,000 annually

The American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highways is called on continually to rule on engineering and operations policies as a guide for State highway and transportation departments to follow. The Committee desires to obtain guidance on a reasonably prompt schedule through a continuing research program geared to the needs and wishes of the Committee in the development of guides, standards, policies, and other AASHTO activities. In earlier years, objectives of the Committee were attained through the establishment of a continuing research capability at the Texas Transportation Institute (TTI) of Texas A&M University. In June 1973, the Committee stipulated that accomplishment of task research could be through any agency deemed by the NCHRP to possess the necessary expertise, provided the research could be initiated quickly.

The project includes a series of tasks specified by the Committee to obtain data required by the Committee to fulfill its responsibilities.

The status of each of the tasks undertaken in this project is as follows:

Task 1, "Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements" (TTI). Research has been completed, and the task report published as NCHRP Report 148, "Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach." The report describes a hazard model that can be used to evaluate the effectiveness of a roadside safety improvement program.

Task 2, "The Relation of Side Slope Design to Highway Safety" (TTI). Research has been completed, and the task report published as NCHRP Report 158, "Selection of Safe Roadside Cross Sections." Tentative criteria for the selection of safe side slopes and safe slope and ditch combinations are proposed.

Task 3, "Development of an Effective Earth-Berm Vehicle Deflector" (TTI). The final report has been completed, and the results summarized in NCHRP Research Results Digest 77. The study was exploratory in nature, and further research is recommended.

Task 4, "Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures (TTI). The final report has been completed and accepted by the AASHTO Standing Committee. NCHRP Research Re-

sults Digest 55 summarizes the results of the study. The study found that, although more needs to be known about the limitations of the existing AASHTO curve design policy, the present policy will in most instances provide safe, conservative designs for highway curves.

Task 5, "Effect of Curb Geometry and Location" (TTI). Research has been completed, and the task report published as NCHRP Report 150, "Effect of Curb Geometry and Location on Vehicle Behavior." The study provides recommendations regarding curb configuration and placement.

Task 6, "Development of Impact Attenuators Utilizing Waste Materials" (TTI). Various used-tire configurations and a fiberized aluminum product were examined in the laboratory and analytically, and by full-scale field testing in some instances, to determine feasibility and to develop design information regarding the use of these materials for vehicle impact attenuation. Research has been completed, and the task report published as NCHRP Report 157, "Crash Cushions of Waste Materials." Designs are proposed for attenuators using two different configurations of scrap tires.

Task 7, "Safety at Narrow Bridge Sites" (TTI). Research has been completed. A bridge hazard index is proposed for assessing the degree of hazard of narrow bridges. Guidelines are offered for remedial treatments at narrow bridges. The essential findings have been published in NCHRP Research Results Digest 98. The revised agency report has been published as NCHRP Report 203, "Safety at Narrow Bridge Sites."

Task 8, "Energy and Transportation Systems" (California Department of Transportation). This study was designed to establish "energy factors" for the various elements of energy use in constructing, maintaining, and operating transportation systems; to develop procedures for evaluating the energy use by such systems by applying the established energy factors; and to develop a rational method for reporting the results. Research has been completed, and copies of the agency report have been distributed to the Program sponsors. Microfiche of the report may be purchased (see final page of this section for ordering information).

Task 9, "Review of Highway Management Studies Co-Sponsored by AASHTO and HUFSAM" (Management and Transportation Associates, Inc.) This was an evaluation of the Highway and Transportation Management Institute and the National Highway and Transportation Management Conference that have been offered annually over the past several years to improve the management skills of highway department personnel. The study findings indicate that there is a continuing need within highway and transportation agencies for management training, but it is becoming increasingly difficult to justify the travel, time, and expenses required by the courses currently being scheduled. As an alternative, the report recommends development of a two-week course to be presented once each year in each of the four AASHTO regions. Research has been completed, and copies of the agency report distributed to the Program sponsors.

Task 10, "Review of Vehicle Weight/Horsepower Ratio as Related to Passing-Lane Design Criteria" (The Pennsylvania State University). The current AASHTO publications on highway geometrics use a loaded truck with weight/horsepower ratio of 400:1 as the design vehicle in determining the need for passing lanes on hills. The objective of this task was to evaluate the currently used design vehicle. Research has been completed. A recommendation is made that a truck with a weight/horsepower ratio of 300:1 be used where truck traffic is the controlling factor. An automobile pulling a travel trailer with a combined weight/horsepower ratio of 60:1 is recommended as the design vehicle on sections of highway not subjected to truck traffic but heavily used by recreation vehicles. Research has been completed, and copies of the agency report have been distributed to the Program sponsors.

Task 11, "Longitudinal Occupancy of Freeways by Utilities" (Byrd, Tallamy, MacDonald and Lewis). The objective of this task was to determine the over-all feasibility and practicality of joint occupancy of freeway ROW by trunk-line and transmission-type utility facilities. Research has been completed. Interviews have been conducted with highway and utility personnel. Existing joint occupancy sites have been studied for identification of potential problems. Possible benefits to the general public have been assessed. Copies of the agency report have been distributed to the Program sponsors.

Task 12, "Guidelines for Citizen Participation in Transportation Planning" (Kathleen Stein Hudson). The AASHTO Standing Committee on Planning has compiled material for preparation of guidelines for citizen participation in transportation planning. The objective of this task was to prepare draft guidelines from the materials that have been compiled. The project report has been published by AASHTO as: "Guidelines on Citizen Participation in Transportation Planning."

Task 13, "Guidelines for Safety Criteria for Low-Volume Roads" (John C. Glennon). The objective of this task was to evaluate and suggest modifications for existing safety criteria with regard to their applicability and relevancy for roads carrying less than 400 vehicles per day at normal and reduced speeds. Research has been completed, and the report has been published as NCHRP Report 214, "Design and Traffic Control Guidelines for Low-Volume Rural Roads."

Task 14, "A Policy on Geometric Design of Highways and Streets" (John F. Holman & Co., Inc.). The objective of this task was the preparation of an edited version of a new AASHTO publication being compiled by the Task Force on Geometric Design of the AASHTO Subcommittee on Design. The new publication will replace the current AASHTO publications, *A Policy on Geometric*

Design of Rural Highways—1965 (Blue Book) and *A Policy on Design of Urban Highways and Arterial Streets—1973* (Red Book). Research has been completed, and the new book, *A Policy on Geometric Design of Highways and Streets,* has been published by AASHTO.

Task 15, "Development of a Simplified Pavement Management System" (ARE, Inc.). The objectives of this task are to (1) prepare a synthesis report on pavement management system (PMS) research and development and (2) develop a simplified PMS suitable for assisting highway agencies in rehabilitation programming of existing pavements. The synthesis report has been completed and the report published as NCHRP Report 215, "Pavement Management System Development."

A simplified PMS has been developed as accomplishment of item 2. Research has been completed and copies of the agency report have been distributed to the program sponsors.

Task 16, "Regulation of Movement of Hazardous Cargoes" (D. M. Baldwin). Mr. Baldwin was retained as a consultant to prepare a report on the current state of the art on the task subject and to suggest specific objectives for further study. Research has been completed, and copies of the consultant's report have been distributed to the Program Sponsors.

Task 17, "Evaluating AASHO Road Test Satellite and Environmental Studies" (Texas A&M University). The objectives of this task were to (1) compile available data and information from satellite road tests and from sections of the AASHO Road Test subsequent to the completion of the road test and (2) determine the feasibility of using the information to propose revisions to the "AASHO Interim Guide for Design of Pavement Structures, 1972." Research has been completed on the initial phase and a report submitted indicating little feasibility of using satellite road test data to revise the pavement design guides developed from the AASHO Road Test data. However, it was found that overlay design procedures could be developed from satellite road test data on a climatic region basis. Additional funding was provided for a second phase of the study to develop such overlay design procedures for at least two climatic regions. Research has been completed, and copies of the agency report have been distributed to Program Sponsors.

Task 18, "Standard Specifications for Highway Bridges" (Howard Needles Tammen & Bergendoff). The objective of this task is the preparation of a completely reorganized and edited version of Standard Specifications for Highway Bridges and Structures for publication by AASHTO. Research has been completed, and the reorganized and edited version, Standard Specifications for Highway Bridges, has been published by AASHTO.

Task 19, "The Engineering Aspects of Highway Traffic Safety in an Age of Limited Resources" (TRB). A conference on the above subject was jointly sponsored by AASHTO, FHWA, and others and was held in St. Louis, Mo., November 2-5, 1981. The AASHTO funding support in the amount of $25,000 was allocated from Project 20-7. The TRB was responsible for the planning and conduct of the conference. Proceedings of the conference have been distributed to the conference sponsors.

Task 20, "Vehicle Acceleration and Deceleration Characteristics" (University of Michigan). The objective of this task is to evaluate the influence of changes in vehicle size, weight, power, and brake systems on acceleration and deceleration capability. The results will be used during future revisions of highway geometric design. The task was being combined with Project 15-8, "Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics." Research has been completed, and the findings included in NCHRP Report 270, "Parameters Affecting Stopping Sight Distance."

Task 21, "Need for Pavement Markings on Low-Volume Roads" (John C. Glennon). The objective of this task was to verify or modify the suggested warrants for centerline and no-passing markings of low-volume roads as described in NCHRP Report 214. Research has been completed, and copies of the agency report have been distributed to Program Sponsors.

Task 22, "Encasement of Pipelines Through Highway and Railroad Roadbeds" (Byrd, Tallamy, MacDonald and Lewis). The objective of this task is to develop procedures for determining the need for pipeline encasement based on (1) a review of literature on underground pipeline design and performance, (2) a limited stress analysis of underground pipelines, and (3) an evaluation of field experience by highway, railroad, and utility agencies of encased and unencased pipelines under roadbeds. Research has been completed, and copies of the agency report have been distributed to Program sponsors.

Task 23, "Contracting Policies and Payment Procedures" (Bergstrahl-Shaw-Newman, Inc.). The objectives of this task were to evaluate current contracting practices and methods of determining pay-quantities for highway construction work in the United States and to suggest any appropriate improvements. Research has been completed, and copies of the agency report have been distributed to program sponsors.

Task 24, "AASHTO Pavement Design Guide" (Dr. Frank McCullough—Mr. Fred Finn). NCHRP Project 1-24 is funded from the FY '84 program in the amount of $500,000 with the objective being the preparation of a revised and expanded pavement design guide for consideration by AASHTO to replace the current publication, *AASHTO Interim Guide for Design of Pavement Structures—1972 (Chapter III Revised 1981).* In the interest of expediting this work, the entire project was conducted as Task 24 of Project 20-7. Research has been completed, copies of the proposed new *AASHTO Guide for Design of Pavement Structures* have been distributed to program sponsors, and the document has been approved for publication by AASHTO.

Task 25, "STRS Support Task" (Various consultants). The purpose of this task was to respond to the desires of the Executive Committee of AASHTO to obtain preliminary study designs for the six research areas identified in the Strategic Transportation Research Study (STRS) report. Nine consultants were retained by NCHRP to assist in preparation of the study designs. Work has been completed and the report distributed to the STRS Task Force and program sponsors.

Task 26, "Research and Development Needs in Construction Engineering Management" (Bergstrahl-Shaw-Newman, Inc.). The objective of this task is to update the research and development program for highway construction engineering recommended in the *FHWA Report No. FHWA-HO-79-1*, assess the accomplishments since publication of the report, and evaluate the need for additional recommendations. Research is nearing completion.

Task 27, "Relationships Between Vehicle Configurations and Highway Design" (Transportation Research Board). The overall objective of research on this problem is to develop recommendations for coordination of heavy vehicle configurations and pavement, bridge, and highway geometric design to produce the most practical and efficient transportation of goods and services over the highway system. The objective of the initial phase of the research (NCHRP Project 20-7/27) is intended to (1) collect, review, and evaluate available information pertaining to the problem, (2) conduct a pilot analytical study involving the more significant factors and sample data, and (3) assess the feasibility and practicality of further development of an optimum solution. The end product of the initial research phase is anticipated to be recommendations for further research intended to produce (1) short term improvements in interactions of heavy vehicles with the existing highway system having potential for early implementations and (2) long term optimization of the heavy vehicle-highway design interaction intended to produce improved efficiency of the highway transportation system. Research is in progress.

