NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1981

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1981

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1981

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. This program is supported on a continuing 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 the 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 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 Administration. The programs are referred to the Transportation Research Board for administration, and research projects addressing the specific needs are defined by the Board. 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 the Academy and its Transportation Research Board.

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.

CONTENTS

FIGURES

TABLES

MAILING ADDRESS:

TRANSPORTATION RESEARCH BOARD
2101 Constitution Avenue NW
Washington, D. C. 20418

OFFICES AT:

2100 Pennsylvania Ave. NW
Washington, D. C.
Phone: 202-334-3224

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS

THROUGH 1981

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 out under a three-way agreement between 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 for administration by the Academy through the Transportation Research Board of its National Research Council. Each State annually contracts with the Academy to commit an amount equal to 4½ % of its 1½ % Federal-aid highway planning research (HPR) funds. From these contributions, a cooperative pool of about $4.5 million is made available for NCHRP's contract research and for its administrative and technical operation.

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 637 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, 55 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 sixteenth issue covers the Program from its inception through December 31, 1981, 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 following 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.

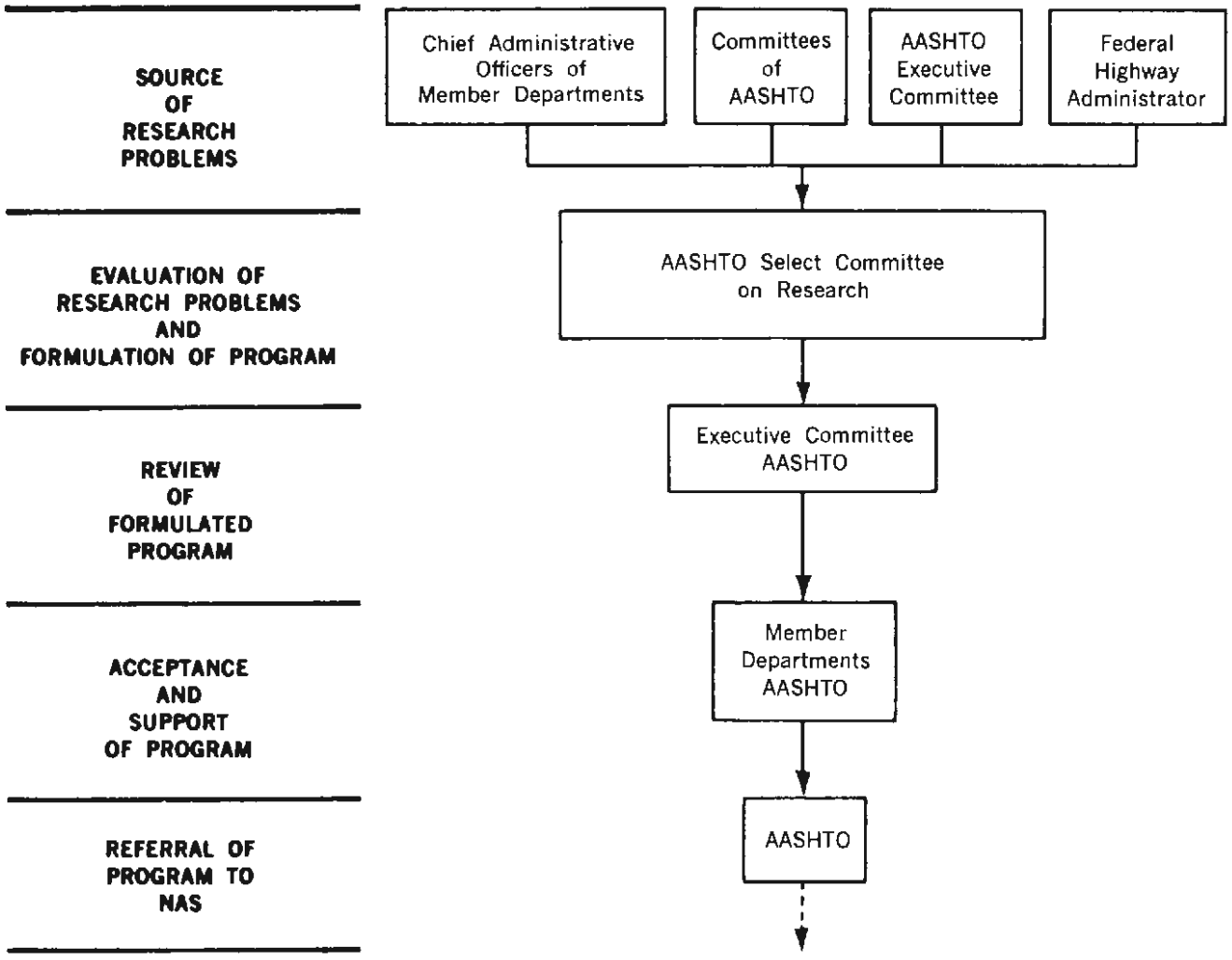

FIGURE 1

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. Within the Academy structure, 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

The first research program was received when the three-way agreement was signed and consisted of 34 problems with an average funding of about $55,000. A similar pattern existed for the second program; however, subsequent years have seen a decrease in the numbers of problems programmed and an increase in the levels of funding for individual projects. Since 1967, each year's program has consisted of some 7 to 10 new problems with funding ranging between $100,000 and $300,000 and a like number of continuations with funding ranging between $100,000 and $360,000. This is not to be taken as a decrease in the needs of the sponsors. To the contrary, the needs are many and are evidenced by an ever-growing list that has ranged as high as 188 problems submitted for evaluation in a single year. Regrettably, funds available to the NCHRP each year permit inclusion of but a fraction of the problems submitted.

In 1980 AASHTO referred the twentieth program (FY '82) of research problems. From all programs through FY '82, 342 research projects have resulted, on which contracts written through December 1981 total some $50.0 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-first group of research problems (FY '83 program) was selected in September 1981 and will be referred to the Academy following the States' ballot on the recommended problems.

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 $4.5 million is made available each year for NCHRP's contract research and for its administrative and technical operation. Funds are scheduled to become available such that research is planned to begin on October 1 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 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 1982 within the fields of Figure 3 is as follows:

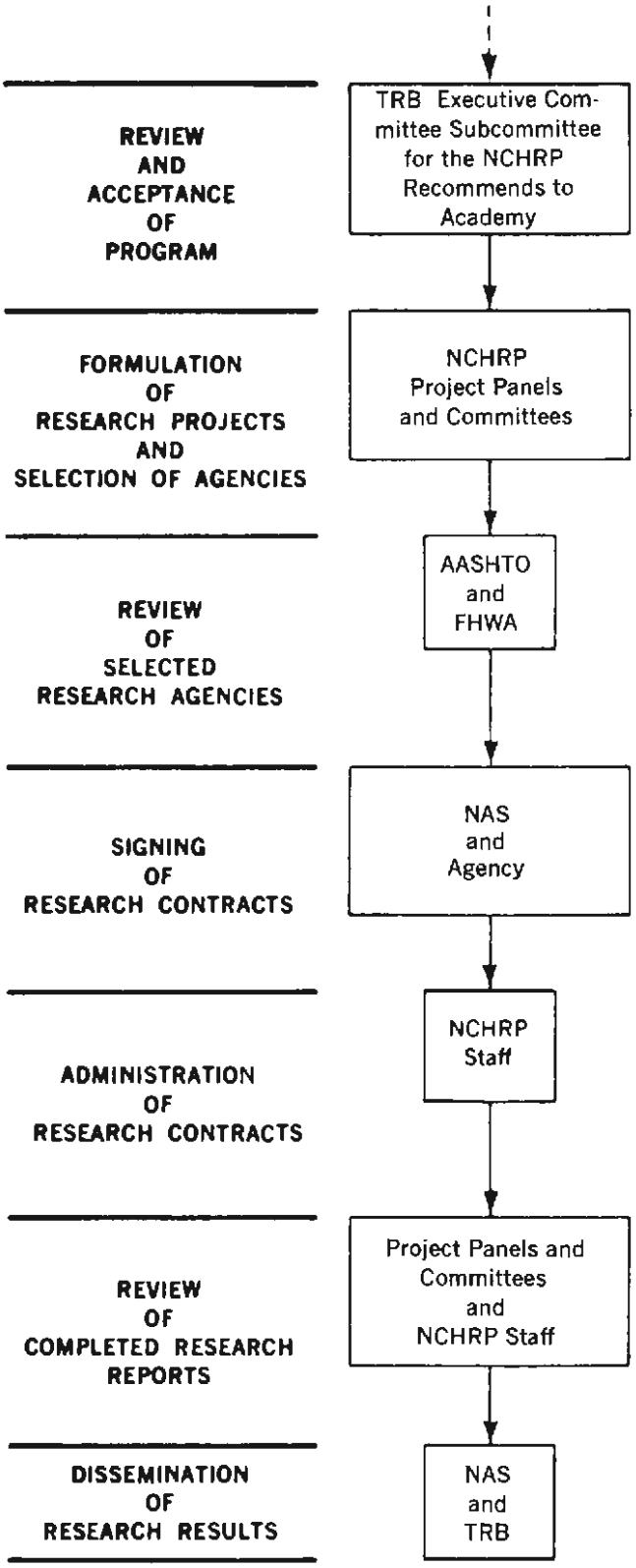

FIGURE 2

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

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
43	11.0	Socio-economic and environmental issues
50	18.3	Urban issues
10	3.8	Multimodal issues
64	17.6	Safety and accident prevention
19	1.1	Legal studies
12	14.4	Special projects (including in-house)
26	6.0	Improved materials quality and performance
21	5.3	Highway maintenance
38	7.8	Specifications, tests, and construction control
59	14.7	Structural design and performance

Members of the project panels do not act as consultants or advisors to project investigators. Members may, according to established policy, submit proposals for research. If they do, they are dropped from panel participation until the research agencies have been selected. If unsuccessful, they may return to full participation. Some 637 individuals serve without compensation on these project panels, and their total yearly contribution to the Program 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 43 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

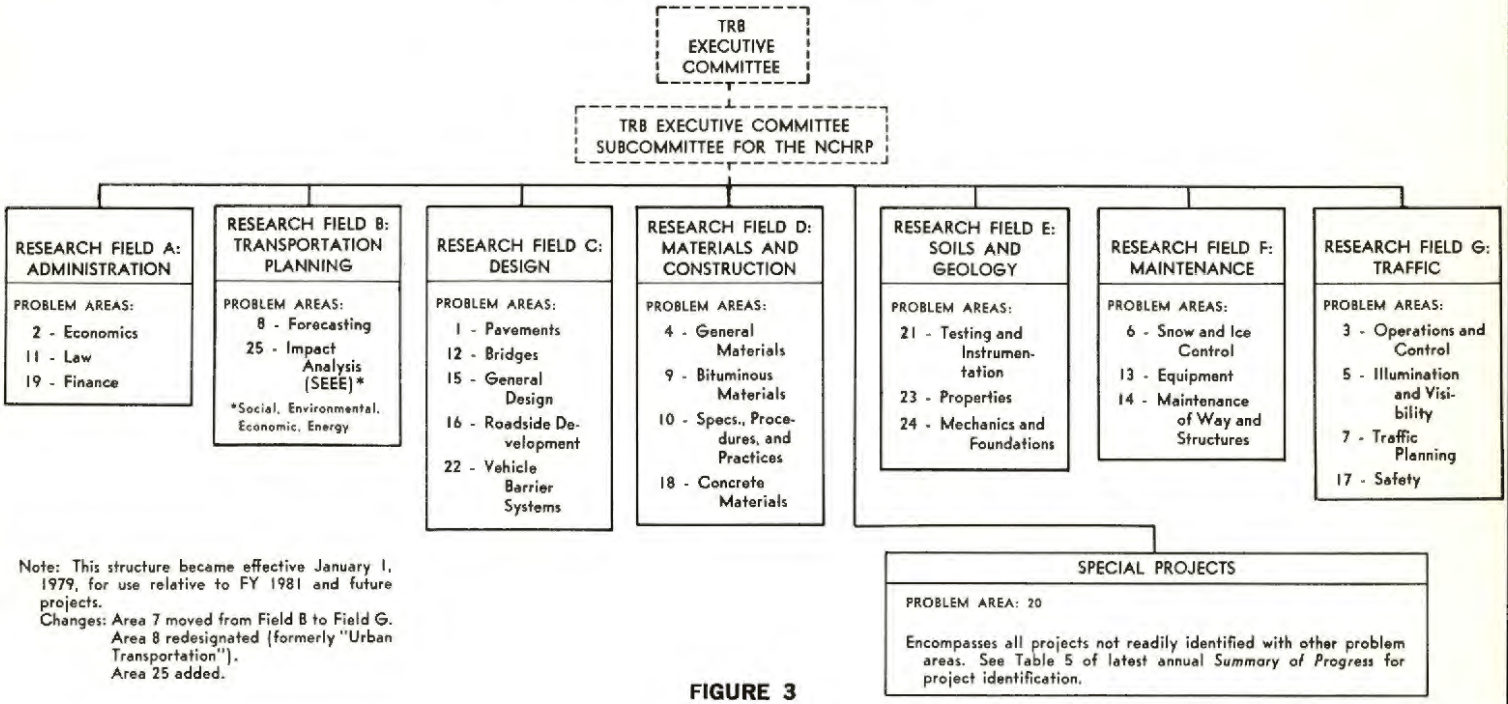

FIGURE 3

Following the NCHRP staff review made after program referral to the Academy, 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 by the Academy 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 he 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).

TABLE 1

DISTRIBUTION OF PROJECT PANEL AND COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departmnets	273	345
Federal Highway Administration	84	127
Special transportation and other governmental agencies	83	96
Educational institutions	69	89
Research institutes	3	4
Industry, consultants, and trade associations	110	145
Professional societies and service organizations	2	2
Transportation Research Board	13	83
All	637	891

TABLE 2

NUMBER OF PROPOSALS SUBMITTED

ITEM	'62-'74 AVE.	'62-'74 LOW	'62-'74 HIGH	'75	'76	'77	'78	'79	'80	'81 *
No. of projects advertised	17	9	34	5	15	15	10	13	10	11
Proposals submitted	176	107	233	64	140	138	116	104	83	94
Proposals rec'd per project (ave.)	11	6	17	13	9	9	12	8	8	9

* Calendar year

TABLE 3

NUMBER OF AGENCIES SUBMITTING ONE OR MORE RESEARCH PROPOSALS

NO. OF PROPOSALS SUBMITTED	NUMBER OF AGENCIES SUBMITTING PROPOSALS '62-'74 AVE.	'62-'74 LOW	'62-'74 HIGH	'75	'76	'77	'78	'79	'80	'81 *
1	68	26	103	44	80	73	67	65	61	48
2	20	8	29	4	14	16	10	10	11	18
3	8	4	14	4	4	4	7	2	0	2
4	4	0	8	0	1	2	2	2	0	1
5	2	0	5	0	2	1	0	1	0	0
6	1	0	4	0	1	0	0	0	0	0
7	1	0	4	0	0	0	0	0	0	0
8	< 1	0	2	0	0	1	0	0	0	0
9	< 1	0	1	0	0	0	0	0	0	0
10	< 1	0	2	0	0	0	0	0	0	0
11	< 1	0	1	0	0	0	0	0	0	0
All				52	102	97	86	80	72	69

* Calendar year

TABLE 4

TYPES OF AGENCIES SUBMITTING PROPOSALS

TYPE OF AGENCY	NO. OF AGENCIES SUBMITTING '62-'74 AVE.	'62-'74 LOW	'62-'74 HIGH	'75	'76	'77	'78	'79	'80	'81 *
Educational institutions	39	25	53	14	36	34	29	30	23	18
Research institutes	16	8	26	8	7	8	8	9	5	7
Industry, consultants, and trade associations	46	14	72	28	54	51	46	40	42	42
Professional societies and service organizations	< 1	0	2	0	0	0	0	0	0	0
State highway and transportation departments	2	0	3	1	3	3	0	0	0	1
Special transportation and other governmental agencies	1	0	3	1	2	1	3	1	2	1
All				52	102	97	86	80	72	69
No. of projects advertised	17	9	34	5	15	15	10	13	10	9

* Calendar year

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.

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 20 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 research 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 of 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 342 projects included in the 20 fiscal year programs conducted to date are listed in Table 5. There are 137 projects in traffic planning research, 163 in physical research, and 42 in the special projects area. To date, 297 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) (used only rarely to date for contracts under $30,000)

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 with the Academy. 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 glance 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.