Task 28, "AASHTO Guide for Design of Pavement Structures-Training Program" (Dr. Frank McCullough and Mr. Fred Finn). The objective of this task is to develop and conduct a training program for users of the *AASHTO Guide for Design of Pavement Structures* to encourage early implementation of the new publication. Research is scheduled to begin January 6, 1986.

Project 20-8 FY '71

Interactive Graphic Systems for Highway Design

Research Agency: Control Data Corporation
Principal Invest.: C. W. Beilfuss
Effective Date: September 1, 1970
Completion Date: July 31, 1971
Funds: $49,672

Improved techniques and procedures making extensive nse of computer and computer-graphics technology are being developed to enhance highway location and design. One prominent highway design evaluation capability under development is the ability to produce, on a variety of computer-controlled graphic display devices, perspective views based on computed design information and actual terrain data. Highway engineers, by making use of these new capabilities, will be better able to achieve optimal highway designs expeditiously.

To make effective use of the new graphic display evaluation techniques, there is a need for a man-machine interaction capability for revising highway designs. The man-machine interaction is the ability of the highway designer to make discrete changes to design parameters as a result of evaluating graphic displays, including animated perspective views, and directing the computer to modify all stored data and produce new displays that reflect the design parameter changes.

This project was a feasibility study to determine the costs and benefits associated with the development of an Interactive Graphics Road Design System (IGRDS). The agency determined that IGRDS is feasible and produced cost and benefit figures to support that finding. The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 20-9 FY '73

Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation

Research Agency: RMC Research Corporation
Principal Invest.: Jon E. Burkhardt
Effective Date: August 1, 1972
Completion Date: December 17, 1976
Funds: $202,579

Residential dislocation is one of the major direct consequences of urban highway projects, and some recent opposition to specific urban highway proposals is based on the fear of citizens that they may be inadequately compensated for the effects of being dislocated from their homes. In the light of these considerations, the objectives of the research were to (1) develop techniques to predict the dislocation consequences of alternate route and design proposals and (2) identify related legislative or regulatory constraints and recommend modifications to assume equity to the displacees.

Analyses of data collected before and after moving at six sites geographically distributed throughout the United States showed that the consequences of residential dislocation do not vary significantly among socioeconomic

and demographic groups except for the elderly. Relocation process characteristics, rather than socioeconomic characteristics, were shown to be related to measures of happiness and satisfaction. The research was successful in identifying ways in which the highway planning process could be improved by (1) increasing the planners ability to forecast the dislocation consequences of particular location and design decisions and (2) suggesting techniques for more adequately compensating persons adversely affected by right-of-way acquisition. Very few recommendations to modify existing legislation or regulations are made because modifications in most instances were found to be unnecessary. Rather, changes in the way regulations are administered were found to be more appropriate and such changes are recommended under three categories: (1) changes in compensation, (2) changes in relocation practice and (3) changes in the highway planning process.

The agency's final draft report is a complete description of theory related to the subject, the research plan, the data obtained, data anlyses, findings, and recommendations. Microfiche of the report may be purchased (see final page of this section for ordering information). A condensation of the research results may be found in the paper, "Residential Dislocation: Costs and Consequences," published by the Transportation Research Board in Transportation Research Record 716. For this paper, the author, Mr. Jon E. Burkhardt, received the 1980 Pyke Johnson Award from the Transportation Research Board.

The data are available in tape form to other investigators who may wish to pursue further data analysis. Inqniries should be made in writing to the NCHRP. For a copy of the tape, a blank 9-track 1600 BPI tape should be provided by the inquirer. Copies of the coding book and data printouts can be made available for the cost of reprodnction and handling.

Project 20-10 FY '73

The Benefits of Separating Pedestrians and Vehicles

Research Agency:	Stanford Reserch Institute
Principal Invest.:	Ronald L. Braun
	Marc Roddin
Effective Date:	August 26, 1974
Completion Date:	April 30, 1976
Funds:	$100,000

In recent decades, the pedestrian has not been given adequate consideration in the decisions for person mobility. Increasing concern for the environment, safety, energy, community cohesion, and health have contributed to a social awareness of the pedestrian. In determining use of space, an inherent conflict exists between vehicles and pedestrians. There was a need to identify and measure benefits of separating pedestrians and vehicular traffic.

The general objective of this research was to identify and quantify the benefits related to separation of pedestrians and vehicles and develop techniques for relating these benefits to the evaluation of proposals for separation.

Four categories of direct and indirect benefits of separating pedestrians from roadway traffic were identified. These were (1) transportation; (2) safety, health, environment; (3) residential/business; and (4) environmental/institutional. The beneficiaries of these benefits were defined. A methodology was developed to weight the benefits identified according to values held by decision-makers and/or the community at large. The methodology was tested at field sites in Seattle, Wash. (a highway overpass); Brooklyn, N. Y. (a mall); and Ottawa, Ont. (a mall).

Results of the research were published as:

NCHRP Report 189: "Quantifying the Benefits of Separating Pedestrians and Vehicles."

Research was continued under Project 20-10(2).

Project 20-10(2) FY '78

The Benefits of Separating Pedestrians and Vehicles

Research Agency:	SRI International
Principal Invest.:	Ronald L. Braun
	Marc F. Roddin
Effective Date:	September 1, 1978
Completion Date:	July 31, 1981
Funds:	$100,000

A comprehensive method for evaluating the transportation, safety/environment/health, and residential/business benefits of proposals for facilities separating pedestrians and vehicles was developed and demonstrated during the course of NCHRP Project 20-10, and described in NCHRP Report 189. The objective of this continuation research was to update, refine, and extend the usefulness of the previously developed techniques for quantifying all of the significant direct and indirect benefits associated with the separation of pedestrians and vehicles.

This objective was met by the simplification of the method and the preparation of audiovisual materials to supplement a technical user guide. The method was simplified by reducing the number of variables from 36 to 27, without loss of precision or detail. Scoring for some of the variables was simplified also. The technical user guide was revised and simplified.

Audiovisual materials consisted of a slide show and a videotape. The slide show, with accompanying music, narration, and sound effects, was prepared for use by those interested in evaluating pedestrian facilities (such as elected officials, merchants, and the general public) but who would not be involved with details of the method. For those who would personally use the method, a videotape has been prepared that illustrates an application to problems encountered by suburban railroad commuters walking to and from the train station.

During this project, the feasibility of applying the evaluation method for use in pedestrian traffic warrants was evaluated. The purpose was to quantify pedestrian conditions to the extent that requirements for specific separate pedestrian facilities could be established. Seven existing pedestrian warrant systems were studied and classified. It was found that a subset of the evaluation method, using only ten variables, can be used for warrant purposes. Scores for these variables are computed, multiplied by an appropriate set of weights, and combined to obtain a score ranging between −1000 and +1000. For scores of +300 or lower, pedestrian separation from vehicles may be warranted, depending on pedestrian traffic volume. For weighted scores of −500 or less, only five pedestrians per hour are necessary to warrant separation. Potential users should note with caution that this proposed warrant has not been field tested.

The project report has been published as:

NCHRP Report 240: "A Manual to Determine Benefits of Separating Pedestrians and Vehicles." The slide show and videotape are available on a loan basis (see final page of this section for ordering information). Borrowers may copy the audiovisual materials to retain sets.

Project 20-11 FY '73

Toward Environmental Benefit/Cost Analysis—Measurement Methodology

Research Agency: Polytechnic Institute of New York
Principal Invest.: Dr. Edmund J. Cantilli
Effective Date: September 1, 1972
Completion Date: May 31, 1974
Funds: $100,000

Environmental factors have been given increasing consideration in the provision, and operation, of public facilities, including highways. Consequently, it is frequently necessary not only to compare facility effects on various aspects of the environment but also to compare effects on the environment of one facility alternate to another. It is also necessary, in order to choose among alternative facility plans, designs, and construction techniques, to assess their differential environmental effects and costs in the context of total benefits and costs.

Whereas various analytical methods are recognized as providing assessments of transportation benefits and costs, only very limited methods that are readily understood by the public have been developed for the assessment of environmental benefits and costs.

The basic objective of this project was to develop methods that are readily understood by the public for the qualitative evaluation of environmental values. Moreover, the methods should be practical and immediately implementable by responsible agencies.

The specific research objectives were to:

1. Identify and categorize environmental elements that are affected by the provision and operation of transportation facilities. These elements may be positive and/or negative, local and/or regional, long- and/or short-term.
2. Determine the significant elements and the relationships among these elements that may be altered by transportation facilities.
3. Develop quantitative scales for measuring quality levels of those environmental elements or categories, as appropriate, that have been identified as significant in Item 2.
4. Develop a method to identify threshold level(s) of adverse and beneficial effects on the quality scales defined in Item 3 for selected environmental elements and/or categories as appropriate.

The scope and direction of this project were modified to restrict the definition of "environment" to ecological and physical considerations. In addition, an energy concept was pursued by the research team, and attempts were made to develop it for use. This concept is a numerical means of calculating the energy lost by an ecosystem when a facility destroys part or all of given system. The energy approach also permits comparisons to be made on various levels—such as nationwide, regional, statewide, and local—between energy lost, energy used in building the facility, and energy to be used in operating the facility. The procedure allows for a comparison of the ecological impacts for transportation alternatives. The concept was applied to the Oyster Bay Bridge (New York) and U.S. Route 29 (Kansas).

The research was completed. The final report was not published, but the agency's unedited final draft may be obtained on a loan basis upon written request to the NCHRP. Microfiche of the report may be purchased (see final page of this section for ordering information).

Project 20-11A FY '74

Toward Environmental Benefit/Cost Analysis—Measurement Methodology

Research Agency: Cornell University
Principal Invest.: Dr. Arnim H. Meyburg
Mitchell J. Lavine
Effective Date: September 1, 1975
Completion Date: November 30, 1976
Funds: $27,212

Since the passage of the National Environmental Policy Act of 1969 and other similar legislation spurred by growing environmental concerns, there has been an increasing demand to develop practical and meaningful environmental impact assessment methodologies. One such methodology, based on the energy-flow concept, had been developed in other research fields and was considered to offer promise for adaptation to transportation-related applications.

The general objective of this research was to identify and describe programs of research being undertaken or

completed that use the energy-flow concept to measure impacts of man-made changes in ecosystems. Specifically, the following tasks were completed:

1. The identification and description of relevant research programs, inclnding a literature search, a description of each of the research programs, and a description of supportive research information.
2. Evaluation of potential applications to transportation facilities planning.
3. The formulation of recommendations identifying particularly promising programs or findings and recommendations necessary for further development and implementation of an energy-flow analysis methodology for transportation-facilities planning.

Research on this project has been completed, resulting in initiation of Projects 20-11B and 20-11C. Microfiche of the agency's draft final report, "Toward Environmental Benefit/Cost Analysis: Measnrement Methodology," is available (see final page of this section for ordering information).

Project 20-11B FY '74

Toward Environmental Benefit/Cost Analysis—Energy-Flow Analysis (Manual)

Research Agency: Cornell University
Principal Invest.: Dr. Arnim H. Meyburg
Mitchell J. Lavine
Effective Date: January 24, 1977
Completian Date: May 4, 1979
Funds: $140,450

A start has been made in developing a usable methodology for assessing environmental impacts of transportation facilities using the energy-flow concept. However, there is no one source available now that succinctly describes the theories, tools, procedures, and data sources necessary to apply the energy-flow analysis methodology. An applications manual will help to assure that the methodology is thoroughly understood and readily usable. Such a reference will explicitly describe the procedures involved and identify their range of applicability in the transportation field.

The general objective of this research was to develop a user-oriented manual to assist any state or local transportation agency in conducting environmental analyses using the energy-flow concept. This work builds on the findings of NCHRP Project 20-11A and other related research efforts. The manual is designed for direct use in project development and system analysis for the movement of people and goods and emphasizes simplified techniques not requiring computer application. It includes:

1. A step-by-step description of the procedure for energy-flow analyses.
2. A checklist and brief discussion of specific parameters (e.g., productivity rates) for which data are required.
3. Methods for obtaining needed data, including a list of sources for data that do not require direct field collection.
4. Case studies that demonstrate the step-by-step methodology as it applies to transportation problems.
5. An explanation of the relationship between the step-by-step procedure contained in the manual and accepted theories of energy flow.
6. A discussion of the application and the limitations of the methodology to the planning, construction, operation, maintenance, and regulation of transportation facilities and services.