TABLE 5
PROJECTS FOR FY '63 THROUGH FY '82 SUMMARY OF STATUS THROUGH DECEMBER 31, 1981

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	Purdue 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	Duke 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 Structural Subsystems	Materials R & D	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	304,863
1-17	Guidelines for Recycling Pavement Materials	Texas A&M	200,000
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	Rummel, Klepper	100,000
1-23	Pavement Roughness and Rideability	KETRON, Inc	250,000
	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*
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*
	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*

START-ING DATE	COMPLE-TION 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.; agcy rep. avail. in microfiche	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	4/30/82	Phase I report in review stage; Phase II research in progress	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—Report being revised	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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	1-15
6/3/74	10/31/81	Completed—Report being revised	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	8/31/83	Research in progress; Task 1 agency rep. avail. for loan; extra copies avail. to sponsors	1-19
5/1/79	3/31/83	Research in progress	1-20
5/15/80	2/14/84	Research in progress; agency interim report available for loan	1-21
9/8/81	12/7/82	Research in progress	1-22
27	months	Contract pending	1-23
6/1/63	11/30/67	Completed—Rep. not publ.; agency rep. avail. in microfiche	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 included 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
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.; agency rep. avail. in microfiche	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
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.; agency rep. avail. in microfiche	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

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA THREE (*Continued*)		
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*
			316,011*
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 of New York	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 Computer-Controlled Traffic	Stanford Res Inst	323,998*
			57,662*
3-18(2)	Traffic Control in Oversaturated Street Networks	Poly of New York	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	249,823
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	308,779*
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	225,891
3-27	Guidelines for Selecting Traffic Signal Control at Individual Intersections	Voorhees & Assoc	153,953
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	150,000
3-28(2)	Urban Signalized Intersection Capacity	JHK & Assoc	331,000
	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 Study 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*
			71,652
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	150,000

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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 in 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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	3-20
6/23/80	2/23/82	Research in progress	3-20A
4/1/74	1/31/76	Completed—Rep. not publ.; agency rep. avail. in microfiche	3-21
12/1/79	6/30/81	Completed—Published as NCHRP Report 235	3-21(2)
4/15/74	12/31/75	Completed—Rep. not publ.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	3-23
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 proj. 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 writeup in latest Sum. of Prog.	3-28
5/1/80	4/30/82	Research in progress	3-28A
10/1/79	2/28/82	Research in progress	3-28(2)
6/1/63	10/31/66	Completed—Rep. not publ.; agency rep. avail. in microfiche	4-1
2/15/63	11/30/66	Completed—Published 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	8/31/67	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.; agency rep. avail. in microfiche	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	Report in review stage	4-8(3)
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.; agency rep. avail. for loan	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

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
AREA FOUR (*Continued*)			
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	199,231
4-15	Corrosion Protection of Prestressing Systems in Concrete Bridges	Wiss, Janney, Elstner	250,000
	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	Visual Information Needed by the Driver at Night	Ohio State U	100,940*
5-4	Economic Study 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	Evaluation 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	Multisystems Inc	199,988
	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*
8-6	Individual Preferences for Alternative Dwelling Types and Environments	U of N Carolina	99,897*

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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	Research in progress	4-14
27 months		Contract pending	4-15
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
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.; agency rep. avail. in microfiche	5-5A
9/1/71	12/31/74	Completed—Rep. not publ.; agency rep. avail. in microfiche	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	11/30/82	Research in progress	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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	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	1/6/83	Research in progress	7-11
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.; agency rep. avail. in microfiche	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
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA EIGHT (*Continued*)		
8-7	Evaluation 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 (Study 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	354,363
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	221,249
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	489,217
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	265,937
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	200,000
	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 Emulsified Asphalt Paving Mixtures	Asphalt Inst	150,172
	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 Measurements 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*
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	174,889
10-13	Ultrasonic Measurement of Weld Flaw Size	The Welding Inst	126,000
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
10-16	Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline	Byrd, Tallamy et al	150,000

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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 agency rep. avail. in microfiche	8-11
		Phase II report published as NCHRP Reports 216 and 217	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—Ph. I rep. not publ.; agency rep. avail. in microfiche	8-13
5/1/76	12/31/80	Ph. II completed—Rep. not publ.; agency rep. avail. in microfiche; Ph. III rep. in rev. stage	8-13(2)
1/1/75	4/30/77	Completed—Rep. not publ.; for avail., see project writeup in latest Sum. of Prog.	8-14
1/1/78	6/13/81	Report in review stage	8-14A
9/1/74	5/31/76	Ph. I completed—Rep. not 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 write up in latest Sum. of Prog.	8-15A
1/1/76	12/31/79	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	Report in review stage	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	Research in progress	8-24
4/1/80	1/31/82	Report in review stage	8-25
5/15/81	8/15/82	Research in progress	8-26
9/1/81	1/31/83	Research in progress	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.; agency rep. avail. in microfiche	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	12/31/82	Research in progress	9-5
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
3/2/70	7/31/73	Completed—Published as NCHRP Report 168	10-8
11/1/69	2/28/74	Completed—Rep. not publ.; agency rep. avail. in microfiche	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—Agency interim and final reports avail. for loan or in microfiche	10-12
7/1/79	10/31/81	Completed—Published as NCHRP Report 242	10-13
4/2/79	3/1/81	Completed—Published as NCHRP Report 237	10-14
4/1/80	5/31/82	Research in progress	10-15
2/16/81	8/15/82	Research in progress	10-16

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TEN (*Continued*)		
10-17	Use of Antistripping Additives in Asphaltic Concrete Mixtures	David G. Tunnicliff	99,810
10-18	Specifying and Obtaining Entrained Air in Concrete	Const. Tech Lab/PCA	74,350
10-19	Adding Dust Collector Fines to Asphalt Paving Mixtures	Penn State U	50,000
10-20	Elastomeric Bearings Design, Construction, and Materials	U of Washington	74,715
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	75,000
10-23	Removal of Lead-Based Bridge Paints	Offshore Power Sys	75,000
10-24	Rapid Replacement of PCC Pavement Segments	ARE, Inc.	240,000
	AREA ELEVEN: ADMINISTRATION—LAW		
11-1	Rules 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*
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	75,000
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-Amplitude, Long-Life Fatigue Loading	Lehigh U	150,000
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbus	214,912
12-17	Evaluation of Repair Techniques for Damaged Steel Bridge Members	Battelle Columbus	50,000
12-17A	Guidelines for Evaluation and Repair of Damaged Steel Bridge Members	G O Shanafelt	100,000
12-18	Development of an Integrated Bridge Design System	Multisystems Inc	224,895
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	100,000
12-20	Bridges on Secondary Highways and Local Roads: Rehabilitation and Replacement	U of Virginia	119,970 50,000
12-21	Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members	G O Shanafelt	58,958
12-22	Thermal Effects in Concrete Bridge Superstructures	Engrg Comp Corp	100,000
	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*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
3/1/81	2/28/83	Research in progress	10-17
5/4/81	2/4/83	Research in progress	10-18
3/1/81	2/28/82	Research in progress	10-19
2/1/81	6/30/82	Research in progress	10-20
2/1/80	9/30/81	Completed—Published as NCHRP Synthesis 86	10-21
18 months		Contract pending	10-22
12 months		Contract pending	10-23
72 months		Contract pending	10-24
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.; agency rep. avail. in microfiche	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 publ.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	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
10/1/70	5/31/72	Completed—Published as NCHRP Report 142	11-5
4/1/74	7/31/75	Completed—Rep. not publ.; agency rep. avail. in microfiche	11-6
2/1/65	6/30/67	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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche	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—Report included in 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	6/30/83	Research in progress	12-15(4)
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	9/30/83	Research in progress	12-17A
9/6/77	12/31/81	Completed—Rep. being reviewed; Phase I report avail. for loan	12-18
1/1/78	12/31/80	Completed—Rep. not publ.; for avail. of Task 1 rep., see proj. writeup in latest Sum. of Prog.	12-19
8/1/79	12/1/81	Report in review stage	12-19A
3/1/78	2/29/80	Completed—Published as NCHRP Report 222	12-20
6/1/80	11/30/81	Completed—Rep. in editorial and publication process	12-20
4/15/79	9/14/80	Phase I completed—Published as NCHRP Report 226	12-21
10/1/81	5/31/83	Contract pending	12-22
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
9/15/72	3/15/76	Completed—Published as NCHRP Report 202	14-3

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
AREA FOURTEEN (*Continued*)			
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	100,000
14-6	Evaluating Deferred Maintenance Strategies	ARE, Inc.	300,000
	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	274,970
	AREA SIXTEEN: DESIGN—ROADSIDE 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
	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 Budgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Budgeting 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, Communication, 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	Public Preference for Future Individual Transportation	Chilton Research National Analysts	195,260* 83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	360,000[c]
20-6	Right-of-Way and Legal Problems Arising out of Highway Programs	TRB	100,000[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	104,400*
	Task 9: Review of Highway Management Studies Co-Sponsored by AASHTO and HUFSAM	Mgmt & Trans Assoc	49,820*

STARTING DATE	COMPLETION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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	3/15/83	Research in progress	14-5(2)
36	months	Contract pending	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.; agency rep. avai. in microfiche	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	Research in progress	15-7
18	months	Contract pending	15-8
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. to be included in Phase II report; agency rep. avail. for loan	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. not publ.; for avail., see project writeup in latest Sum. of Prog.	17-4
4/23/80	9/7/81	Completed—Published as NCHRP Report 236	17-4(2)
4/1/80	1/31/82	Report in review stage	17-5
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	11/1/82	Research in progress; agency interim report avail. for loan	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. not publ.; agency rep. avail. in microfiche	20-3C
5/15/77	12/31/78	Completed—Spec. publ.; for avail., see proj. 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	*	Research in progress: Topic reports published as NCHRP Syntheses 1 through 88	20-5
11/1/68	*	Research in progress: Refer to Table III and proj. write-up 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	3/31/71	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.; agency rep. avail. in microfiche	(Task 8) 20-7
12/1/75	8/31/76	Completed—Report not publ.; available only to sponsors	(Task 9) 20-7

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST ($)
	AREA TWENTY (*Continued*)		
	Task 10: Review of Vehicle Weight/Horsepower Ratio as Related to Passing-Lane Design Criteria	Penn State U	15,493*
	Task 11: Longitudinal Occupancy 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	66,763
	Task 15: Development of a Simplified Pavement Management System	ARE Inc	103,600
	Task 16: Regulation of Movement of Hazardous Cargoes	D. M. Baldwin	7,341*
	Task 17: Evaluation of AASHO Road Test Satellite and Environment Studies	Texas A & M	95,924
	Task 18: Standard Specifications for Highway Bridges	Howard, Needles et al	100,000
	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		25,000
	Task 22: Encasement of Pipelines Through Highway and Railroad Roadbeds		20,000
	Task 23: Contract Payment Procedures and Contracting Practices		75,000
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 of New York	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	99,792*
20-14A	Statistical Analysis of Ozone Data for Transportation/Air Quality Planning	SRI International	189,928
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	74,365
20-17A	Application of Statewide Freight Demand Forecasting Techniques	R. Creighton Assoc	175,000
20-18	Evaluation of Highway Air Pollution Dispersion Models	SRI International	199,643
	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 Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	SUNY Buffalo	29,953*
21-2(3)	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation)	Sw Research Inst	154,764
	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*
22-3A	Field Evaluation of Vehicle Barrier Systems	Arthur L. Elliott	10,000*
	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
	AREA TWENTY-FIVE: TRANSPORTATION PLANNING—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.		
25-1	Effects of Highway Runoff on Wetlands	Rexnord, Inc	159,995

* 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.

[a] 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.

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS ** (for details, see latest Summary of Progress)	PROJECT NO.
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	6/30/82	Research in progress	(Task 14) 20-7
8/29/78	12/1/81	Completed—Phase I rep. publ. as NCHRP Report 215; Phase II rep. not publ.; distr. to sponsors only	(Task 15) 20-7
9/4/79	5/31/80	Completed—Report not publ.; distributed to sponsors	(Task 16) 20-7
7/1/79	12/31/82	Research in progress	(Task 17) 20-7
12/1/80	12/31/82	Research in progress	(Task 18) 20-7
5/19/81	2/15/82	Research in progress	(Task 19) 20-7
		Task in developmental stage	(Task 20) 20-7
—	—	Task in developmental stage	(Task 21) 20-7
—	—	Task in developmental stage	(Task 22) 20-7
—	—	Task in developmental stage	(Task 23) 20-7
9/1/70	7/31/71	Completed—Rep. not publ.; agency rep. avail. in microfiche	20-8
8/1/72	12/17/76	Completed—Rep. not publ.; for avail., see proj. write-up 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.; agency rep. avail. in microfiche	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.; agency rep. avail. in microfiche; sum. in NCHRP Res. Results Digest 114	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	11/30/82	Research in progress	20-17A
3/15/79	11/30/81	Report in review stage	20-18
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Completed—Report not 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—Rep. not publ.; agency rep. avail. for loan	21-2(3)
10/1/70	12/31/71	Completed—Rep. not publ.; agency rep. avail. in microfiche	22-1
3/1/74	5/30/75	Completed—Rep. not publ.; agency rep. avail. in microfiche; 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) reps.	22-2
10/1/73	3/31/75	not publ.; agency rep. avail. in microfiche; sum. in NCHRP Res. Results	22-2
		Digests 84 and 102; Task 2 rep. publ. as NCHRP Rep. 153	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.; agency rep. avail. in microfiche; sum. in NCHRP Res. Results Dig. 76	22-3 22-3
7/1/74	12/31/74	Completed—Rep. not publ.; agency rep. avail. in microfiche; sum. in NCHRP Res. Results Dig. 76	22-3A 22-3A
4/2/79	12/2/80	Report in review stage	24-1
2/16/81	11/15/82	Research in progress	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 '82 at amount shown.

TABLE 6

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '82 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS NO.	%
Educational institutions	124	36
Research institutes	62	18
Industry, consultants, and trade associations	147	43
Professional societies and service organizations	6	2
State highway and transportation departments	4	>1
Special transportation and other governmental agencies	1	<1
All	344	100

KEEPING TRACK OF RESEARCH IN PROGRESS

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

ings," 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 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 measure 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 several 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 research 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. Otherwise, projects that were highly successful might just as well have been failures; the end result is the same—the money will have been spent in vain.

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 AASHO 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.
1-18	Report 228	World Bank	Basis for designing an international calibration exercise for road meters.
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.

* 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
	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.
		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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		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.
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.
3-28	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.
4-8(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.
5-5A, B	Agency report	DeLeuw Cather	Findings incorporated in research study.
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*.
5-7	—	Ohio DOH	Reference source of current and complete information on individual delineation techniques.
	Report 130	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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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 Comm.	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.
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
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.
		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 and Training Materials	FHWA, National Hwy. Inst., State/Local Agencies, & Nomerous Universities	As the basic training aid for short courses. Over 800 state and local officials have participated in 20 courses sponsored by FHWA's Urban Planning Div. in cooperation with NHI. Ten additional courses are planned for next year.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
8-16	Agency final report Appendix, "Transportation Services for the Transportation Disadvantaged"	Am. Public Transit Assoc.	Testimony on proposed DOT regulations to implement Sec. 504 of the Older Americans Rehabilitation Act.
		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.
9-3	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	State Univ. North Dakota	Basic text for a course in statistical quality control taught to both undergraduates and a sizeable number of engineers, the majority of the latter being highway deparment 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.
10-21	Synthesis 86	Delaware River Joint Toll Bridge Comm.	Information of direct relevance in decision regarding replacement of bridge deck on a major bridge.
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	To retrofit bridges.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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.
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*.
		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.
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.
16-3	Report 221	Hittman Assoc. Inc.	Information and illustrations used in a field manual for the Office of Surface Mining, U.S. Dept. of Interior.
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.
		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.
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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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 responsibilties.
	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.
20-6	Res. Dig. 11	Md. Rds. Comm.	In a case before September 1969 term, State Court of Appeals.
	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, "Lateral 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.*
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.
20-16	Report 198	AASHTO	Findings used in testimony before U.S. Senate.
22-2	Res. Results Dig. 43, 53, 84	State highway agencies	Breakaway cable terminal (BCT) installed as a guardrail end treatment in at least 35 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.

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."

SUMMARY

The National Cooperative Highway Research Program is a unique contract research effort designed to respond quickly and efficiently to the needs of State highway and transportation departments through the solution of the pressing transportation problems. Although the Transportation Research Board administers the Program, the research content is solely the prerogative of the American Association of State Highway and Transportation Officials and its member departments. The Program is one of applied (rather than basic) research, and every possible effort is made to help administrators and engineers put the findings to early use. Program policy ensures maximum exposure of the research while in progress in the hope that research results will, in fact, more quickly find their way into practice in the form of policies, procedures, specifications, and standards of State highway and transportation departments.

TABLE 7

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Rep. 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 Guidelines 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 Structures (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 of 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 Outdoor 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 Behavior—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

* 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. The cost is $4.00 per publication.

TABLE 7 (*Continued*)

Rep. No.	Title, Project, Pages, Price
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 Tires—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 Structural 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 (Proj. 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—Literature 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
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 Acquisition (Proj. 11-1), 77 p., $4.40

TABLE 7 (*Continued*)

Rep. No.	Title, Project, Pages, Price
• 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	Junkyard 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 Moisture 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
132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., $7.20
• 133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., $5.60
134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 24 p., $2.80
135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., $3.60
136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., $4.60
137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., $4.20
• 138	Instrumentation for Measurement of Moisture—Literature Review and Recommended Research (Proj. 21-1), 60 p., $4.00
139	Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., $4.40
140	Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., $5.60
• 141	Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., $8.40
142	Valuation of Air Space (Proj. 11-5), 48 p., $4.00
143	Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., $16.00
• 144	Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., $4.40
145	Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17), 120 p., $6.00
146	Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis (Proj. 8-9), 68 p., $4.00
147	Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., $4.80
148	Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., $4.00
149	Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., $4.00
150	Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., $4.80
151	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques (Proj. 1-12(2)), 100 p., $6.00
152	Warrants for Highway Lighting (Proj. 5-8), 117 p., $6.40
153	Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances (Proj. 22-2), 19 p., $3.20
154	Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites (Proj. 1-12), 64 p., $4.40
155	Bus Use of Highways—Planning and Design Guidelines (Proj. 8-10), 161 p., $7.60
156	Transportation Decision-Making—A Guide to Social and Environmental Considerations (Proj. 8-8(3)), 135 p., $7.20
157	Crash Cushions of Waste Materials (Proj. 20-7), 73 p., $4.80
158	Selection of Safe Roadside Cross Sections (Proj. 20-7), 57 p., $4.40
159	Weaving Areas—Design and Analysis (Proj. 3-15), 119 p., $6.40

TABLE 7 (*Continued*)

Rep. No.	*Title, Project, Pages, Price*
160	Flexible Pavement Design and Management—Systems Approach Implementation (Proj. 1-10A), 53 p., $4.00
161	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities (Proj. 14-2), 55 p., $4.40
162	Methods for Evaluating Highway Safety Improvements (Proj. 17-2A), 150 p., $7.40
163	Design of Bent Caps for Concrete Box-Girder Bridges (Proj. 12-10), 124 p., $6.80
164	Fatigue Strength of High-Yield Reinforcing Bars (Proj. 4-7), 90 p., $5.60
165	Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase (Proj. 12-11), 70 pp. $4.80
166	Waste Materials as Potential Replacements for Highway Aggregates (Proj. 4-10A), 94 p., $5.60
167	Transportation Planning for Small Urban Areas (Proj. 8-7A), 71 p., $4.80
168	Rapid Measurement of Concrete Pavement Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems (Proj. 10-8), 63 p., $4.80
169	Peak-Period Traffic Congestion—Options for Current Programs (Proj. 7-10), 65 p., $4.80
170	Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase (Proj. 16-1), 88 p., $5.60
171	Highway Fog—Visibility Measures and Guidance Systems (Proj. 5-6A), 40 p., $4.00
172	Density Standards for Field Compaction of Granular Bases and Subbases (Proj. 4-8(2)), 73 p., $4.80
173	Highway Noise—Generation and Control (Proj. 3-7), 174 p., $8.00
174	Highway Noise—A Design Guide for Prediction and Control (Proj. 3-7), 193 p., $9.60
175	Freeway Lane Drops (Proj. 3-16), 72 p., $4.80
176	Studded Tires and Highway Safety—Feasibility of Determining Indirect Effects (Proj. 1-13(2)), 42 p., $4.00
177	Freight Data Requirements for Statewide Transportation Systems Planning—Research Report (Proj. 8-17), 196 p. $8.80
178	Freight Data Requirements for Statewide Transportation Systems Planning—User's Manual (Proj. 8-17), 155 p. $7.40
179	Evaluating Options in Statewide Transportation Planning/Programming—Issues, Techniques, and Their Relationships (Proj. 8-18), 91 p., $5.60
180	Cathodic Protection for Reinforced Concrete Bridge Decks—Laboratory Phase (Proj. 12-13), 135 p., $7.00
181	Subcritical Crack Growth and Fracture of Bridge Steels (Proj. 12-14), 82 p., $5.60
182	Economic Evaluation of Ice and Frost on Bridge Decks (Proj. 6-11), 73 p., $4.80
183	Studded Tires and Highway Safety—An Accident Analysis (Proj. 1-13), 70 p., $4.80
184	Influence of Combined Highway Grade and Horizontal Alignment on Skidding (Proj. 1-14), 33 p., $3.20
185	Grade Effects on Traffic Flow Stability and Capacity (Proj. 3-19), 110 p., $6.40
186	Travel Estimation Procedures for Quick Response to Urban Policy Issues (Proj. 8-12A), 70 p., $5.60
187	Quick-Response Urban Travel Estimation Techniques and Transferable Parameters—User's Guide (Proj. 8-12A), 229 p., $10.20
188	Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings (Proj. 12-12), 113 p., $6.40
189	Quantifying the Benefits of Separating Pedestrians and Vehicles (Proj. 20-10), 127 p., $7.00
190	Use of Polymers in Highway Concrete (Proj. 18-2), 77 p., $5.60
191	Effect of Air Pollution Regulations on Highway Construction and Maintenance (Proj. 20-12), 81 p., $7.00
192	Predicting Moisture-Induced Damage to Asphaltic Concrete (Proj. 4-8(3)), 46 p., $5.20
193	Beneficial Effects Associated with Freeway Construction—Environmental, Social, and Economic (Proj. 20-13), 110 p., $7.80
194	Traffic Control in Oversaturated Street Networks (Proj. 3-18(2)), 152 p., $9.60
195	Minimizing Premature Cracking in Asphaltic Concrete Pavement (Proj. 9-4), 51 p., $6.00
196	Reconditioning Heavy-Duty Freeways in Urban Areas (Proj. 14-4), 60 p., $6.40
197	Cost and Safety Effectiveness of Highway Design Elements (Proj. 3-25), 237 p., $10.60
198	State Laws and Regulations on Truck Size and Weight (Proj. 20-16), 117 p., $7.20
199	Evaluating Options in Statewide Transportation Planning/Programming—Techniques and Applications (Proj. 8-18), 190 p., $9.00
200	Monitoring Carbon Monoxide Concentrations in Urban Areas (Proj. 20-14), 41 p., $5.20
201	Acceptance Criteria for Electroslag Weldments in Bridges (Proj. 10-10), 44 p., $5.20
202	Improved Pavement-Shoulder Joint Design (Proj. 14-3), 103 p., $7.20
203	Safety at Narrow Bridge Sites (Proj. 20-7, Task 7), 63 p., $6.00
204	Bridge Deck Joint-Sealing Systems—Evaluation and Performance Specification (Proj. 10-11), 46 p., $5.60
205	Implementing Packages of Congestion-Reducing Techniques—Strategies for Dealing with Institutional Problems of Cooperative Programs (Proj. 7-10(2)), 128 p., $7.60
206	Detection and Repair of Fatigue Damage in Welded Highway Bridges (Proj. 12-15 & 12-15(2)), 85 p., $6.80
207	Upgrading of Low-Quality Aggregates for PCC and Bituminous Pavements (Proj. 4-12), 91 p., $7.20
208	Market Opportunity Analysis for Short-Range Public Transportation Planning—Procedures for Evaluating Alternative Service Concepts (Proj. 8-16), 80 p., $6.80
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 Or-

TABLE 7 (*Continued*)

Rep. No.	*Title, Project, Pages, Price*
	ganizational Arrangements (Proj. 8-16), 161 p., $9.20
212	Market Opportunity Analysis for Short-Range Public Transportation Planning—Method and Demonstration (Proj. 8-16), 132 p., $10.00
—*	Freeway Traffic Management (Proj. 20-3D), 68 p., $4.00
213	Bayesian Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress (Proj. 9-4A), 52 p., $6.00
214	Design and Traffic Control Guidelines for Low-Volume Rural Roads (Proj. 20-7, Task 13), 41 p., $5.60
215	Pavement Management System Development (Proj. 20-7, Task 15), 32 p., $5.20
216	The No-Action Alternative—Research Report (Proj. 8-11), 72 p., $6.80
217	The No-Action Alternative—Impact Assessment Guidelines (Proj. 8-11), 174 p., $9.60
218A	Ecological Effects of Highway Fills on Wetlands—Research Report (Proj. 20-15), 34 p., $5.20
218B	Ecological Effects of Highway Fills on Wetlands—User's Manual (Proj. 20-15), 99 p., $7.20
219	Application of Traffic Conflict Analyses at Intersections (Proj. 17-3), 109 p., $7.60
220	Erosion Control During Highway Construction—Research Report (Proj. 16-3), 30 p., $5.60
221	Erosion Control During Highway Construction—Manual on Principles and Practices (Proj. 16-3), 108 p., $14.40
222	Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement (Proj. 12-20), 132 p., $9.20
223	Maintenance Levels-of-Service Guidelines (Proj. 14-5), 118 p., $8.80
224	Guidelines for Recycling Pavement Materials (Proj. 1-17), 137 p., $9.20
225	Plastic Pipe for Subsurface Drainage of Transportation Facilities (Proj. 4-11), 153 p., $9.60
226	Damage Evaluation and Repair Methods for Prestressed Concrete Bridge Members (Proj. 12-21), 66 p., $7.20
227	Fatigue Behavior of Full-Scale Welded Bridge Attachments (Proj. 12-15(3), 47 p., $6.40
228	Calibration of Response-Type Road Roughness Measuring Systems (Proj. 1-18), 81 p., $7.60
229	Methods for Analyzing Fuel Supply Limitations on Passenger Travel (Proj. 8-23), 132 p., $9.20
230	Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances (Proj. 22-2(4)), 42 p., $6.00
231	State Transportation Finance Within the Context of Energy Constraints (Proj. 8-22), 86 p., $7.60
232	Guidelines for Selection of Ramp Control Systems (Proj. 3-22A), 108 p., $8.40
233	Selecting Traffic Signal Control at Individual Intersections (Proj. 3-27), 133 p., $9.20
234	Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks—Field Evaluation (Proj. 12-13A), 64 p., $6.80
235	Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closures (Proj. 3-21(2)), 49 p., $7.00
236	Evaluation of Traffic Controls for Highway Work Zones (Proj. 17-4, 17-4(2)), 189 p., $12.00
237	Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques (Proj. 10-14), 40 p., $6.80
238	Estimating Exceedances and Design Values from Data Collected by Urban Ozone Monitoring Networks (Proj. 20-14A), 121 p., $9.60
239	Multiple-Service-Level Highway Bridge Railing Selection Procedures (Proj. 22-2(3)), 161 p. $10.40
240	A Manual to Determine Benefits of Separating Pedestrians and Vehicles (Proj. 20-10(2)), 56 p. $7.20
241	Guidelines for Using Vanpools and Carpools as a TSM Technique (Proj. 8-21), (In press)
242	Ultrasonic Measurement of Weld Flaw Size (Proj. 10-13), (In press)

Synthesis of Highway Practice

No.	*Title, Pages, Price*
1	Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $2.20
2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00
• **3**	Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., $2.20
4	Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., $2.20
• **5**	Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $2.40
6	Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $2.40
7	Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $2.40
• **8**	Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $2.40
9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80
10	Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., $2.80
11	Development of Management Capability (Proj. 20-5, Topic 12), 50 p., $3.20
12	Telecommunications Systems for Highway Administration and Operations (Proj. 20-5, Topic 3-03), 29 p., $2.80
13	Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., $2.80
14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., $4.00
• **15**	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., $3.60
16	Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., $2.80
17	Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., $3.60
18	Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., $4.00
19	Design, Construction, and Maintenance of PCC Pavement Joints (Proj. 20-5, Topic 3-04), 40 p., $3.60
20	Rest Areas (Proj. 20-5, Topic 4-04), 38 p., $3.60
21	Highway Location Reference Methods (Proj. 20-5, Topic 4-06), 30 p., $3.20

* Special publication.

TABLE 7 (*Continued*)

Synthesis of Highway Practice

No.	Title, Pages, Price
• 22	Maintenance Management of Traffic Signal Equipment and Systems (Proj. 20-5, Topic 4-03), 41 p., $4.00
23	Getting Research Findings into Practice (Proj. 20-5, Topic 11), 24 p., $3.20
24	Minimizing Deicing Chemical Use (Proj. 20-5, Topic 4-02), 58 p., $4.00
25	Reconditioning High-Volume Freeways in Urban Areas (Proj. 20-5, Topic 5-01), 56 p., $4.00
26	Roadway Design in Seasonal Frost Areas (Proj. 20-5, Topic 3-07), 104 p., $6.00
27	PCC Pavements for Low-Volume Roads and City Streets (Proj. 20-5, Topic 5-06), 31 p., $3.60
28	Partial-Lane Pavement Widening (Proj. 20-5, Topic 5-05), 30 p., $3.20
29	Treatment of Soft Foundations for Highway Embankments (Proj. 20-5, Topic 4-09), 25 p., $3.20
30	Bituminous Emulsions for Highway Pavements (Proj. 20-5, Topic 6-10), 76 p., $4.80
31	Highway Tunnel Operations (Proj. 20-5, Topic 5-08), 29 p., $3.20
32	Effects of Studded Tires (Proj. 20-5, Topic 5-13), 46 p., $4.00
33	Acquisition and Use of Geotechnical Information (Proj. 20-5, Topic 5-03), 40 p., $4.00
34	Policies for Accommodation of Utilities on Highway Rights-of-Way (Proj. 20-5, Topic 6-03), 22 p., $3.20
35	Design and Control of Freeway Off-Ramp Terminals (Proj. 20-5, Topic 5-02), 61 p., $4.40
36	Instrumentation and Equipment for Testing Highway Materials, Products, and Performance (Proj. 20-5, Topic 6-01), 70 p., $4.80
37	Lime-Fly Ash-Stabilized Bases and Subbases (Proj. 20-5, Topic 6-06), 66 p., $4.80
38	Statistically Oriented End-Result Specifications (Proj. 20-5, Topic 6-02), 40 p., $4.00
39	Transportation Requirements for the Handicapped, Elderly, and Economically Disadvantaged (Proj. 20-5, Topic 6-07), 54 p., $4.40
40	Staffing and Management for Social, Economic, and Environmental Impact Assessments (Proj. 20-5, Topic 7-02), 43 p., $4.00
41	Bridge Bearings (Proj. 20-5, Topic 6-09), 62 p., $4.80
42	Design of Pile Foundations (Proj. 20-5, Topic 5-04), 68 p. $4.80
43	Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation (Proj. 20-5, Topic 7-05), 57 p., $4.80
44	Consolidation of Concrete for Pavements, Bridge Decks, and Overlays (Proj. 20-5, Topic 7-01), 61 p., $4.80
45	Rapid-Setting Materials for Patching of Concrete (Proj. 20-5, Topic 6-05), 13 p., $2.40
46	Recording and Reporting Methods for Highway Maintenance Expenditures (Proj. 20-5, Topic 7-04), 35 p., $3.60
47	Effect of Weather on Highway Construction (Proj. 20-5, Topic 5-07), 29 p., $3.20
48	Priority Programming and Project Selection (Proj. 20-5, Topic 7-07), 31 p., $3.20
49	Open-Graded Friction Courses for Highways (Proj. 20-5, Topic 8-09), 50 p., $4.00
50	Durability of Drainage Pipe (Proj. 20-5, Topic 5-09), 37 p., $3.60
51	Construction Contract Staffing (Proj. 20-5, Topic 8-02), 62 p., $6.00
52	Management and Selection Systems for Highway Maintenance Equipment (Proj. 20-5, Topic 8-08), 17 p., $4.40
53	Precast Concrete Elements for Transportation Facilities (Proj. 20-5, Topic 8-05), 48 p., $5.60
54	Recycling Materials for Highways (Proj. 20-5, Topic 8-01), 53 p., $5.60
55	Storage and Retrieval Systems for Highway and Transportation Data (Proj. 20-5, Topic 8-06), 30 p., $4.80
56	Joint-Related Distress in PCC Pavement—Cause, Prevention and Rehabilitation (Proj. 20-5, Topic 7-06), 36 p., $5.20
57	Durability of Concrete Bridge Decks (Proj. 20-5, Topic 9-01), 61 p., $6.00
58	Consequences of Deferred Maintenance (Proj. 20-5, Topic 10-01), 24 p., $4.40
59	Relationship of Asphalt Cement Properties to Pavement Durability (Proj. 20-5, Topic 8-11), 43 p., $5.60
60	Failure and Repair of Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 9-08), 42 p., $5.60
61	Changeable Message Signs (Proj. 20-5, Topic 9-03), 37 p., $5.60
62	State Resources for Financing Transportation Programs (Proj. 20-5, Topic 9-09), 34 p., $5.20
63	Design and Use of Highway Shoulders (Proj. 20-5, Topic 8-03), 26 p., $4.80
64	Bituminous Patching Mixtures (Proj. 20-5, Topic 8-12), 26 p., $4.80
65	Quality Assurance (Proj. 20-5, Topic 9-05), 42 p., $5.60
66	Glare Screen Guidelines (Proj. 20-5, Topic 9-11), 17 p., $4.40.
67	Bridge Drainage Systems (Proj. 20-5, Topic 10-06) 44 p., $5.60
68	Motor Vehicle Size and Weight Regulations, Enforcement, and Permit Operations (Proj. 20-5, Topic 10-04), 45 p., $6.00
69	Bus Route and Schedule Planning Guidelines (Proj. 20-5, Topic 7-09), 99 p., $8.00
70	Design of Sedimentation Basins (Proj. 20-5, Topic 9-10), 54 p., $6.80
71	Direction Finding from Arterials to Destinations (Proj. 20-5, Topic 9-07), 50 p., $6.40
72	Transportation Needs Studies and Financial Constraints (Proj. 20-5, Topic 11-01), 54 p., $6.80
73	Alternative Work Schedules: Impacts on Transportation (Proj. 20-5, Topic 9-06), 54 p., $6.80.
74	State Transit-Management Assistance to Local Communities (Proj. 20-5, Topic 10-11), 35 p., $6.00
75	Transit Boards—Composition, Roles, and Procedures (Proj. 20-5, Topic 11-09), 24 p., $6.20
76	Collection and Use of Pavement Condition Data (Proj. 20-5, Topic 10-05), 74 p., $8.00
77	Evaluation of Pavement Maintenance Stategies (Proj. 20-5, Topic 11-08), 56 p., $7.40
78	Value Engineering in Preconstruction and Construction (Proj. 20-5, Topic 11-02, 03), 23 p., $6.40

TABLE 7 (*Continued*)

Synthesis of Highway Practce

No.	Title, Pages, Price
79	Contract Time Determination (Proj. 20-5, Topic 11-10), 45 p., $7.20
80	Formulating and Justifying Highway Maintenance Budgets (Proj. 20-5, Topic 10-03), 49 p., $7.20
81	Experiences in Transportation System Management (Proj. 20-5, Topic 11-14), 88 p. $8.40
82	Criteria for Evaluation of Truck Weight Enforcement Programs (Proj. 20-5, Topic 12-02), (In press)
83	Bus Transit Accessibility for the Handicapped in Urban Areas (Proj. 20-5, Topic 11-13), (In press)
84	Evaluation Criteria and Priority Setting for State Highway Programs (Proj. 20-5, Topic 12-01), (In press)
85	Energy Involved in Construction Materials and Procedures (Proj. 20-5, Topic 12-09), (In press)
86	Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs (Proj. 20-5, Topic 10-21), (In press)
87	Highway Noise Barriers (Proj. 20-5, Topic 12-07), (In press)
88	Underwater Inspection and Repairs of Bridge Substructures (Proj. 20-5, Topic 10-08), (In press)