Research has been completed. The agency's draft final report will not be published but is available on a loan basis upon written request from the NCHRP. Microfiche of the report may be purchased (see final page of this section for ordering information). A summary of the research findings is provided in NCHRP Research Results Digest 114.

Project 20-11C FY '74

Toward Environmental Benefit/Cost Methodology—Energy-Flow Analysis (Study Design)

Research Agency: The Cannon Group
Principal Invest.: W. E. Kirksey
J. C. Kraft
Effective Date: April 1, 1977
Completion Date: March 31, 1978
Funds: $14,786

A start has been made in developing a usable methodology for assessing environmental impacts of transportation facilities using the energy-flow concept, inclnding an evaluation of theoretical energy-flow concepts. It is now necessary to explore in some considerable detail the application of such concepts to transportation planning. The required exploration involves practical application in (a) measuring and interpreting transportation-related impacts and (b) assessing sensitivity to the variety of situations enconntered in the planning of transportation facilities and services.

In view of the complex nature of these research requirements and the apparent broad application of energy-flow analysis to transportation systems and project planning, further specific research on the application of the methodology required carefnl preparation of study designs.

The objective of this project was to develop study designs for a program of research that will provide evaluations of the application of the energy-flow methodology to the planning of transportation facilities and services. Particular attention to the social-cultural and esthetic

considerations that have not been adequately accounted for in preceding studies is provided in the study designs.

The final report will not be published; copies of the study designs are available on a loan basis (see final page of this section for ordering information).

Project 20-12 FY '74

Effects of Air Pollution Regulations on Highway Construction and Maintenance

Research Agency: Howard, Needles, Tammen and Bergendoff
Principal Invest.: Orrin Riley
Effective Date: April 1, 1974
Completion Date: July 31, 1975
Funds: $80,446

This research evaluated the effect of air pollution regulations for fugitive particulates and hydrocarbons on the highway construction and maintenance industry. Research was limited to the on-site construction process rather than off-site materials processing.

A survey of air pollution control officials and highway maintenance and construction officials was conducted. This survey determined the monitoring procedures used by the industry to identify possible violations and tabulated those activities likely to produce illegal emissions. Mitigation methods favored by construction were also listed.

A testing program for fugitive particulates generated by highway construction was performed to measure ambient air quality concentrations. Also, a hydrocarbon testing program evaluated the emissions from both the asphalt paving operation and cutback asphalt application during highway construction.

It was found that fugitive particulate regulations have had little effect on the industry because they are primarily concerned with persistent, permanent sources rather than sporadic, temporary sources such as construction. Conspicuous, costly, and lengthy test requirements make enforcement difficult. Open burning can be adequately controlled through present technology. Site watering reduces particulate levels for a short period of time and is often overused as a mitigant because it causes tracking of the soil from the construction site thereby increasing the dust potential. More efficient mitigants such as oil-based products and temporary pavements should be used more. Fugitive dust particles tend to settle out within right-of-way limits and the industry has long undertaken adequate mitigation procedures in response to neighbors' nuisance complaints.

The hydrocarbon tests revealed that the quantity of reactive hydrocarbons emitted from the more volatile cutbacks is small compared to that of vehicular exhaust, and that which is emitted dissipates within a short distance of its source. Essentially, no violations of the ambient air quality standards were attributable to highway paving and priming.

Research has been completed, and the report has been published as:

NCHRP Report 191, "Effect of Air Pollution Regulations on Highway Construction and Maintenance."

Project 20-13 FY '75

Beneficial Environmental Effects Associated with Freeway Construction

Research Agency: The Pennsylvania State University
Principal Invest.: Hays B. Gamble
Dr. Thomas B. Davinroy
Effective Date: September 3, 1974
Completion Date: August 2, 1975
Funds: $49,965

It is necessary to discuss both positive and negative environmental aspects of a project during preparation of the environmental impact statement. The positive aspects have not previously been documented to any degree. This study provides an evaluation of environmental improvements attributable to freeways in order to place present and future freeways in proper perspective.

The objective of this project was to determine the long- and short-range positive aspects of freeway construction. These were differentiated, where necessary, for urban and rural freeways. The literature was searched, analyzed, and evaluated. The investigators were concerned with studies such as:

1. Improved emergency ambulance, fire, and police services.
2. Movement of goods and services.
3. Influence on land-use planning.
4. Influence on economic growth.
5. Accessibility to recreational and other activities.
6. Pollution control.
7. Energy utilization.
8. Effects on plants and wildlife.

A matrix approach was used to catalogue and classify beneficial environmental effects. Literature reviews and surveys conducted by a multi-disciplinary team were carried out to develop the required information for the matrix.

The project report has been published as:

NCHRP Report 193, "Beneficial Effects Associated with Freeway Construction—Environmental, Social, and Economic."

Project 20-14 FY '77

Monitoring Carbon Monoxide Concentrations in Urban Areas

Research Agency: Technology Service Corporation
Principal Invest.: William S. Meisel
Yuji Horie

Effective Date: October 1, 1976
Completion Date: March 31, 1978
Funds: $99,973

Federal and state regulations have required that air quality reports be included in environmental impact statements in order that compliance with ambient air quality standards could be assessed. Many of these air quality reports needed to include an analysis of on-site monitoring data of urban background carbon monoxide (CO) concentrations. It had been assumed that this monitoring must be performed for at least one year to be reliable. However, practical considerations dictated that the period of monitoring be as short as possible consistent with chosen accuracy. Therefore, an acceptable statistical method for evaluating CO data obtained over a relatively short period of time needed to be developed.

The general objective was to develop a methodology (1) to estimate nrban background CO concentrations from incomplete monitoring data sets for three types of areas (a) where urban background monitoring stations already exist, (b) where source-affected monitoring stations exist, and (c) where there are no existing stations; and (2) to determine the precision of the estimates.

The first step in the development of such a methodology was preparation of a high-quality data base for cities representing a wide geographical distribution throughout the U.S. Once the data base was established, the interrelationships among the CO concentrations at the target site, the CO concentrations at the auxiliary stations, and meteorological data were explored. The preliminary relationships determined were then refined to determine methods for extrapolating the CO concentrations at the target site to estimate the two critical annual statistics: the annual second 8-hour maximum and the annual second 1-hour maximum. From the analysis of CO concentrations, it was found that the 8-hour running average violated the air quality standard when the second-highest-reading-of-the-year standard was violated. This finding allowed research to concentrate on the extrapolating of 8-hour running averages.

The main result of this study was the following: As long as it is possible to monitor during a part of the CO season (October to January, possibly February), the two statistics mentioned can be accurately estimated from one month of sampling. Restriction of monitoring to the CO season represented a change from practice in 1978. The most accurate of the methods tested was the simplest—use the highest 8-hour average observed during the period of monitoring at the highway site as the estimate of the annual second maximum. It must be verified that the monitoring period contained enough meterologically adverse days to make the estimate valid. Such adverse days must be determined using an existing monitoring station nearby which has been operating for at least a year, by a meteorological index, or, less persuasively, by typical rates of occurrence of adverse days for the months encompassed by the monitoring period.

An approach based on using an estimated statistical distribution to estimate the annual statistics from limited measurements was less accurate than the observed-maximum approach.

The degree to which the error in the estimation process creates uncertainty in the estimate was quantified. Means for assessing confidence intervals were recommended.

The project report has been published as:

NCHRP Report 200, "Monitoring Carbon Monoxide Concentrations in Urban Areas."

Research was continued as Project 20-14A.

Project 20-14A FY '79

Statistical Analysis of Ozone Data for Transportation/Air Quality Planning

Research Agency: SRI International Inc.
Principal Invest.: Frank Ludvig
Effective Date: September 15, 1979
Completion Date: December 18, 1981
Funds: $193,907

Federal and state regulations mandate air quality studies to develop strategies for achieving compliance with ozone standards. These air quality studies must frequently inclnde monitoring programs to determine ozone concentrations and the degree of compliance with the air quality standards. However, use of historical data, wherever possible, is a more efficient and practical means to quantify ozone problems and minimize requirements for special monitoring. The major objective of this stndy was to develop the methods needed to analyze existing data and obtain as much information as possible from those data. Corollary objectives were to provide information about additional data needs and ways in which those needs can be met with the least additional monitoring, and to develop methods that provide information necessary for developing effective control strategies. No procedures were developed for designing control strategies, which is a major topic where further research will be fruitful.

All the objectives of the study were met. The rather specialized definitions of "design value" and "expected number of exceedances" that were developed by the U.S. Environmental Protection Agency (EPA) for the case of a single monitor have been broadened for application to regionwide conditions. The approach was to use available data to estimate nnmbers of exceedances and design values for points throughout the region of interest. Initially, points are very widely spaced in order to provide an overall picture of the distribution of these two parameters in the area. The points for which estimates are obtained are then more densely spaced in those areas where the highest design values and the greatest numbers of exceedances have been estimated. In this way it has been possible to estimate the maximum numbers of exceed-

ances and the highest design values occurring in the area and the region in which they are found. These values satisfy the definitions of expected number of exceedances and design value that were derived for a network. Computer programs have been written for processing data to obtain the estimates discussed above. These computer programs and the directions for their use are among the major products of this study.

The deterministic approach to the estimation of regional design values and expected numbers of exceedances described above served as the basis for a probabilistic approach, which used the day-to-day estimates for each grid point of values generated by the deterministic method as a basis for developing conditional probability distributions of ozone concentration. Monte Carlo simulations were used to generate daily estimates of peak-hour ozone concentrations at key locations (those areas where higher design values and greater numbers of exceedances were expected and which had no nearby monitors), based on observed data. This probabilistic method provides a measure of the uncertainty and variability in the deterministic approach. The computer program, and directions for its use to obtain the probabilistic estimates of design value and expected numbers of exceedances are included in the final report.

The methods that have been developed here not only provide estimates of design value and expected numbers of exceedances for the region, but also identify those days when the highest concentrations occurred, which, in turn, allows the analyst to determine the meteorological conditions associated with high ozone concentrations in the region. The air quality data and meteorological information for the high-ozone days can be examined and used to estimate the transported background-ozone concentrations entering the region. The estimation methods are fully described in the report. The determination of the origins of the precursors to the transported ozone through air trajectory analysis is also discussed.

The methods described above were applied to data from four urban regions: Houston, St. Louis, Philadelphia, and Los Angeles. Each of these areas had relatively dense ozone-monitoring networks that had been operated for at least a few months. With the availability of data from these unusually dense monitoring networks, the method could be applied to determine the sensitivity of the results to the number of stations in the monitoring network. A network of about 10 sites was found to be adequate, if the sites are properly located. There is a tendency to underestimate the expected number of exceedances when the number of monitoring sites is reduced. However, the design-value estimates are generally within the range of estimates for a single site, as derived from different EPA-recommended methods.

Studies have shown that a complete monitoring network need not be operated throughout the year. There is a close relationship between peak-ozone value and maximum temperatnre; if data are collected for all days when the maximum temperature in the region exceeds about 20° C, then the estimates of design value and expected numbers of exceedances will be accurate. It appears that the most efficient way to collect adequate ozone-monitoring data in an urban region is to operate about five fixed stations: one in the central part of the city and four in different directions a few tens of kilometers outside the highly urbanized region. This fixed network should be supplemented by mobile monitors operated during warm weather to fill-in the area between the central monitor and the peripheral monitors in the downwind direction.

The project report was published as:

NCHRP Report 238, "Estimating Exceedances and Design Values From Urban Ozone Monitoring Network Data."

The computer tape containing all programs developed during the course of the project may be obtained by request to the NCHRP; a 9-inch diameter (or greater) ASCII 9-track tape (or equivalent) with a density of 800 BPI must be supplied.