TABLE 8
NCHRP RESEARCH RESULTS DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE, PAGES, PRICE
3[b]	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act 18 p. $1.00
6[b]	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[b]	20-6	Valuation Changes Resulting from Influence of Public Improvements 25 p. $1.00
14[b]	12-3	Waterproof Expansion Joints for Bridges 3 p. $1.00
19[b]	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968 21 p. $1.00
20[b]	19-1	Budgeting for State Highway Departments 4 p. $1.00
22[b]	20-6	Valuation in Eminent Domain as Affected by Zoning 19 p. $1.00
25[b]	20-6	Federal Environmental Legislation and Regulations as Affecting Highways 35 p. $1.00
31[b]	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way 12 p. $1.00
32[b]	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[b]	20-6	Legal Effect of Representations as to Subsurface Conditions 17 p. $1.00
40[b]	20-6	Appeal Bodies for Highway Relocation Assistance 16 p. $1.00
41[b]	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases 24 p. $1.00
42[b]	20-6	Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation 20 p. $1.00
45[b]	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned 24 p. $1.00
47[b]	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[b]	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation 31 p. $1.00
55[b]	20-7	Side-Friction Factors in the Design of Highway Curves (Task 4) 9 p. $1.00
67[b]	15-2	Field Evaluation of Tentative Design Procedure for Riprap-Lined Channels 4 p. $1.00
68[b]	20-6	The Meaning of Highway Purpose 15 p. $1.00
76[b]	22-3, 3A	Field Evaluation of Vehicle Barrier Systems 3 p. $1.00
77[b]	20-7	Earth-Berm Vehicle Deflector (Task 3) 3 p. $1.00
78[b]	3-20	Traffic Signal Warrants—A Bibliography 42 p. $1.00
79[b]	20-6	Personal Liability of State Highway Department Officers and Employees 22 p. $3.00
80[b]	20-6	Liability of State Highway Departments for Design, Construction, and Maintenance Defects 49 p. $3.00
81[b]	22-1A	Crash Testing and Evaluation of Attenuating Bridge Railing System 10 p. $1.00
82[b]	1-15	Design of Continuously Reinforced Concrete Pavements for Highways 12 p. $1.00
83[b]	20-6	Liability of State and Local Governments for Snow and Ice Control 16 p. $3.00
84[b]	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[b]	3-24	Current Practices in Use of Retroreflective Signing Materials 6 p. $1.00
89[b]	1-12(3)	Guidelines for Skid-Resistant Highway Pavement Surfaces 12 p. $1.00
91[b]	3-21	Motorist Response to Guide Signing 9 p. $1.00
94	8-13	Disaggregate Travel Demand Models 7 p. $1.00
95[b]	20-6	Legal Implications of Regulations Aimed at Reducing Wet-Weather Skidding Accidents on Highways 31 p. $3.00
97[b]	3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations 8 p. $1.00
99[b]	20-6	Liability of the State for Highway Traffic Noise 14 p. $3.00
100[b]	20-5	Safe Conduct of Traffic Through Highway Construction and Maintenance Zones 5 p. $1.00
102[b]	22-2	Modified Breakaway Cable Terminals for Guardrails and Median Barriers 13 p. $1.00
103[b]	20-6	Payment of Attorney Fees in Eminent Domain and Environmental Litigation 24 p. $3.00
104	Var.	NCHRP Research on Bridge Engineering 6 p. $1.00
105[b]	3-26	Selected Acoustical Parameters of Highway Noise Barriers 8 p. $1.00
106[b]	20-5	Use of Waste Materials in Highway Construction and Maintenance 2 p. $1.00
108[b]	20-6	Trial Strategy and Techniques in Highway Contract Litigation 31 p. $3.00
109[b]	20-6	Control of Conflicts of Interest in Highway Construction Contract Administration 56 p. $3.00
110[b]	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[b]	20-6	Trial Aids in Highway Condemnation Cases 11 p. $3.00
112[b]	20-6	Legal Implications of Control of Access to Uncontrolled-Access Highways 22 p. $3.00
113[b]	20-6	Right to Compensation in Eminent Domain for Abrogation of Restrictive Covenants 12 p. $3.00
114[b]	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[b]	20-6	Payments to Public Utilities for Relocation of Facilities in Highway Rights-of-Way 35 p. $3.00
118	Var.	NCHRP Research on Bridge Engineering 6 p. $1.00
119[b]	20-6	Recovery of Condemnation Blight Under Inverse Law 11 p. $3.00
120	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
222[b]	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	22-2(3)	A Modified Foundation for Breakaway Cable Terminals 7 p. $1.00
125	20-5	Continuing Project to Synthesize Information on Highway Problems 7 p. $1.00
126	3-18(4)	Performance Evaluation of Signalized Network Control Strategies 4 p. $1.00
127[b]	8-19	The Vehicle-Miles of Travel—Urban Highway Supply Relationship 7 p. $1.00
128	20-6	Continuing Project on Highway Right-of-Way and Legal Problems 7 p. $1.00
129	20-6	Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines 17 p. $3.00
130	1-20	Variability in Temperature Susceptibility of Asphalt Cement 5 p. $1.00

[a] See Table 5 for project titles. Numbers missing from the series have been superseded by published reports. Orders must be prepaid if for less than $10.00. Make request to Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, DC 20418.

[b] Final publication.

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 Date: 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 Research 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 research 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 translation 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 determine 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 Pavements."

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 design 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 Research and Development
Principal Invest.:	F. N. Finn Dr. C. L. Saraf Dr. W. S. Smith
Effective Date:	February 1, 1974
Completion Date:	April 30, 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 are undertaking new materials testing to generate new data, and some correlation testing between them and other laboratories is also under way.

Meanwhile, preparation of the final report is under way.

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 highway, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all of the various 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 minimum skid resistance 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 meth-

ods developed under NCHRP Project 1-12 for determining vehicular longitudinal acceleration forces and to relate these forces to the incidence of vehicle skidding through loss of traction at the tire-pavement interface. The over-all 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.

The essential findings of the study will be published as an NCHRP Research Digest. 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 for $4.00 prepaid. Send check or money order, payable to Transportation Research Board, 2101 Constitution Ave., N.W., Washington, DC 20418.

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 pavement 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 ponding 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 been 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 resulted 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. McCullough
Dr. W. R. Hudson
Effective Date: August 1, 1972
Completion Date: August 31, 1975
Funds: $151,870

Most of the thousands 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 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 for $4.00 prepaid from Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 accomplishment 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 will be published as an NCHRP Research Digest. 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 for $4.00 prepaid. Send check or money order, payable to Transportation Research Board, 2101 Constitution Ave., N.W., Washington, DC 20418.

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:	$200,000

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
Principal 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
	Dr. S. H. Carpenter
Effective Date:	January 23, 1978
Completion Date:	August 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. Many changes have been, and continue to be, made in the design and construction of PCC pavements. It is believed to be highly important to determine the effects of these changes in order to avoid the possibility of constructing additional miles of pavement that might fail prematurely. It is also 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. Considering the mileage of PCC pavement built each year, any deficiency in their design and construction can result in continuing maintenance problems of significant proportions.

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, is beyond the realistic scope of this project, the objectives of this project are (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.

Toward these objectives the following tasks were identified:

1. Development of a practical system for continuous evaluation of the performance of PCC pavements. The system was intended to:
   - (a) Be capable of considering all physical factors that could affect PCC pavement performance, including structural design and components, environmental conditions, and traffic loadings.
   - (b) Be capable of considering distress in relation to such factors as drainage conditions, subgrade, subbase, design features, materials, construction methods, age, and maintenance activities.
   - (c) Be suitable for collection and analysis of information on an individual state basis and on a nationwide basis so that it can be used for the planning, design, and formulation of maintenance and rehabilitation strategies.
   - (d) Permit correlations between such factors as design features, environment, traffic, pavement performance, and distress.
   - (e) Provide a framework for implementation.
2. Demonstration of the system developed under Task 1. This task consists of applying and refining the system developed under Task 1 to the survey and evaluation of jointed PCC pavements representing a range of serviceability, climates, and regions of the country.

Task 1 is complete and resulted in a Concrete Pavements Evaluation System (COPES). COPES is essentially a data collection system that will interface with selected, standard computer packages for data management and statistical analyses. Data from field trials in Illinois and Georgia were collected and used in the development of COPES and as a partial demonstration of the system under Task 2. However, during the research effort, it became evident that field trials in several states were financially impossible.

Consequently, additional funding was approved in the FY '80 program.

The agency was asked to submit a continuation proposal for Task 2 which was subsequently accepted by NCHRP. The continuation of Task 2 will permit field trials in additional states for the purpose of further testing and refining COPES.

During the summer of 1981, the data collection sheets of COPES, developed under Task 1, were revised and then used for field trials in Utah and Minnesota. The data collected and the methods used are now under further evaluation by the researchers in preparation for additional field trials in the spring of 1982.

An agency report was prepared documenting the initial development of COPES under Task 1. Included in the report were examples of COPES' potential uses, procedures for data collection, and a concrete pavement distress identification manual. Copies of the agency report are available on loan upon written request to the NCHRP. In addition, a limited number of extra copies are available for permanent retention by NCHRP sponsors.

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:	March 31, 1983
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 over-all objectives of research on this problem are:

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.

These overall objectives are intended to be accomplished in two phases.

Research has been completed on Phase I of the study covering item 1 of the overall objectives. 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 have 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. An interim report covering Phase I has been distributed to Program sponsors. The essential findings from the interim report have been published as NCHRP Research Results Digest 130. Loan copies of the interim report are available from the NCHRP upon written request.

Research is in progress on Phase II of the study to accomplish items 2, 3, and 4 of the overall objectives.

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:	February 14, 1984
Funds:	$300,000

A significant portion 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. There is a need to determine the most 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. There is a further need to determine at what distress level repairs cease to be cost-effective.

Recognizing that the study of all types of defects and deterioration in PCC is beyond the realistic scope of this project, the objective of this research is 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 (including various degrees of distress and deterioration) to be considered include faulting, D-cracking, restraint cracking, corner cracking, and load transfer. The contributing causes will be identified, and special consideration

will be given to techniques that retard or slow down joint deterioration. The techniques of overlay and recycling will not be considered as part of this research.

Accomplishment of the project objectives requires completion of the following tasks:

1. Review the available literature, determine techniques presently used by operating agencies, and evaluate the effectiveness of these methods. Consideration will also be given to identifying and evaluating new/alternate methods and materials. The relative cost-effectiveness of repair techniques will be quantified, and unusual traffic control procedures identified.

2. Include selected field trials to verify promising methods and techniques. Maximum use is to be made of operating agencies willing to bear the cost of field trials. Emphasis during this task will be on positive evaluation of the effectiveness of the techniques from the operational and performance standpoint.

An agency interim report has been submitted to NCHRP documenting the work conducted under Task 1. The report contains descriptions of joint repair methods identified from the literature, state visits, and a workshop held in the offices of the American Concrete Pavement Association (ACPA), subcontractor to the agency. The report also lists the following repair techniques to be pursued under Task 2: full and partial depth patching, undersealing, load transfer restoration, edge beams, grinding of faulted joints/cracks, and joint resealing.

Task 2 work is underway. Some field trials have already been observed in New Mexico and Illinois. The researchers are presently negotiating for additional state field sites and assisting in the planning of others. Work also progresses on developing repair procedure guidelines and specifications.

A limited number of copies of the agency interim report are available for loan upon written request to NCHRP.

Research is in progress. Initial activities include the review of appropriate literature and field interviews with highway agency personnel familiar with shoulder design and use practices.

Project 1-22 FY '81

Shoulder Geometrics and Use Guidelines

Research Agency:	Rummel, Klepper and Kahl
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 broadened 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 is to determine optimum use of highway shoulders considering such factors as safety, economics, traffic operations, roadway functional classification, and traffic volume. The end product is expected to be a set of shoulder geometric design and use guidelines that will encourage greater uniformity. Consideration should be given to other shoulder uses, some of which are listed in the problem statement.

Project 1-23 FY '82

Pavement Roughness and Rideability

Research Agency:	KETRON, Inc.
Principal Invest.:	M. S. Janoff
Effective Date:	27 months
Completion Date:	
Funds:	$250,000

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 are 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.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 research.

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: June 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 number 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 calculation 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 Com-

mission 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 wages and benefit indexes to develop multipliers. The assumptions of this technique and the limitations of applying the derived results 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 dusty 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 and urban arterial comparisons.

The results presented in the project report have been 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, such 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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, interview 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 regard 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 Associations 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 movement 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 used 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 input 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 Transportation Officials, 444 North Capitol St., N.W., Suite 225, Washington, D.C. 20001

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, NW., Washington, DC 20418.

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 communication systems were completed. These involved both night and day study of car-following for no signal display, for the conventional brake light, for the trilight 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 were 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	$316,011

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.

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 environ-

mental 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, 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 pre-

sented 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 efficiency 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 included 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 substantiated 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 primacy 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 signing 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 purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 algorithm 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 highway 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 the 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 published; however, microfiche of the report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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. Analyses 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 for the cost of mailing and handling.

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. Loan requests for the film or the report, "Improved Control Logic for Use with Computer-Controlled Traffic," should be directed to: TRB Audio-Visual Library, 2101 Constitution Avenue N.W., Washington, DC 20418. To purchase the report, a check or money order in the amount of $10.00 should be made payable to *Transportation Research Board* and sent to the Publications Office, Transportation Research Board, same address.

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 evaluation 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 docu-

mented 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. Loan requests should be directed to: Program Director, NCHRP, 2101 Constitution Avenue N.W., Washington, DC 20418. To purchase the manual, a check or money order in the amount of $10.00, plus $1.00 for postage and handling, should be made payable to *Transportation Research Board* and sent to the Publications Office, Transportation Research Board, same address.

Project 3-18(4) FY '76

Methodology for Performance Evaluation of Signalized Network Control Strategies

Research Agency: Computran 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 could 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 general use; 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 upon written request to the NCHRP, or microfiche of the report may be purchased for $4.00 prepaid, from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 on 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	$80,000

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 determination of need for traffic signal control, or consider them only in general terms. It is often 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Project 3-20A FY '80

Peak-Hour Traffic Signal Warrants

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

The need for a traffic signal warrant based on peak-hour conditions has been identified. This warrant would be used 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 have been proposed but have not been verified in regard to the acceptability of the underlying assumptions and the actual numerical values. These elements need to be investigated and verified to determine which should be adopted for general use.

The objective of this research is to evaluate and verify the peak-hour warrant suggested by the Signals 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 supporting documentation and justification is desired for adoption of a warrant, including either modifications to the above warrants that may result from this research or consideration of an alternative warrant.

Field studies have been 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.

Each warrant element is being evaluated in terms of reasonableness, ease of data collection and application, and acceptability of underlying criteria and assumptions. If one or more of the proposed warrant elements are determined to be both verified and acceptable, a specific recommendation for the adoption of a warrant will be prepared. The recommendation will include the applications and limitations of the warrant. If the proposed warrant elements can not be verified or are found unacceptable, modifications and/or alternatives will be proposed.

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. Microfiche of

the report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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: June 30, 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.

Various situations require closure of one or more traffic lanes as a result of planned or unplanned 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 various 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 bulb 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 for $4.00 prepaid from Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. Loan copies are available from NCHRP.

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:	$300,000

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 number 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 $6.00. To purchase the report, a check or money order in the amount of $6.00, plus $1.00 for postage and handling, should be made payable to the *Transportation Research Board* and sent to the Publications Office, Transportation Research Board, 2101 Constitution Ave. NW, Washington, D.C. 20418.

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.

About 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 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:	$225,891

Noise barriers are becoming increasingly important as noise abatement measures along new highways as well as along existing highways. 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 for $4.00 each prepaid. Send check or money order, payable to *Transportation Research Board*, to Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418. Research Results Digests 105 and 122 cover Phases 1 and 2 findings, respectively.

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:	$153,953

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 upon written request to the NCHRP.

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: April 30, 1982
Funds: $150,000

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) has 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 is part of the Phase II effort, which is 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 have indicated a need for improvement in several elements of the technical analysis.

Recent studies have produced new empirical data describing certain aspects of traffic operations on two-lane, two-way rural highways. Understanding of the fundamental relationships among many of the capacity-related variables has been enhanced through development of comprehensive analytical tools such as computer simulation. However, the new empirical data and emerging analytical techniques have not been assembled and structured into a comprehensive and coordinated procedure for direct application by HCM users.

The objective of this research is 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. Multilane roads and intersections are excluded.

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, are now being used to indicate the general level of accuracy for the MRI model.

Relationships between traffic volume, levels of service, and related parameters will be determined using the field data and the simulation model. These relationships will be restructured, including simplification where feasible and approximations where necessary, 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 will be prepared suitable for inclusion in a revised HCM.

Problems encountered in the field studies caused a schedule slippage of about 3 months; a time extension is anticipated.

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

Urban Signalized Intersection Capacity

Research Agency: JHK & Associates
Principal Invest.: William R. Reilly
Effective Date: October 1, 1979
Completion Date: February 28, 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), is directed to satisfying the highest priority research needs identified in Phase I.

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

Previous research efforts related to intersection capacity analysis have been 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 have been evaluated. An evaluation of the most promising procedures through illustrative case studies has also been completed.

Traffic service measures such as delay, stops, and saturation flow have been collected at intersections in Alexandria, VA; Atlanta, GA; and Tucson, AZ. Additional field data have been 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 have been developed. The effects of traffic signal timing and phasing are included in the procedures. Draft material for the revised HCM has been prepared and is currently being reviewed by the NCHRP project panel.

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: June 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Project 4-6 FY '65

Protective 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, '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 rectangular 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, subgrade 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	$71,652

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.

Ultimately, the aggregate properties and the asphalt cement characteristics that affect adhesion must be identified. This knowledge is basic to the development of techniques that are needed for optimizing the choice of materials or for specifying appropriate corrective measures where loss of bond is likely to be a problem. However, the accomplishment of these ultimate objectives requires fundamental studies that are time consuming and necessitate the development of test systems for correlating the findings with field performance. The objective of this project is to meet an interim 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 preliminary draft report has been reviewed and approved. It will be published in the NCHRP report series.

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. I, 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 elastomeric 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 pressure 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 distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP report series, but loan copies are available from the NCHRP upon written request.

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 supplies 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 use as aggregates in portland cement concrete, bituminous mixes, and base courses.

The 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 Date:	Sept. 1, 1972
Completion Date:	Nov. 30, 1973
Funds:	$53,663

Although an abundant 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 supplies 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 having the greatest potential for use as 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 Invests:	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:	$150,000

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 devised 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: $30,721

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 Institute of Technology
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 is 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 has been collected on current practices by questionnaire responses and visits with state materials and bridge engineers. An accelerated testing program has been 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. The preliminary draft final report, containing tentative guidelines for use of conventional and more recently developed coating systems, has been submitted and is in the review and revision process.

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: *Completion Date:*	(27 months)
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.

The Task 1 report will be submitted within 6 months after the beginning date of the contract period. NCHRP approval of the interim report will be required before the initiation of subsequent tasks.

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, but 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.

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 numerical score 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. Ernst
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 existing 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 encountered, 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.

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 quantitative 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Project 5-5B FY '72

Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing is Prevalent

Research Agency:	Texas A & M University Research Foundation
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 compatible 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 at specific locations; and to prepare guidelines for the design of lighting. Benefits from fixed-source 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 should 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 should 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 role 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:	November 30, 1982
Funds:	$199,999

Over the years, researchers have devoted considerable effort to the general area of freeway lighting. These efforts—carried out under the auspices of NCHRP, FHWA, individual states, and others—have provided a considerable amount of information on the visual environment requirements, the benefits to be derived, and warrants concerning the provision of lighting. Close examination of these efforts

indicates that the major thrust of the work has been on complete or continuous lighting.

As a means of facilitating the driving task and reducing 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. This premise is for the most part unsubstantiated and is subject to doubts concerning the effectiveness of partial lighting.

The objective of this research is to determine the effectiveness of partial lighting of interchanges and to develop recommendations for its use. A methodology will be developed for evaluating the effectiveness of partial lighting relative to no lighting and to complete lighting of interchanges. The methodology will be 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 will be investigated. The boundary conditions for roadway and traffic characteristics for which no lighting, partial lighting, or complete lighting is appropriate will be determined through field studies at cloverleaf and diamond freeway interchanges.

A questionnaire was sent to each state and selected Canadian provinces to determine the current lighting practice, and an interim report presenting the findings was prepared. Field work has been delayed because a site with all of the desired characteristics has not been located. A small pilot study to test the data collection technique has been completed, and the search continues for a suitable site for the major field effort.

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: February 15, 1963
Completion Date: February 29, 1964
Funds: $25,000

This study was primarily one of searching the literature and appraising the current status of knowledge of the subject. In addition to a literature survey, 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: February 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 of 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 such

methods as (1) coatings on reinforcing bars, (2) inhibitors in concrete mixtures, (3) inhibitors in deicing chemicals, and (4) cathodic protection.

The project report has been published as:

NCHRP Report 23, "Methods for Reducing 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 surface 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 terminated 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 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 project report was not published in the regular NCHRP report series; however, microfiche of the report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 Structures."

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:	January 1, 1965
Completion Date:	June 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 studies 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 evalnate 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 or 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 artificial 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. Clyde Herrick
Effective Date:	February 1, 1964
Completion Date:	August 31, 1967
Funds:	$73,391

The purpose of this research was to develop new or improved methodology for weigbing 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:	February 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 bas 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 tbe 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 ser-

vices: 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 '71

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 determining 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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.

Mntually 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 Program Director or in microfiche for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. 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).

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: Multisystems, Inc.
Principal Invest.: J. H. Batchelder, H. S. Levinson, M. Golenberg
Effective Date: April 6, 1981
Completion Date: January 6, 1983
Funds: $199,988

Reduced transportation funding levels, environmental concerns, and shortages of construction materials are some of the reasons that dictate more emphasis on implementing low-cost TSM projects in the future. Transportation agencies need to make cost-effective decisions in their selection and priority of implementing low-cost TSM projects in order to obtain maximum benefits from the transportation dollar.

Various reports have identified categories and types of low-cost TSM actions. Traffic engineering, ridesharing, transit operations, and traffic restraint actions are examples of broad categories of low-cost TSM projects. Goals for these actions include increasing transportation efficiency with a minimum of expenditures, reducing energy consumption, and improving environmental quality and safety. Data are available to determine, in a general sense, the feasibility and applicability of these actions. Numerous publications have listed criteria to be used in the evaluation of projects identified as low-cost TSM improvements. Because of deficiencies in estimating impacts, there is a need to assemble, refine, and/or develop systematic analysis methods to estimate quickly and evaluate the direct travel impacts of proposed low-cost TSM actions in each category. In turn, these travel impacts can be used as input into estimating the effects of the specific TSM actions on energy consumption, air quality, and safety factors. These estimates of impacts are needed to set priorities objectively for proposed projects within each category and against projects in other categories. Simplified methods are needed where a quick-response estimate of the impact of the action is required, and where technical resources are limited. These methods should be based on data readily obtainable by the user. The general objective of this research is to improve the capability of transportation agencies to estimate quickly the impacts of, and to determine priorities for, proposed, low-cost TSM actions so that decisions can be made on better information.

It is anticipated that this objective will be accomplished with a two-phased project. The first phase objectives include the assembly, refinement, and/or development of simplified procedures to estimate the travel impacts from the implementation of low-cost TSM projects. Additionally, the first phase objectives include the development of recommended procedures for setting low-cost TSM project priorities. Given successful accomplishment of all Phase I objectives, and availability of future-year funds, a Phase II is planned for verification of the findings from Phase I and provision of opportunities for "hands-on" user experience and demonstration with the manual expected from Phase I. To accomplish the objectives of Phase I, the following tasks are planned.

Task 1. Define purposes and constraints: (A) Identify potential users of impact estimating procedures and their resource constraints. This could include state agencies, MPO's, and local agencies. Develop categories of users by technical resource constraints. (B) Determine appropriate classification of low-cost actions for the development of impact estimating procedures. These classifications should relate to the needs and resources of users identified in Task 1(A). (C) Define the set of impact measures required for travel assessments (including energy, air quality, safety). (D) Identify the input data that are readily obtainable by each category of user.

Task 2. Develop impact estimation procedures: (A) Develop a structured framework for application of simplified, quick-response impact estimating procedures classified by level of effort criteria for each category of user. (B) Review and synthesize existing, simple, quick-response impact estimation techniques. (C) Identify specific deficiencies of existing impact estimation techniques with respect to their validity, simplicity, applicability, etc. Special attention should be given to identifying types of actions for which impact estimation capabilities are deficient or nonexistent.

Task 3. Develop recommended procedures for low-cost TSM project priority setting. Special attention should be given to how use of quantitative impact estimates can be expanded in the priority setting process. (This task is envisioned to take approximately 10 percent of the project resources.)

Task 4. Prepare a research report.

Task 5. Prepare a user's manual. This manual will include (a) documentation of selected methodologies including step-by-step procedures, data needs, estimated time to complete, and cost; (b) an example of the application of each technique to a project (field work is not anticipated); and (c) discussion of actions to improve the use of impact estimations in the decision-making process.

Progress to December 31, 1981 includes completion of a TSM action classification system which relates TSM actions to the geographical context and to the type of problem recognized by the local planner/designer. The analytical framework being developed as part of Task 2 will call for the TSM action or action packages to be related to potential impacts that in turn will lead to the identification of available estimation techniques. Work on Task 3, priority setting, is in the start-up stage.

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 ade-

quacy 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 metroplitan 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 network. 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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, and 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 canvass 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 determining local transit needs and providing activity-center traffic estimates to assist in assessing the localized impact of land-use changes on the transportation system.

Research has been completed, and the project report has been 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 puhlic 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 transportation 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 in 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 variance 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: February 28, 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 for $4.00 prepaid 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. Send check or money order to the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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, tables, 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 techniques 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 transportation 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 has developed over the past two decades, is characterized by the creation of long-range systems plans based on simulations of regional travel patterns using models developed and calibrated with aggregate zonal data. Three of the basic criticisms that have been made of the regional simulation and planning process have been that the presently used aggregate models cannot be readily used for subregional and project planning; they are not responsive to the policy issues that planners are being asked to address; and they require 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. In the report, the models are appraised in terms of their advantages in travel demand analysis, their low data collection costs, their transferability, and their flexibility in application. Several hypothetical applications are provided.

Research is being 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 is a continuation of Project 8-13. The overall objective of the research is 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 an approach 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 will provide valuable information for the preparation of manuals called for in Phase III. 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 al-

ready has some knowledge of some major issues in the field.

The agency final draft report is in the review process and is available on a loan basis upon written request to the NCHRP.

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:	$149,860

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; and (4) traveler responses to hypothetical systems with specified performance characteristics. Furthermore, existing procedures are unable to provide information on why a trip is made and are, hence, also unable to provide a means for estimating, under a variety of assumptions, changes in the number and characteristics of trips that an individual will make.

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 is available for $4.00 prepaid. Send check or money order, payable to *Transportation Research Board,* to Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418.

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 Evaluation; 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 13, 1981
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 is no subsuming theory of travel behavior which generates those models; they are merely convenient formulations for expressing and forecasting travel and assume stable relationships. Disaggregate models, although offering significant advantages over present techniques, deal almost entirely with individual choices, thus ignoring basic processes that generate travel. A major deficiency in both approaches is 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 the key elements relating to individual and household behavior and incorporating those elements into operational travel forecasting procedures, such as the Urban Transportation Planning System.

With additional support from the Federal Highway Administration in the amount of $75,000, the key elements or concepts tested included the following:

1. Models of travel behavior derived from theories of household activity choice, duration, scheduling, and location.
2. Activity and travel patterns can be related to demographic descriptors such as social class, ethnicity, life cycle, and status.
3. Intervening factors between activity and travel patterns include social roles, attitudes, resource constraints, social norms, and perceptions of opportunities.
4. The distribution and form of activity sites, such as residential population density, and transportation system variables affect activity and travel patterns.

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.

Research has been terminated with the development of household activity and travel behavior models. Difficulty experienced in structuring the models exhausted project resources budgeted to (1) validate the models in cities other than Baltimore, and (2) incorporate the models into operational travel forecasting procedures. Nevertheless, substantial findings for the project are worthy of consideration by model developers in universities and larger MPO and state agencies.

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, and 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.

The agency draft final report is in the review process. This report and the interim report, entitled "Behavioral Science Concepts for Transportation Planners," are available on a loan basis upon request to the NCHRP.

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 is 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, serve to higblight this need.

The general objective of this research is to develop an improved understanding 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 is being 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 for $4.00 prepaid. Send check or money order, payable to *Transportation Research Board,* to Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418.

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 will not be published; however, loan copies are available upon written request to the NCHRP or microfiche may be purchased for $4.00 prepaid. Send check or money order, payable to *Transportation Research Board*, to Publications Office, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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: $489,217

Public transportation traditionally has been 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, has caused growing deficits. Public concern about energy, environment, auto dependency, congestion, and the quality of urban living in general has 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, have posed questions concerning how much financial support is appropriate, what services are required, and how these services should be provided. Public officials need 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 has been completed, and the project report has been 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 giudance 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 planners 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 transportation 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 could 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 Investigator:	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 reqnirements 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 for $4.00. Results are summarized in Research Results Digest 127, which may be purchased for $1.00 plus postage and handling. Send check or money order, payable to *Transportation Research Board,* to Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418.

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 production 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.

The draft final report is in the review process.

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

A fundamental strategy of transportation system management is to encourage more efficient use of highway and roadway vehicles and space through higher vehicle occupancies. Although highway and transportation departments, transit authorities, and other public agencies can and do encourage increased commuter use of carpools and vanpools in large and small urban areas in a variety of ways (computer matching, purchase of vans for vanpooling, parking incentive programs, preferential highway treatment, etc.), many people fail to take advantage of, or even resist, these opportunities when offered. Decisions to participate in commuter-ridesharing arrangements appear to be based on many factors (economic, social, and psychological). Not well understood is how the two ridesharing alternatives of carpooling and vanpooling differ in their appeal to commuters in urban regions, and how the great variety of incentives for carpooling and vanpooling affect their use. An understanding of the underlying factors that motivate the decision to ride-share is necessary in order to assess the full potential of ridesharing development and to determine effective strategies to achieve that goal.

In addition many existing institutional factors (regulatory, zoning, insurance, profit motive, funding limitations, sponsor types) shape the kinds of carpooling and vanpooling incentives it is possible to implement. The determination of effective strategies and the subsequent evalua-

tion of their implementation require methods and criteria that consider social, economic, travel, energy, and environmental impacts, as well as the perceptual, preferential, and attitudinal concerns of the public and decision-makers generally. Such concerns and impacts have not been determined or assessed.

The general objective of this research is to identify effective policies and their impacts to encourage vanpooling and carpooling use based on an understanding of individual and household preferences and behavior. Specifically, the research is expected to analyze individual and household attitudes, preferences, and behaviors related to ridesharing. The goal is to use the analysis results to develop guidelines for transportation practitioners and policymakers for selecting techniques that are compatible with other TSM strategies and are likely to result in significant increases in ridesharing over the short term (2 to 5 years).

A three-phase study was designed. In Phase I, draft guidelines were developed after review of available literature and research data. Knowledge gaps were identified in order to shape the research of Phase II. New data gathered in the second phase involved operating agencies and employers, as well as potential ridesharers. Based on the data analysis, the draft guidelines were modified to be (1) more responsive to policy and program realities and to the needs and working styles that may maintain carpooling/vanpooling programs, and (2) more sensitive to the motivations and likely behavior of potential ridesharers. Phase III has been a production phase that included manual and research report review, editing, and final report production.

The guidelines have been published as:

NCHRP Report 241, "Guidelines for Using Vanpools and Carpools as a TSM Technique." The final draft research report is anticipated early in 1982, at which time loan copies may be obtained from the NCHRP or may be purchased in microfiche.

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 evaluations 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

Recent changes in transportation planning give increasing importance to the accuracy, simplicity of approach, reliability, and acceptability of travel forecasts. Transportation planners forecast 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 these variables can be carried forward to cause substantial errors in information provided to decision-makers in the evaluation of transportation alternatives. Furthermore, local involvement in the transportation planning process has increased considerably and local officials are often reluctant to accept forecasts of socioeconomic variables, particularly if declines in populations, income, or employment are forecasted.

One frequently encountered difficulty is that different techniques to forecast the same socioeconomic variables often produce significantly different values. For example, population forecasts are made using a variety of techniques such as cohort survival, ratio methods, and trend line analysis. Some forecasting techniques produce data that are incomplete or lack sufficient detail for travel estimates and impact assessments. Furthermore, some existing techniques do not recognize changing social trends such as increasing labor force participation of women, or changing planning functions. Such changing norms challenge the basic assumptions on which the techniques are based. Another reason for challenging the basic assumptions of forecasting techniques is that future transportation facilities very often have been assumed to be in place notwithstanding a likelihood that they would never be built.

In the near future, all states will be asked to accept official federal population forecasts or be required to justify an alternative forecast. Within each state, the allocation of the official population forecasts to individual counties and localities will be treated by close cooperation between state and local authorities. The problem of ensuring that population forecasts are appropriately nested at various levels of aggregation, and are consistent with other forecasts such as employment, is likely to be a major concern.

With very limited funds available for data gathering efforts, it is particularly important to determine the sensitivity of transportation forecasting procedures to variations in the values of input parameters. State and local planners need assistance in choosing techniques that utilize available forecasts of input parameters and in allocating state-level forecasts. Therefore, research is needed to document techniques that (1) are appropriate for a given level of aggregation, (2) are accurate to acceptable limits, (3) will be acceptable at the local planning level, and (4) can be implemented and updated by users who do not possess a sophisticated economic or statistical background.

The general objective of this research is to summarize and evaluate techniques of using previously forecasted, independent, socioeconomic variables at appropriate levels of geography necessary for urban, rural, and statewide transportation planning. To accomplish this objective, the following tasks are planned:

Task 1. Examine the sensitivity of transportation forecasting and simulation procedures, including the FHWA/UMTA traffic simulation process, to variations in independent variables. The sensitivity analysis should take into account the size, growth trends, economic functions, density, and other significant characteristics of differing geographic areas.

Task 2. Review techniques for using available sources of forecasted independent variables in the light of (a) the foregoing sensitivity analysis, (b) current and anticipated planning functions, and (d) other factors, such as resource constraints. At least the following variables should be considered: (a) population and population characteristics, (b) housing unit and household characteristics, (c) income, (d) employment by major sector, and (e) vehicle availability. Limitations and biases of each technique for particular applications (such as growing vs. declining areas, urban vs. rural, both large and small) should be discussed, as should also the appropriateness of each technique and the availability of base data for small analysis areas such as traffic zones.

Task 3. If satisfactory techniques for the modification and application of available forecasts are not found, propose new techniques.

Task 4. Prepare a final report to include:

(a) Documentation of available techniques and their attributes for utilizing socioeconomic variables.

(b) Research findings, specifically addressing items under Task 2.

(c) Applications of techniques to geographic areas with the following characteristics: (1) growing versus declining; (2) urban versus rural; (3) large versus small.

Progress to December 31, 1981 includes the completion of Tasks 1 and 2 and substantial work on Task 4. Task 3 has not been found to be necessary. There are such a variety of techniques, methodologies and data, and such distinct differences in agency resources, expertise, and ex-

pectations for projection that perscription of a single projection procedure, or even adequate explanation of various techniques, is prohibitive. Instead, guidance to the transportation planner will be given in the final report on a few basic techniques.

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

The intercity bus industry serves 15,000 communities, including 14,000 small towns and innumerable crossroads and "flag stops" in rural America where it provides the only form of public transportation available. Moreover, the industry often serves a major segment of the population that has little or no alternative public transportation available.

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 result of this lower return is for carriers to (1) reduce the rate at which buses are replaced and terminals are improved, and/or (2) reduce schedules and eliminate marginal routes and marginal communities served, or (3) go out of business. This loss of present service(s) and potential loss of future services has prompted many communities to look to the state and the Federal Government for aid in the preservation and, in some cases, expansion of intercity bus services. Furthermore, the national and state trend for deregulation of intercity bus carriers may cause additional fear of terminated services on marginal routes and to marginal communities.

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 have been 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. Geographic, economic, demographic, and other characteristics of communities are described in route-level demand estimation equations.

Alternative bus service designs have been 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 has been 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 have also been 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.

In addition to the regular NCHRP research report, a handbook is being prepared for use by state and local transportation agencies. Draft versions of both documents are being reviewed by the NCHRP project panel.

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: August 15, 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 nsed 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.

There is a need not only to establish accepted procedures for translating various inputs into project traffic data, but also to specify the content, accuracy, and limitations of the data for the problem being addressed. This type of information is required to meet the diverse needs of the highway designer, the environmental planner, and others. For example, the environmental planner dealing with air quality and noise impacts expects one kind of data, while the highway designer expects another. Some of the needs may be better met by drawing from historical data, others from assignment data, and others from a combination of inputs.

The objectives of this research are 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 techniques to the maximum extent possible, develop a user-oriented manual containing procedures for the full range of plannning and design needs together with illustrative case studies.

A number of transportation agencies have been contacted to determine the various needs for highway traffic data used in project planning and design and the procedures used to develop such data. Contacts also included producers of highway traffic data to determine the procedures, data inputs, and analysis techniques used to develop the information to meet the user requirements. Significant procedural steps, resources involved, kinds of projects to which the techniques are applied, and presentation format were solicited along with other information that can be used for comparative purposes.

The procedures and analysis techniques that have been proven reasonably successful will be 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 will be addressed. On the basis of this evaluation, existing, modified, and/or new procedures with appropriate analysis techniques will be recommended for application to the full range of identified highway project planning and design needs.

A user-oriented manual will be developed describing recommended procedures. Each phase of the procedures will include a commentary describing the benefits, shortcomings, and the circumstances that may require alternative steps. Design project "cases" will he defined and appropriate traffic estimating steps will be described. Cases to be analyzed will be selected to ensure coverage of the full range of applications and will include as a minimum: (1) major new highway construction with regional impacts, (2) upgrading an existing facility with subarea impact, and (3) interchange design with local impact.