Project 20-15 FY '77

Ecological Effects of Highway Fills on Wetlands

Research Agency:	University of Massachusetts
Principal Invest.:	Dr. Paul W. Shuldiner
	Prof. Carl A. Carlozzi
Effective Date:	December 1, 1976
Completion Date:	December 31, 1979
Funds:	$152,085

Many people and organizations are encouraging increased use of bridges rather than earth fills across wetlands to be traversed by highways. Earth fills produce various ecological effects, frequently reported to be detrimental, on wetlands. Reported effects include (a) inhibition of storm water and tidal distribution, (b) increased water turbidity, (c) alteration of water circulation patterns, (d) removal of natural filtration systems, (e) introduction of exotics, (f) inhibition of movement of animals, (g) alteration of biological productivity, and (h) alteration of nutrient flux.

Determination of the impact of a bridge or earth fill on the ecology of a specific wetland is a very complex problem. Nevertheless, transportation agencies are required to make environmental assessments for proposed wetlands facilities. Consequently, a need exists for a better understanding of the ecological effects of highways on wetlands as well as for guidance in making highway location and design decisions when wetlands and associated flood plains are involved.

The over-all objective of this project was to determine the ecological effects of placing highway fills on wetlands and associated flood plains and to develop initial guidelines as a management tool for the decision-making proc-

ess regarding routes, fills, bridges, and other design alternatives.

Research has been completed. Based on a thorough literature review and the experience of the researchers, a state-of-the-art report on the ecological effects of highway fills on wetlands has been prepared and distributed to state highway and transportation agencies. The final report, including manual on the assessment of ecological effects, is scheduled to be published as:

NCHRP Report 218A, "Ecological Effects of Highway Fills on Wetlands—Research Report." NCHRP Report 218B, "Ecological Effects of Highway Fills on Wetlands—User's Manual."

Project 20-16 FY '77

State Laws and Regulations on Truck Size, Weight, and Speed

Research Agency:	R. J. Hansen Associates, Inc.
Principal Invest.:	Ralph D. Johnson
	John C. Laughland
Effective Date:	October 11, 1976
Completion Date:	Septemer 1, 1978
Funds:	$281,975

There is evidence that the diverse requirements of current state laws, regulations, and interstate agreements controlling the interstate and interregional movement of trucks may add unnecessarily to the cost of trucking operations and state administration. A need existed for comparative analyses of the effects of the existing diversities and for the establishment of alternatives to eliminate or minimize those effects by improving the uniformity of the laws, regulations, and agreements. Alternative systems should be designed to facilitate interstate and interregional truck operation with due consideration given to economy, safety, and administrative efficiency.

The objectives of the research were to:

1. Identify and describe the effects of current state size, weight, and speed laws, regulations, and interstate agreements on trucks and the highway systems they use.
2. Investigate the potential benefits and disadvantages of increased uniformity in truck size, weight, and speed limits among states.
3. List and evaluate the available alternatives for eliminating or minimizing the differences in truck size, weight, and speed limits among states.

The research was originally envisioned in two phases. This first phase was intended to synthesize the present system of state regulation of truck size, weight, and speed and to describe its effects.

Phase I included the following tasks:

1. Compilation and comparative summarization of state laws, regulations, and interstate agreements relating to size, weight, and speed of trucks on all highway systems. The results of this task were presented as a synthesis of present state legal requirements regarding (a) regulation of truck size, weight, and speed; (b) the extent of uniformity; (c) the major considerations that have prevented achievement of greater uniformity; and (d) the major measures of interstate cooperation that have been developed to facilitate compliance with the administration of diverse state requirements regarding truck size, weight, and speed.
2. Identification and description of the effects of differences in current size, weight, and speed laws, regulations, and interstate agreements on truck operations among states, including, but not limited to, equipment selection, route selection, equipment utilization, vehicle qualification (permits), and fuel and operating costs. In this task, (a) classifications were developed based on the type of carriers and operations that are responsive to differences in vehicle size and weight, and (b) data were developed to show the impacts of states' nonuniformities of size weight, and speed laws, regulations, and interstate agreements on these classifications.
3. Identification and description of: (a) the influence of different maximum allowable truck sizes, weights, and speeds on the structural and geometric requirements of highways, with appropriate consideration of safety and operational characteristics; and (b) the special state problems and costs of administering the present system of differing truck size, weight, and speed laws, including, but not limited to, record keeping, processing of permits, participation in interstate agreements, revenue accounting, and manpower.

Dependent on the findings of Phase I, a second phase was planned to identify and evaluate alternatives to eliminate or minimize the adverse effects of states' nonuniformities of truck size, weight, and speed limits.

After completion of part of Phase I, the research agency proposed and the project panel approved a plan to merge both phases of the research.

Trucking interests and state highway agencies were contacted through both mail questionnaires and personal visits. Responses were summarized and evaluated. A commodity flow network was developed, and alternative size and weight levels were formulated and evaluated.

Research has been completed, and the final report has been published as:

NCHRP Report 198, "State Laws and Regulations on Truck Size and Weight."

Project 20-17 FY '79

Statewide Freight Demand Forecasting Procedures

Research Agency:	Cambridge Systematics, Inc.
Principal Invest.:	Dr. Paul O. Roberts
	Dr. Brian C. Kullman
Effective Date:	April 1, 1979

Completion Date: July 31, 1980
Funds: $73,151

NCHRP Project 8-17, "Freight Data Requirements for Statewide Transportation Systems Planning," identified many current state planning issues related to freight transportation, described existing analysis techniques that address those issnes, and catalogued a wide variety of available data sources and collection procedures to support those techniques. Projects 20-17 and 20-17A extend this preliminary effort to provide operational freight forecasting techniques for use in policy, system, and project planning at the state level.

The objective of Phase I (20-17) was to propose appropriate, cost-effective, policy sensitive, multiregional and state freight demand forecasting techniques that utilize available information and data, while recognizing the issues states face in freight planning.

In Phase I, the uses of freight demand forecasts in statewide planning, the freight forecasting procedures available, the population and economic activity information necessary as input to freight forecasting procedures, the extent to which the existing procedures meet statewide planning needs, and the types of new procedures required to meet these needs were addressed. The most appropriate techniques to provide the needed levels of forecast detail were determined, and preliminary specifications for statewide freight demand forecasting procedures were prepared.

Loan copies of the agency's final report on Phase I are available (see final page of this section for ordering information). Phase II (20-17A) is currently under way.

Project 20-17A FY '81

Application of Statewide Freight Demand Forecasting Techniques

Research Agency: Roger Creighton Associates, Inc.
Principal Invest.: Frederick W. Memmott
Effective Date: June 1, 1981
Completion Date: January 31, 1984
Funds: $193,500

Freight demand forecasting techniques are not readily available to state agencies for direct application. A related and equally important problem is the lack of freight-flow data at the national and state levels in a form that can be used in forecasting techniques. Because of this paucity of appropriate data and analysis techniques, state agencies cannot adequately address the anticipated impacts of deregulation, shifts in the economic base of an area, transport rate changes, energy availability, service changes, etc. Two major concerns are the availability of service and the effects on transportation facilities caused by overall growth or decline in freight volume, shifts of freight flows among regions or corridors, and shifts between modes.

Several techniques and data bases have been developed but have not been widely applied or fully tested. Further, most of these techniques and data bases were not specifically developed for application at the state level and, therefore, need adaptation for state-level analyses.

The first phase of this research (Project 20-17) identified freight transportation issues that need to be addressed by demand forecasting techniques and proposed a comprehensive research approach to develop a spectrum of such techniques. However, because of limited funding, extensive development work is not possible in this continuation phase.

The objective of Project 20-17A is to demonstrate the applicability of a freight demand forecasting technique for direct use by state agencies. The technique has been designed to develop freight flows by highway, rail, and water for the current year; forecast the likely annual freight volumes and shifts among the modes over the short term (5 years or less); and provide origins and destinations by commodity within a corridor or region at the substate, state, or multi-state level. The technique uses generally available data and methods to facilitate application to specific problems (e.g., deregulation and rate changes).

A user's manual has been developed setting forth how to apply the technique to problems such as the effects of deregulation, energy availability, industry shifts, infrastructure development and maintenance, or financing availability on modal competition. The user's manual provides a step-by-step set of procedures for state agencies to follow in obtaining data and techniques, modifying them if necessary, and applying them to yield appropriate freight forecasts. The user's manual describes (1) the level of analysis to be conducted (i.e., system, network, corridor, etc.); (2) the time frame involved (i.e., the base year and forecast years); (3) the modes included; (4) the commodities to be considered; (5) the specificity of origins and destinations to be developed (e.g., county-to-county); (6) the output of the techniques to be applied; (7) the usefulness of the techniques for various analysis problems; and (8) the role of available demographic and economic forecasts.

Case studies have been completed describing the analysis of commodity flow changes on the New York State Barge Canal System, of grain movements in Montana, and of the technique's applicability in forecasting changes in truck travel. The final report (user's manual) has been completed and published as:

NCHRP Report 260, "Application of Statewide Freight Demand Forecasting Techniques."

Project 20-18 FY '79

Evaluation of Highway Air Pollution Dispersion Models

Research Agency: SRI International
Principal Invest.: W. F. Dabberdt

Effective Date: March 15, 1979
Completion Date: February 28, 1982
Funds: $207,509

Federal and state regulations required that environmental impact statements (EIS) be prepared for highway projects. The air quality portion of an EIS usually includes micro-scale modeling of current and future carbon monoxide concentrations. A number of microscale models had been developed; they vary in approach, complexity, accuracy, and cost. However, due to lack of an independent comprehensive analysis of model performance for a variety of data bases, predictions made with these models might be unreliable. The air quality, meteorological, and traffic data necessary for such an analysis existed but had not been assembled or evaluated. Therefore, analyses of these models and existing data were needed.

The general objective of the research was to develop methods for evaluating the performance of highway air pollution dispersion models, assemble and document a data base to be used to assess model performance, and perform a preliminary evaluation of selected models to demonstrate the application of the methodology.

All of the study objectives were met. The evaluation methodology comprises both statistical analysis and sensitivity analysis. In the statistical method, six statistics were defined that describe the predictive performance of dispersion models in three complementary categories; ability to predict exceedances of concentration thresholds (which may be equal to ambient air quality standard); ability to track pollutant levels in space and time; and ability to replicate the numerical value of observed concentrations. The six statistics were combined into a single figure of merit that describes the composite performance of the model. The statistical method takes into consideration the presence of error in the measured pollutant concentrations. The formulas for the six statistics have been modified to include the effect of two types of observational error: errors defined as a percentage and errors specified as a constant bound. A computer program was prepared that performs several diagnostic analyses of model behavior. A method was defined for performing sensitivity analysis by computing the sensitivity matrix given the estimated errors in the input parameters of the model.

A comprehensive data base was assembled, which includes data from (1) at-grade, elevated, and depressed roadways; and (2) five data sets provided by SRI International, Texas A&M University, New York State Department of Environmental Conservation, California Department of Transportation, and General Motors Corporation. The application of the evaluation methodology was demonstrated by performing a preliminary assessment of the performance of six selected models, four Gaussian and two numerical.

The final report has been published as:

NCHRP Report 245, "Methodology for Evaluating Highway Air Pollution Dispersion Models." The computer tape containing the model evaluation method and the comprehensive data base may be obtained by request to the NCHRP; a 12 inch diameter and an 8 inch diameter ASCII 9-track tape (or equivalent) with a density of 1600 BPI must be supplied.

Project 20-19 FY '85

Pedestrian Convenience and Safety on Suburban and Rural Highways

Research Agency: JHK & Associates
Principal Invest.: Steven A. Smith
Effective Date: May 1, 1985
Completion Date: July 31, 1986
Funds: $160,000

As the American population shifted from urban centers to more dispersed settings in suburban and rural areas, traffic volumes on highways increased substantially. The population shift, combined with changing land use patterns, increasing energy costs, and a renewed interest in physical fitness, has resulted in increased pedestrian demand. Highway planners and designers have been cognizant of increased traffic volumes, but have been remiss in not adequately considering the convenience and safety of those walking in suburban and rural areas.

Pedestrian circulation systems in suburban and urbanizing rural areas are incomplete and ineffective. These situations have resulted in a rising level of pedestrian-vehicle conflicts on high-speed, high-volume highways. In the past solutions to pedestrian vehicular conflicts in these areas, which differ from the conflicts of urban areas, have favored vehicular traffic. Convenient, yet safe, pedestrian access to and from magnets, such as redeveloping and changing strip commercial areas, shopping centers, office complexes, and mixed-use areas, is needed. Pedestrians need facilities that will not force them either to be dependent on automobiles or to take the risk of walking in unsafe circumstances. They need convenient and low-risk linkages between magnets.