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. Wagmann
Effective Date:	September 1, 1981
Completion Date:	January 31, 1983
Funds:	$200,000

Recognizing the mobility problems faced by physically and mentally handicapped people, transportation providers are trying to develop cost-effective ways to meet the transportation needs of these people. There is a need for methods to allow transportation providers to evaluate the cost-effectiveness of the various transportation options available. The costs and benefits of carrying out directives such as U.S. Department of Transportation's ruling implementing Section 504 of the Rehabilitation Act of 1973 are uncertain. Existing transportation services are often competitive, thereby draining away available public resources. Federal, state, and local agencies have a concern with these issues.

Currently, handicapped people and subgroups of that population are taking trips, for a variety of reasons, and using a variety of transportation service options. There are a number of such options available to serve the needs of these people, encompassing both modal and nonmodal responses. But current trip demand and mode choice are affected by availability and cost of each option; and, in turn, costs and effectiveness of these options are affected by ridership demand. Changes and variations in supply options may well change existing trip demands and trip distribution by the handicapped. To some extent, these changes may represent totally new trip-making; they may also represent diversion from existing services.

In each urban area and rural community, difficult choices will have to be made concerning the provision of transportation services to handicapped people. It is, therefore, necessary to know the cost-effectiveness of various modal and nonmodal supply options in meeting the transport needs of mentally and physically handicapped groups.

The purpose of this research is to provide needed information to federal, state, and local decision-makers balancing available resources against the needs of handicapped persons. No new federal funding is available to implement regulations or respond to these needs; hence, actions must compete with other needed service improvements.

The objective of this study is to determine the cost-effectiveness of transportation service options for improving the mobility of handicapped people. The methods used to achieve this objective should be described in a form useful to state and local transportation providers in conducting their own evaluations. The study will be limited to assessing the needs of people who because of physical or mental handicaps cannot use existing transportation systems or can only do so with difficulty. While the focus of the study is on an urban context, rural areas should also be studied. In order to meet this objective, the following tasks will he performed:

Task 1. Prepare and describe the cost-effectiveness methods to be used in the study.

Task 2. Review relevant literature.

Task 3. Define characteristics of the group in terms of urban/rural, type of handicap, trip purposes, ability to use public transportation, and current travel patterns by mode and purpose.

Task 4. Describe and review characteristics of major service and system options as a means of removing barriers to travel (including, but not limited to, fixed-route buses, paratransit, taxis, shared rides, pedestrian improvements, urban and commuter rail and user training).

Task 5. Assess the impact on demand by trip purpose and population subgroups of the service and system options.

Task 6. Evaluate the impact of changes to service on the mobility of the target population subgroups. (How

many trips are diverted from other modes and how many new trips are generated?)

Task 7. Estimate the cost and the effectiveness of providing different options and combinations thereof including, but not limited to, total cost, cost per mile, cost per trip, and cost to the passenger.

Task 8. Refine the cost-effectiveness method based on experience gained in Tasks 2 through 7.

Progress to December 31, 1981 includes the development of the cost-effectiveness methodology to be used in Task 7 and the review of relevant literature. Work has begun on Tasks 3 and 4.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 Verifying 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, 1982
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 is 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."

Accomplishment of this objective involves the following tasks:

1. Based on an evaluation of the mix design methods described in the reference documents, determine tentative applicability of the mix design methods and criteria for prediction of field performance of base and surface courses. The base and surface courses considered shall involve slow- and medium-setting emulsions meeting AASHTO and ASTM specifications as well as various types, grading, and qualities of aggregate. The evaluation also should consider the relationships between the properties of the mixtures as determined in the laboratory and the rate of attainment of these properties in the field under different environmental conditions.
2. Propose additions to or modifications of the methods and criteria described in the two methods.
3. Develop plans for verification of the design methods and criteria as modified in Task 2 covering various emulsions and aggregates in different climatic regions.
4. Conduct the verification program developed under Task 3.
5. Prepare a final report containing a detailed description of the recommended procedures and criteria for design of emulsified asphalt paving mixtures.

Research is in progress. Preliminary laboratory and field evaluation at the Asphalt Institute and the University of Illinois mix design procedures indicate inadequacies within each procedure and incompatibilities between the procedures.

Simplified mix design procedures have been developed using either Marshall or Hveem laboratory specimens. The simplified procedures were used to determine the asphalt emulsion contents for a field project in Arkansas and two projects in Virginia. No construction or short-term performance problems were encountered on these jobs during the spreading and compaction of the asphalt emulsion mixtures. Emphasis during the remainder of the project will be on further field verification and modification of the simplified mix design procedures.

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; gradation 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, natural variations inherent in work and material, and variations inherent in methods of measurement and control test procedures.

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 included 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 research 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 with 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-course 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 Measurements 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 consuming 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, and 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 nondestructive 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, accuracy, 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 seal-coat 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 in-

stallation 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:	$174,889

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 climatic 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 for $4.00 prepaid from Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Project 10-13 FY '79

Ultrasonic Measurement of Weld Flaw Size

Research Agency:	The Welding Institute (England)
Principal Invest.:	Timothy J. Jessop
Effective Date:	July 1, 1979
Completion Date:	October 31, 1981
Funds:	$126,000

There is an urgent need for ultrasonic testing procedures that can he 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.I to determine the acceptability of structural welds. These provisions are based on an assumed relationship between the ultrasonic "Indication Rating" and flaw size. Experience indicates that this relationship may not be valid. Research is needed to advance or develop 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 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 such as cracks or incomplete fusion, with some consideration of slag inclusions.

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. The study 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.

Through December 31, 1981 research has been completed, and the final report has been published as:

NCHRP Report 242, "Ultrasonic Measurement of Weld Flaw Size."

Project 10-14 FY '79

Locating Voids Beneath Pavement Using Pulsed Electromagnetic Wave Techniques

Research Agency:	Georgia Institute of Technology
Principal Invest.:	Dr. J. D. Echard
	Dr. W. J. Steinway
Effective Date:	April 2, 1979
Completion Date:	November 1, 1980
Funds:	$99,850

Voids often develop over a period of years beneath portland cement concrete pavements at approaches to bridges and at other locations such as pavement joints due to pumping, consolidation, subsidence, and erosion of the support material from beneath the pavement. This loss of support results in pavement distress manifested by cracking, settlement, bumps, and depressions in the roadway that are rough and often bazardous to rapidly moving traffic. Maintenance activities and restoration of rideability of these distressed pavements are time consuming, costly, and disruptive to normal traffic movement. Such activities include patching, slabjacking, and replacement of pavement sections.

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 $\pm$ ½ inch in depth and $\pm$ 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. Additional 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
Completion Date: May 31, 1982
Funds: $125,000

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 superstructures are limited and provide little information that can he used 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-determining characteristics of the in-service bridge are known, whereas they have been assumed in the original design calculations. Recognition 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 can 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 an appreciable length of time and showed no distress. Because of this change, 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 the proposed research 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 methodology was directed to rigid frames and skewed simple and continuous spans. Span lengths up to 80 ft were considered. Bridge types included were slab, girder, T-beam, and box beam.

The research included the following tasks:

Task 1. Review and summarize the present state of the art of: (a) concrete bridge inspection, with particular emphasis on quantifying the consequences of various types and amounts of deterioration on the structural strength; and (b) structural strength evaluation.

Task 2. For the previously listed kinds of structures, develop practical methods to predict structural capacity for load rating.

Task 3. Prepare and summarize guidelines for identifying, evaluating, and recording deficiencies, which must be considered in the developed methodology but for which the present state of the art is inadequate.

Task 4. Make at least two comparisons between results of past full-scale tests for which data are available and results predicted by the proposed method. In addition, at least four sample calculations shall be made using data derived from actual cases.

Task 5. Prepare the final report documenting the study findings and presenting the developed methodology in an AASHTO format. Recommendations and requirements for a full-scale in-situ field-test program for further validation of the proposed methodology shall be included.

Through December 31, 1981, research is nearly completed, and the preliminary draft final report will soon be submitted for project panel review.

Project 10-16 FY '81

Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline

Research Agency: Byrd, Tallamy, MacDonald & Lewis
Principal Invest: Martin Rissel
Effective Date: February 16, 1981
Completion Date: August 15, 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 is intended to use and extend research conducted under NCHRP Project 20-5 "Synthesis of Information Related to Highway Problems." Topic 10-08 of Project 20-5, which is entitled "Below-the-Waterline Inspection and Repair of Bridge Substructures," will result in a two-part report on current practice. Part A will identify problems found in substructure components and will evaluate procedures, equipment, and techniques currently used to inspect bridge elements below the water surface. Part B will cover methods and materials used for underwater maintenance and repair of bridge substructures.

The objectives of this study are: (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 substruc-

tures below the water surface and in the splash zone. Accomplishment of these objectives will involve the following tasks:

Task 1. Addressing the deficiencies cited in the previously mentioned synthesis report, (a) review and summarize 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. 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 is 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 will be prepared documenting the study findings and presenting the results in a practical format.

Through December 31, 1981, research is progressing on schedule, and an interim report has been reviewed and approved by the project panel.

Project 10-17 FY '81

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:	February 28, 1983
Funds:	$99,810

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 maintenance 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 immediate specific objective of this research 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.

Accomplishment of this objective is expected to involve the following tasks:

Task 1. Survey the state of the art of procedures used by state and other agencies for the (a) determination of the need for antistripping additives, (b) determination of the dosage where an additive is needed, and (c) identification of required construction control procedures for incorporation of additives into asphaltic concrete mixtures.

Task 2. Develop test procedures using equipment generally available to highway agencies to evaluate asphaltic concrete mixtures with regard to (a) the need, selection of, and concentration required for antistripping additives; and (b) the effect of the variables encountered in mix production and placement on performance of the additives.

Task 3. Conduct a test program using selected asphalt-aggregate combinations utilizing typical additives and test procedures developed in Task 2(b). Evaluate the effect on the adhesion of asphaltic mixtures containing antistripping additives of such variables as (a) methods of incorporating the additives and the effect of storage time and temperature on asphalt cement additive combinations; (b) asphaltic concrete mix times and temperatures, including the range of conditions encountered in pugmill and drum-type mixers, and (c) hot storage of the asphaltic concrete mix for varying lengths of time.

Task 4. Prepare and submit a final report that includes (a) state-of-the-art procedures for use of antistripping additives as determined in Task 1, (b) guidelines for the use of antistripping additives in asphaltic concrete paving mixtures using the results obtained in previous tasks, and (c) description of a long-range testing program to develop criteria for the selection and use of antistripping additives and to provide information on their effectiveness.

Research is in progress. A survey of states has been conducted to identify potential field construction problems associated with the use of antistripping additives. Testing procedures are being developed and materials acquired for the testing program to be conducted by the Chicago Testing Laboratories under a subcontract.

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:	February 4, 1983
Funds:	$74,350

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 is to develop practical guidelines for specifying and obtaining the optimum amount of entrained air in concrete. Consideration shall be given to interactions between typical concrete ingredients and various admixtures.

Accomplishment of this objective is expected to involve the following tasks:

Task 1. Prepare a synthesis on the theory and experience of using entrained air in portland cement concrete in relation to performance (i.e., freeze-thaw durability and workability). This shall include interactions of materials and air-entrainment admixtures.

Task 2. Identify and verify the existence of field-control problems and possible solutions relating to use of air entrainment. This should be based on surveys, field visits, and preliminary studies.

Task 3. Based on the information from Tasks 1 and 2, prepare guidelines for specifying and obtaining air entrainment in concrete.

Task 4. Prepare a program for verification and modification of the guidelines.

Research is in progress. Task 1 has been completed and a synthesis has been prepared. It is in the review process. A questionnaire has been sent to state highway materials engineers to identify field control problems. On-site visits are being made to evaluate the field problems. Guidelines will be prepared for specifying and obtaining the desired amount of air entrainment.

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:	February 28, 1982
Funds:	$50,000

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 guidance 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. Accomplishment of the project objectives required the following tasks:

Task 1. Conduct a state-of-the-art survey to (a) document all studies since 1969 on the effects of dust collector fines on asphalt cement and asphalt concrete, and (b) determine how fines now being removed by dust collectors are used or wasted. A description of current agency practices regarding fines will be included, together with tests now in use by agencies for compliance with their specifications, and a tabulation of these specifications. Additionally, there will be included a summary of the types of plant equipment now used to collect and return dust collector fines to the mix. The method and location for introducing fines will be noted.

Task 2. Solicit, obtain, and test sufficient baghouse fines from separate sources to cover the major generic aggregate types now being used to produce asphalt concrete in the United States. A sufficient number of samples will be acquired from each source to determine typical within-day and day-to-day variations of the fines collected. The type of equipment and sequential arrangement used for dust collection and handling at each plant from which samples are taken will be carefully recorded. Plant type and operating conditions, such as air flow, temperature, production rate, and the like, will also be recorded. Particle-size measurements for each sample shall be obtained and the within-day, day-to-day, and plant-to-plant variations in baghouse dust particle size determined.

Task 3. Prepare a final report including all research findings, technical annotation of the information obtained under Tasks 1 and 2, suggested practices pertaining to the use of dust collector fines in asphalt concrete, and recommendations for future research.

Task 1 is complete, but the execution of Task 2 has delayed the project and the agency's submittal of a preliminary draft final report due November 30, 1981. The researchers had arranged for the receipt of samples of baghouse fines from asphalt paving plant operators. The operators experienced difficulty accommodating the sampling schedule. However, sufficient samples are expected

as of December 30, 1981, and the agency's preliminary draft report by January 29, 1982. Adjustments to contract time are anticipated to allow sufficient time for NCHRP review of the final report and agency revisions if needed.

Project 10-20 FY '81

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
Completion Date:	June 30, 1982
Funds:	$75,000

The full potential of elastomeric bridge bearings will not be realized in the United States until the present AASHTO specifications are modified and expanded.

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 current AASHTO specification for elastomeric bearings has probably, in large measure, been a catalyst for the accelerated growth of elastomeric bearing applications in the United States; yet it may no longer reflect the best information available.

These specifications are limited in a number of ways. For example: axial load capacity for steel-reinforced bearings is below that allowed by other codes; axial loads are not related to rotation or translation, separately or in combination; shear forces that are generated by temperature-induced translation are undefined; laminate reinforcement is not related to load levels; and the relationship between compression stress and compressive strain is not specified.

Innumerable elastomeric bearing research projects have been completed during the last two decades 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 is not presently 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 based on the behavior and capacity of plain and reinforced elastomers are needed.

The objective of this research is to develop specifications for unconfined, plain and reinforced elastomeric bridge bearings. The project includes the following tasks:

1. Review of current domestic and foreign codes of practice, research findings, and performance data.
2. Analysis and evaluation of the information generated in Task 1 to establish a rationale for the development of design, construction, and materials specifications for unconfined, plain and reinforced elastomeric bearings. The findings of Tasks 1 and 2 have been presented in an interim report that has been reviewed and approved by the project panel.
3. Preparation of specifications in a format suitable for consideration for adoption by AASHTO. The recommended specifications shall be accompanied by a detailed commentary intended to facilitate their understanding and use.
4. Identification of further research that is needed to improve and expand the use of elastomeric bearings.

Through December 31, 1981 research is progressing on schedule.

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 identify 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.

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:	18 months
Completion Date:	
Funds:	$75,000

Weathering steel has been used in the construction of about 1,000 bridges in the United States during the past decade, 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 this research are (1) to assemble a systematic body of information on the performance of weathering steel, (2) to document and evaluate the current state of practice, and (3) to develop, where feasible, practical guidelines for design, construction, maintenance, and rehabilitation of bridges using this material.

The research will include the following tasks:

Task 1. Identify problems that have developed and other factors that have limited the use of weathering steel in the United States and abroad. The topics to be considered include, but are not limited to: corrosion, salt exposure, other environmental factors, pitting, fatigue, in-service inspectability, location within the bridge, structural details, shims and bearings, bolted connections, welding, adequacy of specifications, alloy content of the steel, initial cleaning and painting, and remedial cleaning and painting. Particular emphasis shall be placed on the adverse effects of corrosion on fatigue life.

Task 2. Assemble existing experimental and field performance data, and synthesize and evaluate the current state of practice in regard to the use of weathering steel in bridges. Applicable data on other structural steels should be examined.

Task 3. Based on the findings of Tasks 1 and 2, propose guidelines for application of weathering steel in new bridges and make recommendations to extend the life of weathering steel components in existing bridges.

Task 4. Identify areas in need of further investigation. Recommend priorities and estimate time and costs for the needed research.

Task 5. Prepare a final report on the findings of Tasks 1 through 4.

Project 10-23 FY '82

Removal of Lead-Based Bridge Paints

Research Agency:	Offshore Power Systems
Principal Invest.:	B. S. Fultz
Completion Date:	12 months
Effective Date:	
Funds:	$75,000

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 is 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, such as Iowa, California, and Massachusetts Port Authority, have had partial success in limiting the paint waste with relatively moderate efforts. Among the approaches are tarps, vacuum blasting, rigid enclosures, and chemical removal with containment. In addition, the FHWA is planning a study for the development of a prototype unit to prepare steel surfaces based

on the use of controlled water jet cavitation. However, none of the new and conventional methods investigated has demonstrated the capability of economically removing and recovering old lead-based paint from most bridges in the United States.

It is necessary to extract information from the various state and government agencies on previous work and identify possible ways to modify, optimize, or redesign equipment and procedures. Because of the variability in the type, location, and circumstances of bridges, it is unlikely that any one technique will be suitable for all conditions under which old paint poses a hazard.

Although the toxicity of lead is well documented, 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, including the Massachusetts Port Authority, the California Departmeot of Transportation, and the U.S. Army Corps of Engineers, have been required to test toxicity levels of paint and abrasive wastes. High levels of potential toxicity may require disposal in Class I 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.

Research is needed to demonstrate the severity of toxicity and pollution, and to establish improved procedures for recovering paint and residue from bridge cleaning. Consequently, the objective of this study is to identify the severity of pollution related to bridge cleaning and recommend improved techniques for removal and recovery of lead-based bridge paints. Accomplishment of the project objective will require the following tasks:

Task 1—Determine relevant regulations. Review and summarize federal, state, and local environmental regulations concerning lead paint removal from bridges. Environmental aspects to be considered are air, water, soil, and wildlife regulations.