Current trends in suburban revitalization (2nd phase growth) fostered by governmental policy and responded to by private development initiatives suggest that there will be many opportunities to modify and improve pedestrian facilities in the near future while remaining cognizant of the need for safe and efficient traffic flow. There is a need for cost effective solutions for pedestrian circulation which take into account the physical and demographic characteristics of an area. Furthermore, there is a need for a methodology for such solutions to assist decision-makers, planners, and the public in understanding and evaluating available options.

The general objective of this research is to develop a planning and implementation methodology to assist planners, designers, decision-makers, and the public in providing convenient and safe pedestrian movement for

suburban areas having a heavy traffic corridor with adjacent pedestrian magnets, and in rural areas that are in, or likely to be in, transition to suburban areas. The planning methodology should have application to the creation of coherent (usable, understandable, continuous) pedestrian circulation for high activity subareas with the potential for connection to communitywide systems, but not dependent on their presence. The following tasks will be performed:

Task 1—Structure the pedestrian problem for suburban and rural areas and conduct a literature review of solutions that provide convenient and safe movement of pedestrians.

Task 2—Define success and failure of existing pedestrian circulation systems. Identify and document examples of success and failure in providing coherent pedestrian circulation. Documentation should cover site-specific conditions, including institutional arrangements (public and private sector roles and responsibilities, and citizen participation) associated with success and failure.

Task 3—Based on an analysis of pedestrian needs, identify possible solutions which have not been discovered in the literature or in field studies but which may be feasible in the current context. Evaluate their effectiveness.

Task 4—Synthesize and evaluate the state of the art and state of practice from the knowledge gained in Tasks 1, 2, and 3. Prepare a synthesis report containing the following major components:

- *Literature Review:* critical evaluation of research related to pedestrian circulation systems in suburban and rural areas.
- *State-of-the-Art:* description of guidelines and procedures currently used in planning for pedestrian systems.
- *State-of-the-Practice:* results of the case study and data collection effort. A review of successful and unsuccessful systems, specifically the applicability of various potential solutions to the various development settings.
- *Alternative Solutions:* a description of new and innovative approaches to problems in pedestrian circulation systems.

Task 5—Develop guiding principles and design considerations that will assist planning and design professionals to provide coherent pedestrian circulation. Formulate these principles and considerations into a planning and implementation methodology. (This task could include the development of new methodology and implementation techniques that are not derived from past practice or experience.)

Progress to December 31, 1985 includes the completion of many activities leading to the characterization of the state of the art and the state of practice for pedestrian planning and implementation Literature has been reviewed for both foreign and domestic experience, accident data analyzed from the Fatal Accident Reporting System and the National Accident Sampling System, data tabulated from agency surveys, interviews of focus groups completed, 160 site inventories completed, and problems categorized. The synthesis is anticipated early in 1986.

Project 20-20 FY '83

STRS Pre-Implementation Research

Research Agency: AASHTO
Principal Invest.: L. Gary Byrd
Effective Date: October 1, 1984
Completion Date: September 30, 1986
Funds: $500,000

The Strategic Transportation Research Study (STRS) conducted by the Transportation Research Board and published in *TRB Special Report 202,* "America's Highways—Accelerating the Search for Innovation," detailed a concerted research effort needed to produce major innovations for increasing the productivity and safety of the nation's highway system. The American Association of State Highway and Transportation Officials (AASHTO), under NCHRP Project 20-20, has overall responsibility for conducting a pre-implementation effort that will produce a plan for carrying out the research identified as, "The Strategic Highway Research Program (SHRP)."

In order to carry out the program, three major tasks must be undertaken. First, a plan must be developed to provide the institutional requirements needed to organize, administer, and coordinate the research program. Second, detailed research plans must be prepared and coordinated for each of the six research areas identified in the STRS report. Third, the institutional arrangements and research plans must be implemented so that the program is fully operational at the earliest practical date (estimated to be in 1986).

Project 20-20 includes the following tasks:

1. Developing and recommending appropriate and detailed institutional plans for conducting and monitoring the Strategic Highway Research Program. Extensive consultation with all affected agencies, both public and private, will be required to be assured that the resulting plan (1) provides a practical, efficient mechanism for carrying out the research and implementing the research findings, (2) interfaces with and supports the ongoing NCHRP, FCP, and HP&R programs, (3) utilizes the technical skills and resources of the research community in an efficient, equitable and uniform manner, (4) includes appropriate private sector participation in technical guidance, administrative support, and, where practical, financial participation in the program, and (5) includes the governments and institutions of other countries in, at least, a coordinating role with an active participating role where practical.
2. Providing support and recommendations useful to the NCHRP in entering into study contracts to obtain detailed research plans in each of the six program areas.
3. Coordinating the proposed Strategic Highway Research Program and the six study areas with existing and on-going research activities in other NCHRP and FCP programs.
4. Providing the coordination, technical support and oversight of the initial $1 million research project already authorized and funded under the NCHRP to study the properties of asphaltic materials.
5. Preparing technical materials and analyses useful in the development of legislation required for the program.

In addition to the primary contract with AASHTO, the following NCHRP contracts have been executed:

Project:	20-20(2), FY '83
Title:	Overview and Integration Planning, SHRP
Research Agency:	University of Maryland
Principal Invest.:	Lowell K. Bridwell

Project:	20-20(3)
Title:	Detailed Planning for Research on Asphalt Properties
Research Agency:	ARE Inc.
Principal Invest.:	Fred N. Finn

Project:	20-20(5)
Title:	Detailed Planning for Research on Maintenance Effectiveness
Research Agency:	Texas Research & Development Foundation
Principal Invest.:	Bertell C. Butler, Jr.

Project:	20-20(6)
Title:	Detailed Planning for Research on Bridge Component Protection
Research Agency:	David G. Manning
Principal Invest.:	Dr. David G. Manning

Project:	20-20(7)
Title:	Detailed Planning for Research on Cement and Concrete
Research Agency:	Construction Technology Laboratories/PCA
Principal Invest.:	Paul Klieger

Project:	20-20(8)
Title:	Detailed Planning for Research on Snow and Ice
Research Agency:	U.S. Army Cold Regions Research and Engineering Laboratory
Principal Invest.:	David Minsk

In addition to the above six NCHRP contracts, the FHWA is conducting Project 20-20(4), "Detailed Planning for Research on Pavement Performance."

The objective of each project is to develop a detailed research plan to provide the basis for a major research effort to be conducted following the pre-implementation project. The detailed research plans will be guided by the budget and schedule shown for the subject research area in *Special Report 202*. The plans will include a detailed description of each individual research project including the tasks, level of effort, required resources, schedule, and budget. The research plans will show the interrelationships of the projects, the timing and sequencing of each, and the assumptions or dependent conditions for each project.

An advisory committee has been appointed to provide guidance to each contractor. A national workshop was also conducted to obtain input from the participants on concepts, criteria, and general content of the research design.

Each study is being guided by the NCHRP Project Panel SP20-20 and the SHRP Interim Director, as well as by input from the advisory committees and other resources. Each agency is responsible also for obtaining iuput from a wide spectrum of the highway commuuity including public, private, domestic, and foreign organizations.

The detailed research plans for each technical area will be completed by February 1986, and an integrated plan will be developed by overview consultant, The University of Maryland. These products will be used by the AASHTO task force on SHRP to develop its final recommendations for the 5-year research program.

Project 20-21 FY '86

Development of an Automated Field Survey Data Collection System

Research Agency: ARE Inc./Cooper Technology
Principal Invest.: Hurbert Henry
Frank F. Cooper
Effective Date: January 6, 1986
Completion Date: April 5, 1987
Funds: $200,000

In the past, few transportation agencies performed comprehensive analyses of survey operations within their organizations. However, with a diversity of high-tech "total stations" and "data collectors," and various software systems now available, many agencies are faced with problems of integrating these components into their surveying operations. Unfortunately, there is uncertainty as to how to best accomplish this integration. In addition, field survey data must be suitable for fast, efficient transfer to and from other engineering systems, such as computer-aided design and drafting programs. These issues, coupled with an increase in transportation construction projects nationwide, and an increased need for more accessible survey data, create pressure on agencies to provide "quick fix" purchases and approaches. This, in turn, results in possible wasted time and duplicated effort, as similar, but incompatible, systems are developed and tested.

Because of the demand for field survey information in varying formats and accuracies for projects and records, there is a need to integrate the different phases in handling survey information and to automate as many tasks as possible. An initial step in dealing with this problem is to develop an automated field survey data collection system that includes preprocessing and storage of the data in a standard file for subsequent electronic transfer to engineering design systems.

The objective of this research project is to define, develop, and demonstrate an automated system for collecting, preprocessing, and storing field survey data in a standard file format. The file format shall be suitable for subsequent and selected electronic transfer to transportation engineering design systems, such as RDS, ICES, and IGDS. To accomplish this objective, the following tasks are required.

Task 1—Define the data file elements needed from field surveys to universally support various transportation engineering design systems. A standard ASCII file format shall be specified for storing the data elements.

Task 2—Determine the needed raw field survey data that must be collected or specified to calculate the elements of Task 1. Define the functional requirements for a generic electronic data collector using RS232-C interfacing for receiving information from commercially available survey total stations and for the subsequent transfer to the preprocessing system to be developed in Task 3.

Task 3—Develop the processes for converting the raw data of Task 2 into the standard, universal file format of Task 1. Interactive edit capabilities shall be included. All software is to be written in Fortran 77 language capable, with minimal specialized tailoring, of being run on micro-, mini-, and mainframe computers.

Task 4—To the extent possible on existing equipment or as modified, demonstrate the system developed in Tasks 1 through 3 for collecting, preprocessing, and storing of field survey data in the standard file format. In addition and as part of the demonstration, data from the standard file shall be electronically transferred to selected portions of one or more major engineering design systems.

Task 5—Prepare a complete software documentation package for all developed programs and systems, including specifications for user-developed interface programs. This documentation shall be in conformance with all elements of FIPS-PUB-38 titled, "Guidelines for Documentation of Computer Programs and Automated Data Systems," level 4. An outline of the complete software documentation package will be submitted 6 months after contract initiation for review and approval by the NCHRP.

AREA 21: TESTING AND INSTRUMENTATION

Project 21-1 FY '70

Instrumentation for Measurement of Moisture

Research Agency: Research Triangle Institute
Principal Invest.: Dr. L. F. Ballard
Effective Date: August 25, 1969
Completion Date: February 24, 1971
Funds: $35,027

Water in its various states, when insufficient or in excess in the components of a highway system, adversely affects the latter's service behavior. Despite recognition of the importance of the relationship between the presence of water and service behavior, the engineer has been hampered in his effort to provide predictable performance by the lack of instrumentation and techniques for adequate water or moisture measurement. The economic significance of the problem in highway construction and maintenance is particularly evidenced by the large financial investment aimed at removal of excess water which causes loss of supporting capacity of subgrade soils and aggregate bases, embankment instability, and deterioration of pavements.

The objective of this project was to evaluate, on the basis of a comprehensive literature review, the suitability of existing instrumentation and techniques to measure the amount and state of water in highway components such as embankments, subgrades, base courses, and structures.

The research has been completed, and the project report has been published as:

NCHRP report 138, "Instrumentation for Measurement of Moisture—Literature Review and Recommended Research."

Project 21-2 FY '71

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency: Southwest Research Institute
Principal Invest.: Dr. C. G. Gardner
Effective Date: February 1, 1972
Completion Date: January 31, 1974
Funds: $64,976

There is an immediate need for reliable instrumentation to measure the moisture, in situ, in soil and untreated granular materials used in such highway substructures as subgrades, embankments, slopes, backfills, and base courses.

It is recognized that the moisture sensor is the critical component of any moisture measurement instrument or technique. For this reason, this project is to concentrate on the development of new and innovative, or modification of currently available, sensors for moisture measurement.

The objectives of this project were to design, build prototype models, and conduct laboratory verification programs for one or more sensors capable of measuring moisture in granular and soil materials that would be suitable for highway needs. During the initial phase of the study, nuclear magnetic resonance (NMR) and microwave absorption approaches were investigated independently. In general, satisfactory performance was achieved using the NMR approach, but considerable difficulty was encountered with the microwave technique. As a result, the experimental verification phase was limited to the NMR sensor.

Research has been completed, and an NMR sensor has been developed for measurement of moisture in fine-grained soils. The prototype model has undergone laboratory testing and is considered suitable for further development and field evaluation.

The technology on which the prototype sensor is based is described in a paper by Gardner & Matzkanin, published in TRB Record 532. Information contained in the project report is included in the Project 21-2(3) report.

Project 21-2(2) FY '72

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency: State U. of New York at Buffalo
Principal Invest.: Dr. E. T. Selig
Effective Date: April 1, 1972
Completion Date: September 30, 1973
Funds: $29,953

There is an immediate need for reliable instrumentation to measure the moisture, in situ, in soil and untreated granular material materials used in such highway substructures as subgrades, embankments, slopes, backfills, and base courses.

It is recognized that the moisture sensor is the critical component of any moisture measurement instrument or technique. For this reason, this project is to concentrate on the development of new and innovative, or modification of currently available, sensors for moisture measurement.

The objectives of this project were to design, build a prototype model, and conduct a laboratory verification program for a sensor capable of measuring moisture in granular and soil materials that would be suitable for highway needs.

Research has been completed, and a sensor has been developed based on the use of electrical capacitance as a measure of soil moisture. The prototype model has undergone laboratory testing and is considered suitable for further development and field evaluation.

The technology on which the prototype sensor is based is described in a paper by Selig, Wobschall, Mansukhani, and Motiwala published in TRB Record 532. Information contained in the project report is included in the Project 21-2(3) report.

Project 21-2(3) FY '75

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation)

Research Agency: Southwest Research Institute
Principal Invest.: George A. Matzkanin
E. T. Selig (SUNY)
Effective Date: September 3, 1974
Completion Date: December 31, 1979
Funds: $154,452

There is an immediate need for reliable instrumentation to measure the moisture, in situ, in soil and untreated granular materials used in such highway substructures as subgrades, embankments, slopes, backfills, and base courses. It is recognized that the sensor is the critical component of any moisture measurement instrument or technique. For this reason, NCHRP Projects 21-2 and 21-2(2) concentrated on the development of new and innovative moisture sensors. Prototype moisture sensors based on nuclear magnetic resonance (NMR) and electrical capacitance technology have been developed under these projects and subjected to laboratory testing.

The objective of this project was further refinement and field evaluation of the two prototype moisture sensors

developed under Projects 21-2 and 21-2(2). This included fabrication of the sensors and readout instrumentation, their installation in the subgrade portions of pavements in Arizona and Pennsylvania, and evaluation of data collected at the field sites.

Research has been completed, with accomplishment of the intended tasks. Although neither sensor meets all of the desired criteria, the research indicates that each has some potential for practical applicaton to the soil moisture measurement problem. Operational problems encountered during the field evaluation should be resolved during the development of production models. A production model of the dielectric sensor is available from Ecotec Corp., Needham Heights, Mass.

The essential findings of the study have been published as NCHRP Research Results Digest 121. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series but is available on a loan basis (see final page of this section for ordering information).

AREA 22: VEHICLE BARRIER SYSTEMS

Project 22-1 FY '69

Concepts for Improved Traffic Barrier Systems

Research Agency: Walter W. White
Principal Invest.: Walter W. White
Marvin A. Shulman
Effective Date: October 1, 1970
Completion Date: December 31, 1971
Funds: $25,000

Conventional traffic barrier systems are presently being applied widely by highway and bridge engineers. All of these existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized, longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails. The system should present a reasonably consistent appearance to the motorist as he moves along the highway and over structures, although parameters (such as height, post spacing, section properties, and anchorage) may vary to suit the application. Emphasis should be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

The objective of the research was to produce one or more traffic barrier system designs, described with sketches and narrative to the degree necessary to convey understanding, that offer promise of: preventing penetration by a standard-size U.S. automobile weighing 4,000 to 5,000 lb and impacting at 25° and 65 mph; smoothly redirecting errant vehicles relatively parallel to traffic flow; providing a range of controlled dynamic deflections by varying design parameters; retaining longitudinal continuity following a collision; permitting adequate visibility; being capable of quick and easy repair; performing satisfactorily in various foundation conditions; limiting decelerations at the center of gravity of the vehicle to 5g lateral, 10g longitndinal, and a total of 12g when averaged over any 200-millisec period; having reasonably low first cost and pleasing appearance; and minimizing vehicle damage. The design was analyzed and technical information was presented to demonstrate the degree of achievement of the foregoing. Working drawings suitable for fabrication and installation of a prototype were prepared for each barrier system.

The final report was not published in the NCHRP report series; however, microfiche of the report may be purchased (see final page of this section for ordering information).

Project 22-1A FY '73

Testing and Evaluation of Bridge Rail Concepts

Research Agency: Texas A & M University Research Foundation
Principal Invest.: T. J. Hirsch
Effective Date: March 1, 1974
Completion Date: May 30, 1975
Funds: $40,000

Conventional traffic barrier systems are presently being applied widely by highway and bridge engineers. All of these existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized, longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails. The system should present a reasonably consistent appearance to the motorist as he moves along the highway and over structures, although parameters (such as height, post spacing, section properties, and anchorage) may vary to suit the application. Emphasis should be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

The objectives of NCHRP Project 22-1, "Concepts for Improved Traffic Barrier Systems," were accomplished by the development of a traffic barrier system that was analyzed using the Barrier IV computer program. The results of this analysis indicate that the proposed system meets the desired criteria.

The objective of Project 22-1A was to evaluate the prototype of the proposed barrier by full-scale impact tests.

The accomplishment of this objective included the following tasks:

1. Fabrication and construction of the barrier system shown in Figure 6 of the final report on Project 22-1 (Pages 148 to 173, *NCHRP Summary of Progress Through 1972*).

2. Testing and evaluation of the system under the following impact conditions:

(a) A passenger vehicle impacting the bridge rail at 60 mph and 25°.
(b) A passenger vehicle impacting the bridge rail at 60 mph and 7°.
(c) A passenger vehicle impacting the approach railing-bridge rail transition at 60 mph and 25°.

Research has been completed, and the essential findings have been summarized in NCHRP Research Results Digest 81, "Crash Testing and Evaluation of Attenuating Bridge Railing System."

Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

Project 22-2 FY '69, FY '72 and FY '73

Traffic Barrier Performance and Design

Research Agency:	Southwest Research Institute	
Principal Invest.:	M. E. Bronstad	
	J. D. Michie	
Effective Date:	Jan. 1, 1972	Oct. 1, 1973
Completion Date:	Sept. 30, 1973	Mar. 31, 1975
Funds:	$125,000	$80,000

Conventional traffic barrier systems are presently being widely applied by highway and bridge engineers. All of the existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails.

Among the most important of current needs in the area of vehicle barrier systems is a safer terminal design. The work of Project 22-2 was structured to emphasize the systematic experimental development of terminal treatments to fulfill this need. Terminal treatments for a number of selected guardrail systems were investigated. This study built on earlier preliminary NCHRP efforts that are described in NCHRP Reports 118 (1971) and 129 (1972).

The initial task in Phase I included a review of terminal concepts previously developed under Project 15-1(2), the development of several new concepts, and an examination of concepts developed outside the NCHRP. More than 20 of these concepts have come under consideration. This work was covered in an interim report that was submitted to the project panel in April 1972 and was subsequently accepted. Although the report will not be published, it is available on a loan basis.

Based on the interim report, the project panel selected designs and established priorities for full-scale testing of several terminal systems. The experimental program consisted of some 26 full-scale crash tests. Interest in this testing was concentrated on a breakaway cable terminal (BCT) in combination with the W-beam guardrail and median barrier systems most often used. Ten crash tests were carried out on the BCT with the flared W-beam guardrail. The second part of the experimental program, comprising some 16 tests, was concentrated on the development of a crash-cushioning terminal for use with median barriers.

Microfiche of the agency's Phase I report may be purchased (see final page of this section for ordering information).

Phase II research has been completed. Task 1 led to the refinement of BCT designs to provide more safety to smaller cars and to improve economy relative to the first cost, maintenance, and repair. Findings from the Phase II research were reported in NCHRP Research Results Digest 84 (March 1976).

Microfiche of the agency's final report on Phase II may also be purchased (see final page of this section for ordering information).

Subsequently, the Federal Highway Administration sponsored additonal tests on the median barrier BCT. NCHRP Research Results Digest 102 summarized the findings of these and previous tests and clarified recommended details for both guardrail and median barrier terminals with either steel or timber posts.

A separate task of Phase II, funded at $20,000, was intended to develop uniform barrier testing criteria and procedures. Research has been completed on this task, and the final report has been published as:

NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances."

Project 22-2(2) FY '73

Multiple Service Level Highway Bridge Railings—Performance and Design Criteria

Research Agency:	Southwest Research Institute
Principal Invest.:	M. E. Bronstad
Effective Date:	August 1, 1976
Completion Date:	April 30, 1979
Funds:	$195,000

Current design specifications for bridge railing systems are predicated on a general performance requirement of assured containment. Decelerations and trajectories experienced by "average" vehicles impacting bridge railings at speeds and angles normally associated with primary and Interstate highways must be tolerable. The "average" vehicle referred to in AASHTO specifications is not defined but is generally considered to be a full-size domestic passenger car. Impacts by 4,000- to 4,500-lb (1,820 to 2,040 kg) vehicles at speeds in the 50- to 70-mph (80.5

to 112.6 kph) range with impact angles of up to 25° have been considered to be appropriate full-scale crash test conditions. Excessive vehicle decelerations or penetration of the bridge railing under these test conditions have been considered to constitute unacceptable performance.

Bridge railing systems used on primary and Interstate highways can be categorized as "normal service level" railings and must meet the above performance requirements. These are generally designed through application of static-elastic design criteria expressed in the AASHTO Standard Specifications for Highway Bridges. The resulting designs may have substantial structural integrity and a concomitant substantial cost. Routine verification of these designs through full-scale impact testing is not required by AASHTO specifications.

Many secondary or local roads are designed for and subjected to operating speeds, traffic volumes, vehicle weights, and possibly vehicle-barrier impact angles that are somewhat less than the "normal service level." These roadways can be considered to serve a "lower service" need, and, in the view of some, the application of "normal service level' bridge railing design criteria may not be cost-effective in these instances.

There are also situations where circumstances call for a higher level of performance than usual on primary or on Interstate highways. This may be due to heavy traffic volume, a preponderance of truck traffic, severe geometric conditions, or vulnerable land use beneath the bridge. In these cases, designers may consider using a high-performance railing such as the collapsing steel ring system recently developed by the Federal Highway Administration.

Accordingly, development of an array of service levels, performance criteria, and design criteria would prove useful to those desiring to use more appropriate and cost-effective bridge railings.

The initial objective of this project was to identify and document realistic performance criteria and correlated design criteria for bridge railing systems on roadways providing various (at least three—normal, higher, and lower) levels of service. The major objective was to develop at least one design based on criteria for the lower service level and to validate this system using analytical and full-scale testing methods.

The research included the following tasks:

1. Identify traffic and other parameters for use in defining appropriate categories of roadway service levels.
2. Establish reasonable performance criteria for bridge railings to be employed in each category.
3. Propose bridge railing design criteria for each category.
4. Develop and validate, through analytical simulation and full-scale testing (in accordance with the relevant provisions in NCHRP Report 153), at least one lower service level bridge railing design with first cost and maintenance advantages over normal service level systems. The railing will be designed according to the criteria proposed in Task 3, to give performance consistent with the criteria developed in Task 2. Bridge railing designs considered in this task may include some already in use.
5. Through analytical simulation, evaluate the performance of this railing when struck by a 25,000-lb (11,340 kg) school-type bus under various impact conditions.
6. Compare the developed bridge railing design with the present AASHTO static-elastic bridge railing design requirements.
7. Recommended appropriate modifications to current bridge railing design practice based on this study.