Task 2—Determine severity of toxicity and pollution. (a) Review available data on the toxicity and pollution concerning lead paint removal and disposal. (b) Determine the degree to which existing paint removal practices prodnce conditions that violate regulations compiled under Task 1. (c) Determine the degree to which existing data are conclusive in establishing the toxicity. (d) Describe test methods for determining concentrations of potentially toxic or polluting airborne particulates and lead paint residues, including methods for fish bioassay, leachability, and high-volume air-quality samples. (e) Identify the gaps in the toxicity and pollution data. In particular, consider the need to differentiate between types of lead-based hridge paints.

Task 3—Technologies for bridge paint removal. (a) Review activities of public agencies and private industry concerning existing and developing systems that have the potential of removing and recovering paint and residues. (b) Evaluate each of these systems with regard to the following: capital and operating costs, production rate, completeness and efficiency of recovery, advantages and disadvantages, and versatility for different types and sizes of structures.

Task 4—Improved technology. (a) Using the information gained in Task 3, consult with major contractors and manufacturers to solicit ideas about developing new and improved systems. (b) Select three or more of the most promising techniques for development. At least one of these techniques shall be appropriate for truss structures. Describe in detail how this improvement would influence the items discussed under Task 3(h). (c) For each technique provide detailed suggestions to improve its effectiveness.

Task 5—Final report. (a) Provide a summary of the results, findings, and conclusions of the research performed under Tasks 1 through 4. (b) Include detailed working plans for the following: additional testing needed to fill in the data deficiencies uncovered in Task 2; and the construction, testing, and implementation of the most promising technologies of Task 4.

Project 10-24 FY '82

Rapid Replacement of PCC Pavement Segments

Research Agency:	ARE Inc.
Principal Invest.:	Dr. A. H. Meyer R. P. Smith
Effective Date: *Completion Date:*	72 months
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. Much of the money is being spent on improvement projects requiring 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 nsed. 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; climatic 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 and sites recommended for further field evaluations shall be obtained prior to proceeding with Task 2. Interim report no. 1 shall be submitted within 6 months of the contract starting date.

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 effectiveness 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. Surface texture, rutting or wear, crack distribution and 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. Interim report no. 2 shall be submitted within 24 months of the contract starting date.

Task 4. Prepare a final report documenting all research.

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, and 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: February 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 treatment 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 evidence, 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 involuntary 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 he 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 puhlic 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 use 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: August 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 valuation 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 valuation 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 question 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 dif-

ferent types of outdoor advertising signs. Actual illustrations and case studies were utilized.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. Loan copies of the report are available from the NCHRP upon written request.

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 for $4.00 prepaid from the Transportation Re-

search Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 suggest 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 ful-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 ⅕-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 ⅖-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	$100,000

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 initial 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. Microfiche of the report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. Loan copies are available upon written request to the NCHRP.

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 spec-

trum 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:	$75,000

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 successful 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 evaluated over a 3-year period. Ribbon anodes (as suggested 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 before dismissing galvanic 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 12-12 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 cover-plated 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: June 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 is 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 will be carried out on center-notched 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 bridges on high volume arteries where large numbers of random variable stress cycles are expected.

Through December 31, 1981 the test program is progressing on schedule.

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 application 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 survey, 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 investigatinn verified, under service conditions, the indications from the laboratory evaluations. Based on results of the laboratory evaluation, a limited number of decks selected so as to provide examples of the most important findings were studied.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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:	$50,000

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 informa-

tion 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Project 12-17A FY '79

Guidelines for Evaluation and Repair of Damaged Steel Bridge Members

Research Agency:	George O. Shanafelt
Principal Invest.:	Willis B. Horn
Effective Date:	October 1, 1981
Completion Date:	September 30, 1983
Funds:	$100,000

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 is 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 this second phase of research (Project 12-17A) is to extend the effort carried out under Project 12-17 and to develop a manual of recommended practice.

Research under Phase II will produce a detailed procedure for assessment and evaluation of damage. Recommendations of repair techniques and the effects of those repairs will be detailed to the extent possible using currently available information. These results will be presented in a user's manual recommending procedures and specifications for steel bridge repair.

Through December 31, 1981, the working plan has been approved and the investigators are gathering information.

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, 1981
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.

Several computerized bridge design systems now exist. But, for various reasons, many highway agencies are not making adequate use of them. There is a need for research to assess the available software, determine the constraints on its use, and begin a unified effort to meet the needs of bridge engineers.

The immediacy of the need for developmental research is heightened by recent changes in the AASHTO specifica-

tions which have rendered obsolete much of the existing software.

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 integrated system must be generally accepted by a wide range of users in the state, federal, and private sectors. It must also—as much as possible—allow for its implementation on a variety of computer system configurations.

The objective of this research is 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 will consist of two phases to be performed consecutively under one contract. Phase I is intended to be 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 will take place 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. This information will provide the basis for establishing the feasibility of an integrated bridge design system.
2. Review existing bridge design systems and provide an assessment of their relative merits and limitations. This will allow the researchers to draw on the experience gained in the development and implementation of those systems.
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 shall be 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. A section of this report shall serve as a development guide for potential module contributors.

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-hase 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 compnter 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 structures. 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 currently in progress, combines structural analysis and member selection modules in a manner that illustrates the linking of modules. The demonstration will be conducted using at least two different representative computer configurations.

Through December 1981, research has been completed, and the agency's final report is being reviewed by the project panel.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. A continuation of this project is under consideration.

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:	$100,000

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 structural elements other than the top surface of the deck. Accomplishment of this objective required the following tasks:

Task 1. Identification of current and potentially available methods, materials, and concepts that held promise for protection of concrete bridge members (other than the top surface of decks) by preventing penetration of chloride ions.

Task 2. Preliminary analysis of methods, materials, and concepts identified in Task 1. Particular attention was given to sealers that were impermeable to liquid but were vapor-permeable, thereby permitting drying of the concrete while preventing chloride intrusion.

Task 3. Submission of a letter report that described various sealers and the reasons for their rejection or selection for further study. This report included an updated working plan for laboratory evaluation of 5 promising sealers.

Task 4. Laboratory evaluation of the 5 sealers for the purpose of establishing efficacy.

Task 5. Development of guidelines for selection and use of sealers to protect concrete structures.

Task 6. Preparation of a final report that included all research findings and recommendations for application of the results.

The research has been completed, and the agency final report is now being reviewed.

Project 12-20 FY '78

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
	Feb. 29, 1980	Nov. 30, 1981
Completion Date:		
Funds:	$119,970	$50,000

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 and 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.

Through December 31, 1981, Phase II has been completed, and the final report is in the editorial and publication process.

Project 12-21 FY '79

Evaluation of Damage and Methods of Repair for Prestressed Concrete Bridge Members

Research Agency:	G. O. Shanafelt
Principal Invest.:	W. B. Horn, G. O. Shanafelt
Effective Date:	April 15, 1979
Completion Date:	September 14, 1980
Funds:	$58,958

Prestressed concrete bridge members often are subjected to accidental damage due to vehicle impact, mishandling, or fire. Methods currently used or potentially available for repair of such members need to be identified and evaluated for various levels of damage. At present, 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 is necessary to assemble and assess information concerning the effect 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.

A two-phase study is anticipated. Only the first phase has been carried out at this time.

The over-all objective of this study is 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 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 will be to evaluate the effect of the damage and the positive and negative aspects of selected repair techniques on the behavior of the structure, and to define the limits within which these techniques can be used. This is expected to be accomplished through application of the selected techniques to damaged members and subsequent field or laboratory testing.

The Phase I survey of structural damage will indicate that primary emphasis in this study should be placed on damage to girders impacted by over-height vehicles; however, information on assessment and repair of other types of damage was also collected and analyzed. The investigation included consideration of both pre-tensioned and post-tensioned construction.

Phase I included the following tasks:

Task 1. Identify and categorize the types of accidental damage found in prestressed concrete bridge members and the severity and frequency of their occurrence.

Task 2. Identify and analyze present practice and equipment used for assessing damage and making repairs on highway bridges, railroad bridges, and other prestressed concrete structures.

Task 3. Based on existing experimental and field performance data, evaluate techniques that have been applied or may have application and postulate other methods of assessing and correcting structural damage. Included in the topics considered were: (1) Selection of materials, methods, and engineering solutions used in repair; (2) Effect of the repair on significant structural behavior and integrity such as fatigue life, ultimate flexural strength, bond strength, service, and overload response; (3) Speed of repairs, durability, relative costs, user inconvenience, and esthetics.

Task 4. Prepare a report summarizing the findings of Phase I and proposing a basic outline of research topics for Phase II.

Phase I has been completed, and the final report has been published as:

NCHRP Report 226, "Damage Evaluation and Repair Methods for Prestressed Concrete Bridge Members."

A continuation of this project is under consideration.

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:	May 31, 1983
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 is to develop recommended specifications and design procedures for consideration of thermally induced stresses and movements in concrete bridge superstructures. The project shall include 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 include 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 accompanied 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.

Through December 31, 1981, Task 1 is nearly completed and Task 2 has been initiated.

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-density 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 through the joint. Therefore, some water is likely to enter through 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 subsurface 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 Heavy-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 include 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, structure, 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".

A continuation of research is planned to test the method

for additional maintenance elements. The method is capable of considering twenty to twenty-five elements.

Project 14-5(2) FY '81

Maintenance Levels-of-Service Guidelines

Research Agency:	Woodward-Clyde Consultants
Principal Invest.:	Ron B. Kulkarni
Effective Date:	September 15, 1981
Completion Date:	March 15, 1983
Funds:	$100,000

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 exists 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 is to develop a user's manual that can be used by transportation agencies in establishing maintenance levels-of-service. The manual should be comprehensive, i.e., it should describe all the steps involved in implementing the methodology; it should be self-sufficient, i.e., transportation agencies should be able to use the methodology without consultant assistance; and the manual should be fully tested, i.e., several transportation agencies should review the manual and feel confident that they can use it to establish appropriate maintenance levels-of-service.

The various tasks that will be undertaken to accomplish the objectives of the study are as follows:

Task 1. Prepare a Draft User Manual.

Task 2. Test and Revise the User's Manual. An iterative procedure will be used for testing and revising the user's manual. Woodward-Clyde Consultants (WCC) will work successively with transportation agencies selected for the testing program. The user manual will be revised after testing in the first agency and then tested in a second agency. The process of testing and revision will continue until a final manual is produced that in the last transportation agency, no consultant assistance is required.

Task 3. Document Testing Experience. The final report will document the chronology of the initial preparation of a draft of the user's manual, successive revisions in the manual, and preparation of the final manual. The comments and concerns of the NCHRP panel and the state transportation agencies involved in the review of the manual will be described. The specific revisions made to address these concerns will also be discussed.

Progress to December 31, 1981 includes substantial completion of the draft manual. Testing is anticipated in the mid-year.

Project 14-6 FY '82

Evaluating Deferred Maintenance Strategies

Research Agency:	ARE Inc.
Principal Invest.:	Bertell C. Butler Fred N. Finn
Effective Date: *Completion Date:*	36 months
Funds:	$300,000

It has been documented in many studies that the nation's pavements and bridges are deteriorating at alarming rates. In part, this is due to the practice of highway agencies deferring maintenance activities because of decreased funding. Deferred maintenance is 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 are not known. However, one consequence would be much greater costs to the highway agency to reconstruct the system. Another effect would be lower serviceability levels that generate manifold, higher user costs. A consequence for bridges would be the replacement of bridge decks, with ensuing, extensive interruptions to traffic. Timely maintenance can prolong pavement and bridge life, with resulting lower life cycle costs to the road agency and road user. A need exists to describe and quantify the trade-offs between deferred maintenance and the consequent agency and user costs. Once quantified, the relationships can be used to plan more effectively maintenance expenditures in pavement and bridge management systems.

The general objective of this study is 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. To achieve these results, it is necessary to investigate fully the consequences of alternative maintenance strategies over the life cycle of a highway facility in terms of cost to highway agencies, highway users, and other affected parties.

Specific objectives are:

1. To produce an interim report that presents background information on the consequences of deferring maintenance activities and provides a framework for the evaluation of such consequences. The report is to present the theory of making trade-offs in selecting maintenance strategies. It will explain how bridge and pavement life-cycle costs, including costs to the highway user, are affected by changes in maintenance strategies. Finally, it will discuss

broad economic, environmental, and social impacts of maintenance deferral and identify impacted parties.

2. To gather secondary and, if necessary, primary data describing changes in (a) the deterioration of pavements and bridges arising from a range of maintenance strategies and varying climatic or regional conditions over the life cycles of such facilities; (b) user costs including safety; (c) the environment; (d) the economy, and (e) the impacts to the nonuser. Emphasis is to be given to pavements and the data banks being developed for use in pavement management systems. User cost consequences of deferred maintenance are considered to be highly significant in the determination of total costs. Data collected must be used with a method to determine trade-off relationships over facility life cycles for choosing maintenance strategies.

3. To adopt or develop a method of evaluating maintenance strategy alternatives.

4. To provide "real world", example applications of the method for pavements and bridges. The intent is to illustrate the method for use by state highway agencies.

5. To prepare a final report.

The research will be initiated in early 1982; no reports are available at this time.

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 objectives 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 prepare 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 as 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 Procedure 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 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 vehicle 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."

Project 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 for the cost of mailing and handling.

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 reduction 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 various 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 is to provide simple and reliable procedures 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, is assumed to be available to the user, and its development is not within the scope of this study. The products of this investigation are intended for use in general assessment and preliminary planning rather than for detailed design.

Accomplishment of this objective required the following tasks:

1. Review, examine, synthesize, and evaluate all available information and on-going research relevant to the over-all objective, covering (a) available flood-routing and water-surface profile computational methods, (b) studies and case history data that may be used for verification of the computational methods, and (c) information on the significance and realistic ranges of the pertinent variables.
2. Analyze the information from task 1 to select or develop procedures possible for estimating likely changes in flows and water-surface elevations resulting from placing highways and related developments in flood-prone areas. Such analyses might range from simplifying an existing detailed flow-routing model to defining a simple stochastic relationship.
3. Test the simple procedures against the more sophisticated procedures and available case history data and assess their relative accuracy.
4. Prepare a final report documenting the study, including a user's manual setting forth both graphical and small programmable calculator applications and examples of the simplified procedures.

Research is essentially complete. The agency has submitted a draft final report with an appended user's manual. Both are now under review by NCHRP.

Project 15-8 FY '82

Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics

Research Agency:	Highway Safety Research Institute University of Michigan
Principal Invest.:	Dr. Paul L. Olson
Effective Date: *Completion Date:*	18 months
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 current highway design criteria are based on vehicle fleet characteristics over 10 years old.

The primary objective of this research is 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. The research findings will demonstrate either that the criteria proposed in the draft report from NCHRP Project 20-7, Task 14, "A Policy on Geometric Design of Highways and Streets," are supportable under today's conditions or that the parameters have changed substantially enough to warrant modification in stopping sight distance criteria. A second objective of this research is to update vehicle acceleration and deceleration rates to be representative of the current vehicle fleet.

A critical review of the literature will be conducted related to safe stopping sight distance and acceleration/deceleration characteristics. Recent and ongoing research sponsored by FHWA and others will also be reviewed. The adequacy of available data for evaluating each parameter will be determined and documented. To the maximum extent possible, existing data will be used in this research.

Design values for driver height of eye and height of object on the roadway will be determined. Criteria contained in the draft report from NCHRP Project 20-7, Task 14, will be 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 will be determined over a range of design speeds.

Recommendations for driver perception time related to a hazardous object in the roadway and for reaction time will also be developed. The research will consider: (1) contrast between the object and its background; (2) visibility and weather conditions—e.g., night vs. day, glare (especially from wet pavements); (3) driver expectancy—e.g., urban vs. rural conditions and land use type; and (4) driving population characteristics including age, vision, driving experience, and the like. Field and laboratory tests will be conducted to supplement existing information.

The specific performance characteristics of tires and brakes for the current vehicle fleet, including autos, buses, and trucks (loaded and unloaded), will be determined. Effects of changes in vehicle mix, tread and brake wear, pavement skid resistance, and grades on stopping sight distances will also be considered.

In addition, acceleration and deceleration characteristics for the current vehicle fleet will be determined. This phase of the research will be limited to a literature review and an evaluation of the results of the braking distance study described above.

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 alternatives (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 Associates
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 in 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 evaluated 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 construction 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 study, while focusing attention on the need for a major research effort, also uncovered a large quantity of information, often fragmented or underevaluated, 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 volumes as:

NCHRP Report 220, "Erosion Control During Highway Construction—Research Report"; and NCHRP Report 221, "Erosion Control During Highway Construction—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 causation 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 statistically 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 report 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 7, 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: January 31, 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 generally adopted highway cross section, which includes an unobstructed area of relatively flat slopes outside the normal shoulder limits, has resulted in substantially increased construction costs. The extra width of cross sections may entail larger grading costs, increased cross-road structure lengths, and additional right-of-way, in addition to affecting the maintenance requirements. Some measures of the effectiveness of this clear recovery area in reducing the frequency and severity of run-off-the-road accidents are necessary in order to ensure cost-effectiveness of design.

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 and 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, is in the review process.

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 Uuiversity
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 Project 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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:	November 1, 1982
Funds:	$199,900

It has been reported that nearly one-third of all highway bridge decks in the U.S. are seriously deteriorated because of corrosion of reinforcing steel. This corrosion is usually caused by chloride ions that have penetrated the concrete as a result of repeated application of deicing salts. Accumulation of corrosion products around the reinforcing steel causes cracks to develop in the concrete cover. This allows intrusion of additional chloride solution, thereby accelerating corrosion and causing spalling of the deck.

Considerable research has been directed to the problem of prevention of corrosion in new bridge decks and several promising methods are available. However, restoration of existing decks is a more difficult and pressing problem.

Low-permeability overlays have been applied to hundreds of deteriorated bridge decks during the past 15 years. The overlay is normally preceded by spot repair, involving removal of all deteriorated concrete. In most cases, however, large areas of chloride-contaminated concrete remain in place. Although field experience has shown such procedures to be cost-effective in extending the usable life of decks by 10 or more years, the presence of large areas of new delaminations and corroding reinforcing steel in contaminated decks that had been overlaid from 5 to 15 years before indicates that detrimental corrosion was not completely arrested by these procedures. Thus, there is a need to strive for long-term rehabilitation procedures.