Research has been completed, and loan copies of the final reports on Phase I (Tasks 1-3) and Phase II (Tasks 4-7) may be obtained from the NCHRP upou written request.

Project 22-2(3) Fy '78

Multiple Service Level Highway Bridge Railings—Selection Procedures

Research Agency:	Southwest Research Institute
Principal Invest.:	Maurice E. Bronstad
Effective Date:	January 1, 1979
Completion Date:	May 31, 1981
Funds:	$200,000

The concept of multiple service level bridge railings was developed in NCHRP Project 22-2(2). The objective of Project 22-2(3) is to further refine these procedures to make them more usable and accurate with respect to the needs of the highway community. Certain improvements have already been indicated from comments received on the initial studies.

Several aspects of the Multiple Service Level Approach (MSLA) are controversial and more comprehensive investigations were needed. The following steps were carried out in this program:

1. Perform a sensitivity analysis and refine MSLA procedures accordingly.
2. Develop bridge railing systems for a number of service levels.
3. Determine total costs of bridge railing systems for a number of service levels.
4. Based on cost, determine number of service levels needed.
5. Develop an upgrading strategy using MSLA.
6. Prepare a users' manual for practicing engineers.
7. Assess the legal implication of MSLA and make modifications as indicated.

Research has been completed, and the final report published as:

NCHRP Report 239, "Multiple-Service-Level Highway Bridge Railings Selection Procedures." The findings of a small side study on the breakaway cable terminal have been published as Research Results Digest 124.

Project 22-2(4) FY '79

Procedures for Testing Highway Appurtenances

Research Agency: Southwest Research Institute
Principal Invest.: Jarvis D. Michie
Effective Date: May 1, 1979
Completion Date: February 28, 1981
Funds: $30,000

In 1962, the first procedures for full-scale vehicle crash testing of guardrails were published in *Highway Research Correlation Services Circular 482.* The one-page document delineated vehicle mass, impact speed, and approach angle. Although *Circular 482* did bring some some order to traffic barrier research being performed at several research agencies, a number of questions arose that were not addressed.

Under NCHRP Project 22-2, SwRI addressed these questions and developed NCHRP Report 153, "Reecommended Procedures for Vehicle Crash Testing of Highway Appurtenances" (1974), which provided testing and research agencies with recommended procedures to vehicle crash test highway appurtenances. The procedure represented technical input from more than 70 individuals and agencies and the results of extensive deliberation of a special ad hoc panel. It was recognized then that several parts of the procedures were based on inadequate experience or research. It was decided, however, to retain coverage of these areas in order to provide a more complete testing procedure.

These procedures have gained wide acceptance since their publication in 1974. It was recognized at that time that periodic updating would be needed, and, in January 1976, TRB Committee A2A04 accepted the responsibility of maintaining the efficacy of the procedures. Questionnaires were submitted to committee members in late 1976 to ascertain areas of the document that needed revision. The responses generally fell into two categories: (1) minor changes that would require expanded discussions of certain provisions and problem areas and the addition of more detailed guidelines; and (2) major changes that would require broadening the scope to include testing with trucks and buses, reevaluating the criteria for impact severity, and treating special highway appurtenances such as construction barriers. The committee agreed to address the minor changes through special committee action; this was done, and *Transportation Research Circular No. 191* is the product of TRB Committee A2A04. For the major changes, the committee felt that the task was beyond its resource and requested TRB/NCHRP to investigate the possibility of having the work performed under a funded research contract. Project 22-2(4) was intended to address these major changes. Its objective was to review, revise, and expand the scope of *Transportation Research Circular No. 191* to reflect current technology. This study permitted research on points needing more in-depth analysis than could be provided by the TRB Committee.

Research has been completed, and the final report has been published as:

NCHRP Report 230, "Recommended Procedures for Safety Performance Evaluation of Highway Appurtenances."

Project 22-3 FY '73

Field Evaluation of Vehicle Barrier Systems

Research Agency: Calspan Corporation
Principol Invest.: J. W. Garrett
N. J. DeLeys
Effective Date: January 1, 1974
Completion Date: February 15, 1975
Funds: $25,000

The relative in-service performance of most guardrail systems is nnknown. Although over-all performance of guardrail installations, in general, might be determined from state and national efforts in accident investigations, limitations in the data preclude the analysis of specific guardrail systems in terms of safety and cost. Accordingly, the relative merits of two or more systems must be evaluated on the basis of idealized laboratory experiments (including full-scale crash tests) and gross accounting procedures. The use of accident data to evaluate the field performance of barrier systems would be very desirable.

The objective of this project was to determine the degree to which accident data currently being accumulatd by varions agencies meet the needs of those concerned with the effectiveness of vehicle barrier systems and, to the extent warranted, to recommend new approaches that may better serve those needs.

Accomplishment of the objectives of this project included the following tasks:

1. Ennmerate the specific items of information that are of interest in evaluation of the field performance of vehicle barriers, including angle and speed of impact, location of impact, frequency of occurrence, cost of damage to barrier system, permanent deformation of system, vehicle damage, occupant injury, and post-impact behavior of both barrier and system.
2. Identify the primary existing sources of accident data.
3. Classify the information available from each of these sources as to its suitability to the needs identified in Task 1.
4. Recommend several alternative processes for using available data and for collecting new types of data that would be more appropriate than those available. This task also considered potential sources of funding.
5. Outline subsequent research to systematically collect and evaluate accident data.

6. To the extent possible within the funding and time constraints, analyze and discuss in the final report such useful data as were discovered during this study.

Research has been completed, and the essential findings from the final report have been summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Microfiche of the agency's final report may be purchased (see final page of this section for ordering information).

Project 22-3A FY '73

Field Evaluation of Vehicle Barrier Systems

Research Agency: Arthur L. Elliott
Principal Invest.: Arthur L. Elliott
Effective Date: July 1, 1974
Completion Date: December 31, 1974
Funds: $10,000

The relative in-service performance of most guardrail systems is unknown. Although over-all performance of guardrail installations, in general, might be determined from state and national efforts in accident investigations, limitations in the data preclude the analysis of specific guardrail systems in terms of safety and cost. Accordingly, the relative merits of two or more systems must be evaluated on the basis of idealized laboratory experiments (including full-scale crash tests) and gross accounting procedures. The use of accident data to evaluate the field performance of harrier systems would be very desirable. The use of formal accident reports has been investigated under NCHRP Project 22-3.

At the same time, Project 22-3A was concerned with an investigation of a less formal approach to barrier evaluation. This approach consisted of personal interviews with highway agency maintenance, safety, and traffic operations personnel to obtain any data they may have and to solicit their subjective opinions on the performance of various barriers. Five representative states were visited for this purpose.

Research has been completed, and the essential findings from the final report have beeu summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Microfiche of the agency's fiual report may be purchased (see final page of this section for ordering information).

Project 22-4 FY '83

Performance of Longitudinal Traffic Barriers

Research Agency: Southwest Research Institute
Principal Invest.: J. D. Michie, M. E. Bronstad
Effective Date: July 1, 1983
Completion Date: December 31, 1985
Funds: $500,000

The number of small cars in use in the United States is growing rapidly, and the changing characteristics of the vehicle fleet must be considered in highway safety design. NCHRP Reprt 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," which was published in 1981, specifies an 1,800-lb vehicle for use in certain crash tests to evaluate safety performance. To date, few longitudinal barriers have been tested under all of the conditions specified in NCHRP Report 230; therefore, designers do not have sufficient information to select barrier systems that will perform satisfactorily.

There is a need to provide such information on guardrail, median barrier, and bridge railing systems that have been fully tested and found to comply with the requirements of NCHRP Report 230, and a need also exists to delineate the upper limits of effectiveness for each system.

The objective of this project is to develop an array of longitudinal traffic barriers and demonstrate their suitability for immediate application based on successful crash test performance.

This project consists of two phases:

Phase I (completed):

Task 1. Reviewed, evaluated, and documented available data from crash tests on longitudinal traffic barriers for the purpose of determining compliance with the requirements specified in NCHRP Report 230. Special emphasis was given to barrier systems presently being installed and those already in-place in large numbers.

Task 2. Evaluated the selected barrier systems for occupant risk by testing with 1,800-lb sedans (Test 12 in Table 3 of NCHRP Report 230). The purpose of this task was to establish baseline data for the occupant risk test with the 1,800-lb sedan. These data were then used to make decisions regarding the adequacy of existing systems, the need for modifying or retrofitting existing systems, and the need for developing new systems. Eleven barrier systems were tested and all provided satisfactory performauce.

Task 3. Based on the results of Task 2, modifications to existing systems did not appear necessary. Therefore, the original scope of Task 3 (to develop modifications) was revised to develop additional tests for existing systems.

Task 4. Prepared an interim report on the findings for Tasks 1, 2, and 3.

Phase II (currently underway):

Task 5. Evaluate the performance of the selected barriers by full-scale crash testing using Test S13 in Table 4 of *NCHRP Report 230.*

Task 6. Prepare a letter report on the findings of Task 5 and propose a detailed working plan for Task 7.

Task 7. By appropriate use of existing data, analyses, and full-scale crash tests, identify and evaluate terminals

and transitions for systems developed in Task 5, and delineate the upper limit of test conditions for which the system will provide adequate performance.

Task 8. Prepare a final report on the findings of the entire study, including a user's manual containing detailed drawings and guidelines for use of the recommended systems, and submit a composite film and accompanying script illustrating the performance of the systems developed in this study.

Throngh December 31, 1985, all research has been completed except for the submission of the draft final report. A 3 to 4 months' time extension is pending.

Project 22-5 FY '84

Develop Performance Standards and Hardware for Low Service Level Guardrail Systems

Research Agency: Southwest Research Institute
Principal Invest.: L. R. Calcote
Effective Date: May 1, 1985
Completion Date: January 31, 1987
Funds: $200,000

Currently operational guardrail systems have been developed for 60-mph, 25-degree impacts with 4,500-lb vehicles. The use of design criteria based on this severe test condition has resulted in relatively expensive installations (e.g., high-cost terminal anchorage systems). For low service level roads, there is a need to determine the conditions under which less stringent guardrail requirements are warranted in order to reduce costs while providing safety performance based on demonstrated need.

The objectives of this project are: (1) to examine the need for guardrails on low service level roads and develop performance standards for guardrails, transitions, and terminals and (2) to design, test, and develop low-cost guardrail systems based on these performance standards.

This project consists of two phases:

Phase I

Task 1—Review, evaluate, and document available data in order to establish performance standards for low service level guardrail systems including transitions and terminals. Establish and, if necessary, develop general warranting criteria for use of such systems.

Task 2—Using the performance standards from Task 1, develop conceptual and preliminary designs with working drawings of the guardrails, terminals, and transitions nsing structural analysis, computer simulation, or other techniques. Existing hardware and systems in widespread use with demonstrated effective field performance will be fully considered. Make estimates of initial and maintenance (life cycle) costs for these guardrail systems.

Task 3—Prepare a letter report on thc findings of Tasks 1 and 2 for review by the NCHRP. This report will also contain a detailed work plan for Phase II including recommendations for further development of the guardrail system(s).

Phase II

Task 4—Test and develop the guardrail systems selected by NCHRP using the approved performance standards.

Task 5—Prepare a final report including the following:

a. Low service guardrail performance standards.
b. Documentation of the design and development of low service level guardrail systems.
c. Recommended low service level guardrail drawings and specifications.
d. Estimated life cycle costs of the guardrail systems.
e. General warrants for use of low service level gnardrail.

Task 1 has been completed, and Task 2 is underway.

Project 22-6 FY '85

Roadside Safety Design for Small Vehicles

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. Hayes E. Ross, Jr.
Effective Date: June 1, 1985
Completion Date: November 30, 1987
Funds: $350,000

Spurred by Federal regulation and consumer demand, auto manufacturers have reduced the weight and size of passenger vehicle models and are developing even smaller models. In addition, consumers are purchasing the smaller sized models in increasing numbers, and the trend is expected to increase dramatically during the 1980's. Currently, several vehicle models in the 1,800-lb range are being marketed in the United States. Furthermore, passenger vehicles of 1,500 lb or less are currently in production overseas, and their distribution in the United States is anticipated.