As part of the rehabilitation process, the top surface of the deck is sometimes scarified prior to application of the overlay. Scarification to a level within ½ inch of the top reinforcement disposes of a large volume of contaminated concrete and can facilitate impregnation of the concrete around the steel. If an economical method were found to nullify the effects of chlorides in concrete around reinforcement under shallow cover, an alternative restoration procedure promising long-term effectiveness could be available.

Polymer impregnation to a depth sufficient to encapsulate the reinforcement is generally expected to ensure long-term protection. However, costs and difficulty of application are impediments to widespread use of this procedure. There is a need for simpler treatments (e.g., water-tolerant monomers or corrosion inhibitors that can readily impregnate concrete around the reinforcing steel) that are capable of arresting corrosion of reinforcement in sound but salt-contaminated concrete, without necessarily enhancing other concrete properties as strength, permeability, resistance to freezing and thawing, and wear resistance.

The objective of this study is to develop and evaluate materials and procedures that can be used in conjunction with low-permeability overlay to prevent continued corrosion on a long-term basis in shallow-depth reinforcement surrounded by chloride-contaminated concrete.

This study addresses polymer impregnation as well as other chemical treatments that might arrest corrosion when used in conjunction with the previously mentioned scarify-overlay rehabilitation technique. Evaluation of materials and procedures will reflect consideration of: (1) economic feasibility, including both materials and application costs; (2) long-term effectiveness; (3) compatibility, including substrate, repaired areas, and overlay; (4) durability; (5) pollution problems; and (6) potential safety hazards. Attainment of the project objective necessitates the following tasks:

Task 1. Identification of current and potentially available methods, materials, and concepts that may hold promise for arresting and long-term prevention of corrosion under the previously described conditions. Emphasis will be given to polymer impregnation, but research will not be limited to the study of conventional monomers that require drying of the concrete and subsequent polymerization using catalysts and heat. Corrosion inhibitors, chloride and oxygen scavengers, and other chemical treatments that increase pH or otherwise stop corrosion will also be considered. This task will be based on a review of the literature, research in progress, manufacturers' information, and other appropriate sources.

Task 2. Preliminary analysis of methods, materials, and concepts indentified in Task 1. Particular attention will be given to evaluation criteria related to ease of application and long-term effectiveness.

Task 3. Submission of an interim report that describes various treatments and the reasons for their rejection or selection for further study. This report will include an

updated working plan for laboratory evaluation of promising treatments.

Task 4. Laboratory evaluation of treatments for the purpose of establishing feasibility based on the desired characteristics outlined earlier.

Task 5. Preparation of a final report that includes all research findings and recommendations for possible field evaluation of selected treatments.

During the last year, the interim report required under Task 3 was submitted and approved by NCHRP. Agency researchers and subcontractor personnel from The Pennsylvania State University are now conducting laboratory investigations under Task 4 on the following techniques: deep grooving, scarification, and water-displacing systems to facilitate polymer impregnation; hydrophobic sealants; hot impregnants; corrosion inhibitors; and electrochemical removal of chlorides. The majority of techniques being investigated are intended for use with low-permeable type bridge deck overlays: low-slump dense concrete, latex-modified concrete, and polymer concrete.

A limited number of copies of the agency interim report are available for loan upon written request to NCHRP.

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.

Although 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 development 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 usable 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 Research 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 previously stored reports for ongoing research.

Project 20-2 FY '66

Research Needs in Highway Transportation

Research Agencies:	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

* 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.

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 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 report has been distributed to the sponsoring agencies.

Microfiche of the agencys' final report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 purchase, and a check or money order in the amount of $4.00, plus $1.00 for postage and handling, should be made payable to *Transportation Research Board* and sent to the Publications

Office, Transportation Research Board, 2101 Constitution Avenue, Washington, D.C. 20418.

Project 20-4 FY '68

Public Preference for Future Individual Transportation

Research Agencies:	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 Behavior—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.:	Dr. Paul E. Irick T. L. Copas
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-'82

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 88 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 125.

The following topic reports have been completed and are in the NCHRP editorial and publication process: "Techniques for Minimizing Reflection Cracking of Pavement Overlays," "Utilization of Information Systems in Construction Engineering Management," and "Use of Data Processing and Accident Location Systems for Highway Accident Analysis."

The following reports are in the review stage: "Pavement Subsurface Drainage Systems," and "New Products Evaluation Procedures."

The following topics are in the research stage: "Resealing Joints and Cracks in Rigid and Flexible Pavements," "Shallow Foundations for Highway Structures," "Coordinating TSM and Land-Use Planning and Implementation to Meet Development and Transportation Objectives," "Bridge Designs to Reduce and Facilitate Maintenance and Repair," "Construction Contract Claims: Causes and

Methods of Settlement," "Methods of Cost-Effectiveness Analysis for Highway Projects," "Managing State Transportation Finance," "Resurfacing with Portland Cement Concrete," "Statewide Transportation Planning," "Transit Ownership/Management Options for Small Urban and Rural Areas," "Storm Water Management for Transportation Facilities," "Bridge Posting Practices," "Highway Inventory Systems," "Risk Assessment Processes for Hazardous Materials Transportation," and "Criteria for Decisions Involving Historic Bridges."

Project 20-6 FY '69 and continuing

Right-of-Way and Legal Problems Arising out of Highway Programs

Research Agency:	Transportation Research Board
Principal Invest.:	Larry W. Thomas
Effective Date:	November 1, 1968
Completion Date:	Continuing
Funds:	$200,000 FY '69-'71
	$125,000 FY '72
	$50,000 FY '73
	$185,000 FY '74
	$125,000 FY '75
	$85,000 FY '76
	$75,000 FY '77
	$100,000 Annually FY '78-'79
	$150,000 Annually FY '80-'81
	$100,000 FY '82

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 today, there is really 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. 10—Right of State to Recover Contract Payments Made Under Contract Violating Competitive Bidding Statute (Canceled)

Study No. 11—Personal Liability of State Highway Department Officers and Employees (Research 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. 14—Admissibility and Use of Severance Studies in Condemnation Litigation (Terminated due to insufficient data on which to base the study)

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 Substitute 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. 18—Compensability and Valuation of Noise,

** Published in *Selected Studies in Highway Law*, Vol. 3.

Pollution, and Other Environmental Factors (Abandoned)

Study No. 19—Right of State to Secure Judicial Review of Federal Administrative Decisions (Study abandoned due to insufficient amount of case law)

Study No. 20—Meaning of "Highway Purpose" (Canceled)

Study No. 21—Duty to Warn Against Highway Defects (Study abandoned due to insufficient amount of case law)

Study No. 22—Compensability for Consequential Damages Resulting from Partial Take or Taking Without Appropriation and Entry Upon the Land (Canceled)

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. 29—Valuation of Scenic Easements (Canceled)

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. 52—The Use of Guarantee or Warranty Clauses in Highway Construction Contracts (Reprogrammed as Study No. 2-11)

Study No. 53—Impact of Civil Rights Legislation and Regulations on State Highway and Transportation Department Activities (Reprogrammed as Study No. 2-02)

Study No. 54—Outdoor Advertising Control and Acquisition (Completed)

Study No. 55—Legal Issues Arising out of Uniform Relocation Assistance and Real Property Acquisition Policy Act of 1970 (Reprogrammed as Study No. 2-01)

Study No. 56—Evaluation of the Adequacy and Equitability of Relocation Assistance Payments (Dropped)

Study No. 57—Legal Aspects of Access Control on Unlimited-Access Highways *** (Research Results Digest No. 112)

Study No. 58—Zoning Changes Adjacent to Highways as a Result of the Highway Beautification Act (Dropped)

Study No. 59—The Effect of Federal and State Public Information Acts on Highway and Transportation Department Activities (Reprogrammed as Study No. 2-10)

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. 2-01—Legal and Procedural Issues Related to Relocation Assistance (Pending)

Topic No. 2-02—Minority Business or Enterprise Requirements in Public Contracts (Pending)

Topic No. 2-03—Condemnation Blight † (Research Results Digest 119)

Topic No. 2-04—Legal Aspects of Historic Preservation in Highway Programs (In Progress)

Topic No. 2-05—Local Land-Use Regulations in Relation to Highway Programs (In Progress)

* 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*.

Topic No. 2-06—Disposition of Minerals on Highway Rights-of-Way (Pending)
Topic No. 2-07—Functional Replacement As a Measure of Value (Included in Topic No. 2-15)
Topic No. 2-08—"State Highway Programs Versus the Spending Powers of Congress" (Completed)††
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 (In Progress)
Topic No. 2-11—Use of Guarantee or Warranty Clauses in Highway Construction Contracts (Pending)
Topic No. 2-12—Legal Interrelationship of State and Local Governments in Highway Matters (Pending)
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" (Pending)
Topic No. 2-17—Update of "Damnum Absque Injuria 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. 2-20—Update of "Trial Strategy and Techniques in Highway Contract Litigation" (Pending)
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 and 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 Highway Agencies for Failure to Repair 'Potholes' or Other Highway Defects" (In Progress)
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 Defective Bridges" (In Progress)
Topic No. 2-37—"Liability of Highway Agencies for Failure to Remove Obstructions In or Near the Highway" (In Progress)
Topic No. 2-38—"Trial Strategy and Techniques in Handling Tort Claims Arising Out of Highway Operations" (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 three-volume text, *Selected Studies in Highway Law*. Volumes I and II, dealing primarily with the law of eminent domain, were published in 1976, and Volume III, 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.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Through December 31, 1981, research continues on new

† Published in second addendum to *SSHL*.
†† To be published in third addendum to *SSHL*.

topics of current interest in both the right-of-way and legal fields. Updating and supplementing the text book will also be continued.

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 Results 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 Penn-

sylvania 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 trunkline 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 Task Force on Geometric Design of the AASHTO Operating Sub-Committee on Design is in the process of updating 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). Major portions of the revised publication have been compiled, reviewed, and incorporated into chapters in rough-draft form of a new AASHTO publication, *A Policy on Geometric Design of Highways and Streets*. The objective of this task is the preparation of an edited version of the new publication for consideration by AASHTO. Research is in progress.

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. V. 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 has been provided for a second phase of the study to develop such overlay design procedures for at least two climatic regions. Copies of the agency report for the initial phase have been distributed to Program sponsors. Research is in progress on the second phase.

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 is in progress.

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 will be distributed to 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 is being combined with Project 15-8, "Parameters Affecting

Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics."

Task 21, "Need for Pavement Markings on Low-Volume Roads." The objective of this task is to verify or modify the suggested warrants for centerline and no-passing markings of low-volume roads as described in *NCHRP Report 214*. Agency selection is pending.

Task 22, "Encasement of Pipelines Through Highway and Railroad Roadbeds." 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. Agency selection is pending.

Task 23, "Contract Payment Procedures and Contracting Practices." The objectives of this task are 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. Agency selection is pending.

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 use 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 for $4.00 prepaid from Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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:	$214,279

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 analyses, findings, and recommendations. Microfiche of the report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. 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. Inquiries 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 reproduction and handling.

Project 20-10 FY '73

The Benefits of Separating Pedestrians and Vehicles

Research Agency: Stanford Research 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 has been 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 have been defined. A methodology has been developed to weight the benefits identified according to values held by decision-makers and/or the community at large. The methodology has been tested at field sites in Seattle, Wash. (a highway overpass); Brooklyn, N. Y. (a mall); and Ottawa, Ont. (a mall).

Results of the research have been published as:

NCHRP Report 189: "Quantifying the Benefits of Separating Pedestrians and Vehicles."

Research has been 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 by request to the NCHRP. 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 are being 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 a 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 has been 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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, including 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: Measurement Methodology," is available from the Transportation Research Board for a prepaid charge of $4.00, mailing and handling included. Send check or money order, payable to *Transportation Research Board,* to Publications Office, Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418.

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
Completion 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418. 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:	$15,000

A start has been made in developing a usable methodology for assessing environmental impacts of transportation facilities using the energy-flow concept, including 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 encountered 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 careful 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 upon written request to the NCHRP.

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 are 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 are 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 urban 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 meteorologically 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: $189,928

Federal and state regulations mandate air quality studies to develop strategies for achieving compliance with ozone standards. These air quality studies must frequently include 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 study 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 numbers 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 exceedances 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 temperature; 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 has been 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 and supplying an ASCII 9 track tape (or equivalent) with a density of 800 BPI.

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 process 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 a 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:	September 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:	$74,365

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 issues, 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 upon written request to the NCHRP. Phase II (20-17A) is currently underway.

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:	November 30, 1982
Funds:	$175,000

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 hy state agencies. The technique will be 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 sub-state, state, or multi-state level. The technique will use generally available data and methods to facilitate application to specific problems (e.g., deregulation and rate changes).

A user's manual will be 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 will provide 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 will describe (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.

A case study will be conducted using either the Buffalo-Albany-New York City corridor or a similar corridor to assess a particular problem(s), such as the effects of deregulation. The case study will include baseline data and provide forecasts for 1980 and 1985 freight flows by mode.

Research is currently underway.

Project 20-18 FY '79

Evaluation of Highway Air Pollution Dispersion Models

Research Agency: SRI International
Principal Invest.: W. F. Dabberdt
Starting Date: March 15, 1979
Completion Date: November 30, 1981
Funds: $199,643

Federal and state regulations required that environmental impact statements (EIS) be prepared for highway projects. The air quality portion of an EIS usually includes microscale 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 asses 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 report, "Development and Application of Methods for Evaluating Highway Air Pollution Dispersion Models," will be published early in 1982. The computer tape containing the model evaluation method and the comprehensive data base may be obtained by request to the NCHRP and supplying a 2-in. diameter and an 8-in. diameter ASCII 9-track tape (or equivalent) with a density of 1600 BPI.

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 beeu 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 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 hy Selig, Wobschall, Mansukhani, and Motiwala published in *TRB Recond 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: $154,764

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 application 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 loan upon written request to the NCHRP.

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 these existing systems have some deficiencies that make applied widely by highway and bridge engineers. All of 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 longitudinal, 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Subsequently, the Federal Highway Administration sponsored additional 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. Recommend 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.

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 implications of MSLA and make modifications as indicated.

Through December 31, 1981, 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 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,* "Recommended 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 procedures 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
Principal 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 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 barrier systems would be very desirable.

The objective of this project was to determine the degree to which accident data currently being accumulated by various 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. Enumerate 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 for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 barrier 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 been summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Microfiche of the agency's final report may be purchased for $4.00 prepaid from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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 adoption by AASHTO. The manual was intended to be suitable for use by agency personnel responsible for the planning, design, construction, operation, and rehabilitation of transportation facilities, and to present information in a logical and orderly manner to:

1. Identify the interrelationships between geotechnical information and engineering projects such as structures, tunnels, excavations, embankments, pavements, and erosion control features.
2. Provide guidance on acquisition and use of reconnaissance, preliminary, and detailed subsurface investigation data for development of engineering projects.
3. Provide pertinent information concerning the practical tools and techniques available for use in subsurface investigations.
4. Provide information on soil and rock classification, field testing, and laboratory testing as required for identification of subsurface conditions.
5. Provide guidance concerning the accurate and orderly presentation of all pertinent geotechnical information so that it is readily utilized in project development.

Research has been completed. Preliminary draft copies of the new manual on subsurface investigations have been received and are in the revision process.

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: November 15, 1982
Funds: $159,995

Wetlands have been recognized by state and federal agencies as a valuable natural resource. Considerable legislation has been enacted to ensure preservation of their natural beneficial values such as in providing wildlife habitats, recreational areas, flood storage, and nutrient sinks. Interest is also increasing on the possibility of creating and managing wetlands to enhance the environment.

Impacts on wetlands may range from partial disturbance, to changes in their characteristics and functions, to elimination. An area of increasing concern is the impact of highway runoff on wetlands as a possible non-point source of pollution. A need exists to identify the interactions between highway runoff and wetlands. An understanding of these interactions is important for environmental assessment and management of highway runoff.

Substantial research on wetland ecology, the function of wetlands, highway runoff constituents, and ancillary subjects has been and is being performed. But there is need for an in-depth analysis of this research to provide practical information for highway applications. A need also exists to identify the gaps in knowledge on the effects of highway runoff on wetlands.

The objectives of this research are to identify the interactions between wetland systems and highway runoff, to identify the effects—beneficial or otherwise—of highway runoff on wetlands, and to develop guidelines for the practical management of highway runoff in wetlands. The research shall address runoff from in-service highway facilities. Highway runoff during construction shall be excluded. The research shall consider all wetland types as described in "Classification of Wetlands and Deep-Water Habitats of the United States (An Operational Draft)" (Cowardin et al., U.S. Fish and Wildlife Service, Washington, D.C., October 1977). Field and laboratory studies are beyond the scope of this research. Accomplishment of the project objectives requires the following tasks:

Task 1. Review available literature and on-going research, analyze in-depth relevant data, and identify gaps in existing knowledge pertaining to project objectives and scope. This will include but not be limited to: (1) short- and long-term changes to wetland ecosystems caused by highway runoff constituents; (2) processes and pathways involved in the uptake and transport of runoff constituents in wetland systems (where possible quantify the process rates, duration of the constituents within the components of the wetland system, and the ultimate fate of the constituents); (3) capability and effectiveness of wetlands to assimilate runoff constituents and mitigate any deleterious

effects; (4) hydrologic aspects of the introduction of highway storm-water runoff into wetlands; and (5) case studies of the effects of highway runoff on wetlands.

Task 2. Determine feasibility of using specific wetland types to mitigate the effects of highway runoff and delineate wetland characteristics required. Actual case studies from the literature will be used, where possible, to support conclusions.

Task 3. Prepare final report that includes all research findings in a comprehensive resource document to assist in the environmental assessment of the effects of highway runoff on wetlands, and provides guidelines for the practical management of highway runoff in wetlands to include but not be limited to: Federal regulations and their implementing guidelines, and, where possible, quantitative assessments of the critical physical, biological, and chemical limits of alternatives.

The agency and its subcontractor at the University of Wisconsin-Milwaukee are now conducting work under Tasks 1 and 2. An extensive literature search and assemblage are well underway. The literature is being analyzed concurrently for the purposes listed under Task 1 as well as for the potential of using wetlands to mitigate any deleterious effects of highway runoff.