Most cnrrent roadside safety appurtenances were designed and tested with passenger vehicles ranging from 4,500 down to 2,250 lb. Research is currently in progress to investigate the performance of hardware and roadside features with vehicles in the 1,800-lb range. Under some conditions, barrier impacts become increasingly hazardous for smaller vehicles; however, little is known about the performance of current hardware and roadside safety featnres with vehicles smaller than 1,800 lb. Research is needed to gain insight on the effectiveness of hardware and roadside features for these vehicles and to determine how small the vehicles can become before the development of effective safety design is no longer feasible.

The objectives of this project are (1) to assess the per-

formance of selected existing highway safety appurtenances and roadside features with passenger vehicles below 1,800 lb and (2) to project the limits of vehicle characteristics that can be safely accommodated through improvements in current hardware and roadside features.

This research includes the following tasks:

Phase I:

Task 1—Review, evaluate, and document foreign and domestic information on the performance of safety appurtenances and roadside features with passenger vehicles weighing 1,800 lb and less.

Task 2—Identify all types of 4-wheel sedans below 1,800 lb that may constitute a significant portion of the vehicle fleet in the United States within the next 10 years. For the vehicle types identified, acquire, measure, or, where necessary, estimate the dynamic properties and other characteristics required for the computerized simulation of their reactions with safety hardware and roadside features.

Task 3—Select specific appurtenances for study in this project. Special emphasis will be given to systems presently being installed in significant numbers and having a reasonable probability of successful impact performance with small cars. The following items will be included: a rigid longitudinal barrier; a flexible longitudinal barrier; a breakaway support; a base-bending support; an impact attenuator; and a guardrail terminal.

Task 4—Select specific roadside features for study to identify performance limits when traversed by small cars. As a minimum, these features will include slopes, ditches, and curbs.

Task 5—Using available data from crash tests with the lightest vehicles tested, calibrate selected existing computer programs for simulation of impact performance, and use the calibrated programs to simulate occupant-risk tests for the selected hardware and roadside features with a 1,500-lb sedan.

Task 6—Prepare an interim report on the findings of Tasks 1 through 5. This report will contain a detailed working plan for the remainder of the study.

Phase II

Task 7—Conduct full-scale crash tests using vehicles in the 1,200 to 1,500-lb range to recalibrate the model and to demonstrate the validity of the computerized simulation to be carried out concurrently in Task 8.

Task 8—Using existing simulation models for a variety of appurtenances and roadside features (including potential improvements), vehicle types (including projections down to the lowest conceivable weight range), and crash test conditions, delineate the limiting values of particular vehicle characteristics for which feasible designs are capable of providing satisfactory performance according to the guidelines in *NCHRP Report 230*. When these evaluation criteria are not satisfied, determine the changes in impact conditions that would be required to achieve compliance.

Task 9—Identify design modifications to hardware and roadside features to improve performance for vehicles at the low end of the weight spectrum. Such modifications will be supported by computerized simulation.

Task 10.—Prepare a final report.

Research on Tasks 1 and 2 has been completed and cars for crash testing are being imported from England. Cars of the desired size are not available in the United States.

AREA 23: SOILS PROPERTIES

No projects

AREA 24: SOIL MECHANICS AND FOUNDATIONS

Project 24-1 FY '79

Manual on Subsurface Investigations

Research Agency: Haley and Aldrich, Inc.
Principal Invest.: Dr. A. W. Hatheway
Effective Date: April 2, 1979
Completion Date: December 2, 1980
Funds: $75,000

There is increasing recognition within transportation agencies of the need for use of geotechnical information in the planning, design, construction, operation, and rehabilitation of transportation facilities. Advances have been made in recent years in methodology for acquiring geotechnical information. Several agencies have made advances in the reporting of geotechnical information to other personnel and the application of such information to engineering activities.

AASHTO's *Manual on Foundation Investigations* applies to the acquisition and use of subsurface investigation data in the design of foundations for bridges and other structures. There is a need for expanding the scope of this publication to include engineering projects such as tunnels, excavations, embankments, pavements, and erosion control features pertinent to the development of transportation facilities.

The over-all objective of this project was preparation of a manual on subsurface investigations applicable to the general transportation field that can be considered for publication by AASHTO.

Research has been completed. Preliminary draft copies of the new manual on subsurface investigations have been received and reviewed. Comments have been forwarded

to the research agency and a revised manual has been submitted. Copies of the manual have been submitted to AASHTO for publication consideration.

Project 24-2 FY '83

Reinforcement of Earth Slopes and Embankments

Research Agency: Dames & Moore
Principal Invest.: Dr. Willem C. B. Villet
Effective Date: August 22, 1983
Completion Date: November 19, 1984
Funds: $150,000

The problem of economically constructing and maintaining stable slopes within limited right-of-way is a continuing concern. Where increasing traffic requires the addition of lanes within the same right-of-way, costly conventional earth retaining structures are often necessary. Such structures are required also where existing or proposed slopes are unstable and flattening of the slope is not feasible.

In recent years, some of the most noteworthy advances in geotechnology have been in the area of earth reinforcement. Powerful, innovative techniques have been initiated and are still being developed here and abroad that have the potential for improving stability at reasonable cost. Examples include: Reinforced Earth®, element walls, and soil nailing. Some of the techniques (e.g., Reinforced Earth) are proprietary, and information on many of the innovative methodologies is not widely distributed. Therefore, there is an urgent need to collect, evaluate, and disseminate the current state of the art on their use and applicability. In order to encourage widespread use of these systems, two pressing questions that need to be answered are: (1) What new systems are available? (2) Where will they provide satisfactory performance at a cost savings over conventional methods?

The objective of this research is a comprehensive summary and evaluation of available earth reinforcement techniques applicable to highway embankment and slope stability problems. It is not intended that this study encompass ground modification techniques, such as chemical stabilization, stone columns, and dynamic compaction. In addition, an investigation of "micro-piles" or "root piles" would be a duplication of FHWA research and is not included in this project. Attainment of the project objective requires the following tasks:

Task 1. Provide for each technique the following:

a. A complete description, including proprietary restrictions.
b. Site conditions for which the technique is applicable.
c. Comprehensive design and analysis methodology with illustrated examples. Related existing computer programs should be iucluded. Drainage, corrosion, creep, and backfill type and compaction should be considered where applicable. Internal stability computations should also be provided; computations of external stability may be excluded.
d. Construction and construction control details including proof tests and performance monitoring.
e. Case histories and cost data. Show all available cost comparisons, including both innovative and conventional systems.

Task 2. Based on the results from Task 1, provide an assessment of future ground reinforcement trends.

A comprehensive working draft documenting the research effort was submitted in late 1984 and subsequently reviewed by the NCHRP. The agency's submittal of the preliminary draft final report is awaited.

A contract time extension was requested by the agency and agreed to by the NCHRP; however, execution of the needed amendment is also awaited from the agency.

Project 24-3 FY '86

Laboratory Evaluation of Piles Installed with Vibratory Drivers

Research Agency: University of Houston-University Park
Principal Invest.: Drs. Michael W. O'Neill and Cumaraswamy Vipulanandan
Effective Date: January 6, 1986
Completion Date: January 5, 1988
Funds: $200,000

State Departments of Transportation often are requested by contractors to use vibratory drivers rather than the more conventional impact hammers to install piles. Vibratory pile drivers can provide substantial savings by reducing the amount of driving time to final penetration under certain soil conditions. However, the lack of a reliable dynamic method of estimating bearing capacity limits their usefulness. Presently, the most common method to determine capacity is to restrike the pile with an impact hammer, but the validity of this method is unproven and the extra operation reduces the potential savings.

Developing a reliable method for dynamically determining bearing capacity of piles installed with vibratory drivers is a complex problem. To supplement current activity, laboratory studies are needed to provide insight into the basic behavior of piles installed with vibratory drivers compared to impact hammers and the influence of various soil parameters on the behavior of piles. Laboratory studies will also assist in the design of future field tests and the analysis of results.

The overall objective of this study is to evaluate the load-deformation behavior of piles installed in the laboratory with vibratory drivers. Specific objectives include: (1) a comparison of load deformation behavior of piles installed with vibratory drivers and impact hammers; (2) the identification of soil parameters that significantly af-

fect load-deformation behavior of piles installed with vibratory drivers; (3) a comparison of load-deformation behavior of piles installed by vibratory drivers with and without restriking using an impact hammer to evaluate the effect of restriking; and (4) the development of a recommended predictive method of determining bearing capacity for further field verification. The research will include the following tasks:

Task 1—Review and assess appropriate reference materials relevant to piles installed with vibratory drivers.

Task 2—Develop a detailed laboratory testing program to meet the stated objectives. To provide limits on the scope of activities, a hollow, closed-end steel pile under saturated soil conditions will be used for all tests. The vibratory drivers modeled in the study shall reflect properties of currently available commercial drivers. Experimental parameters should include, but need not be limited to driver characteristics (e.g., amplitude, frequency, and weight), soil characteristics (e.g., density, grain-size distribution, and shear strength), and pile-soil response. It is anticipated that three grain-size distributions will be studied. Load-deformation behavior shall be determined by static testing with separation of shaft and toe resistance. Submit 20 copies of a summary report of the Task 1 effort and the proposed laboratory testing program for review and approval by the NCHRP. NCHRP approval will be required before proceeding with Task 3.

Task 3—Perform the approved laboratory testing program.

Task 4—Prepare the final report. The report shall include a detailed description of the test methods and instrumentation, ratiouale for parameter selection, analysis of results, and other pertinent information for implementing the technology for field use.

AREA 25: IMPACT ANALYSIS

This area became effective January 1, 1979, and includes only those projects beginning with the FY 1981 program. Refer to Areas 7, 8, and 20 for previous projects in the realm of Impact Analysis.

Project 25-1 FY '81

Effects of Highway Runoff on Wetlands

Research Agency:	Rexnord, Inc.
Principal Invest.:	Dr. Nicholas P. Kobriger
Effective Date:	February 16, 1981
Completion Date:	February 1, 1984
Funds:	$162,360

Many state and federal agencies value wetlands as a natural resource and have enacted considerable legislation to ensure their natural benefits such as in providing wildlife habitats, recreational areas, flood storage, and nutrient sinks. Also, interest increases on possibly creating and managing wetlands to enhance the environment. However, wetlands can be adversely affected with impacts ranging from partial disturbance, to changes in their characteristics and functions, to elimination. An area of mounting concern is the impact of highway runoff.

The objectives of this research were to identify the interactions between wetland systems and highway runoff, to identify the effects of highway runoff on wetlands, and to develop guidelines for the practical management of highway runoff on wetlands. The researchers thoroughly reviewed a substantial amount of information on wetland ecology, the function of wetlands, highway runoff constituents, and other related subjects having either a direct or indirect, but transferable, relationship to the requirements of the research objectives. Although no one situation is exactly like another, the results of this research provide excellent background for understanding the characteristics of wetlands, their functions, and the effects of highway runoff. Practical guidance for the management of runoff from highways in close proximity to wetlands was developed and should be of considerable interest and use. This guidance includes the management of runoff from the highway to and in the wetlands. A possibility also addressed is the use or creation of wetlands to mitigate the effects of highway runoff.

Research has been completed. The project report is comprised of two documents: the main research report and the guidelines. The research report titled, "Effects of Highway Runoff on Wetlands," was not published in the regular NCHRP series. However, a copy of the report was distributed to all Program Sponsors, and the report is available to others on a loan basis or for purchase of Xerox copies (see final page of this section for ordering information). This research report provides an excellent, comprehensive resource document ou the subject and related areas.

The guidelines emanating from Project 25-1 were published as:

NCHRP Report 264, "Guidelines for the Management of Highway Runoff on Wetlauds." This report, in addition to providing guidelines for the practical management of highway runoff in wetlauds, highlights the significant findings of the research and includes an extensive bibliography categorized by the following subject areas: processes and pathways, runoff constituents and aquatic ecosystems, runoff characteristics; state and federal regulations, wetland creation, wetland monitoring, assessing the interactions of highway runoff and wetlands, wetland vegetation and classification, and case studies.

HOW TO ORDER

Items for Sale

1. NCHRP Series Reports, Syntheses, and Research Results Digests (see Tables 7 and 8 for prices).
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