NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1975

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

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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 it 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; 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.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. The Board establishes technical advisory groups to define research projects addressing these needs, and qualified research agencies are selected by the advisors from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation 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.

FIGURES

TABLES

MAILING ADDRESS:

TRANSPORTATION RESEARCH BOARD
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1975

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 an NCHRP Advisory Committee reviews each yearly program to determine its 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 $3½ 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 advisory groups (panels or committees) that are made up of persons knowledgeable in each particular problem area and who advise on the technical aspects of the problem. There are presently some 535 members on these panels coming from 44 States, the District of Columbia, and Canada. They analyze the problems, outline particular projects and their objectives, and then prepare research project statements on 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.

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the broad areas of physical research and traffic planning 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 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. Meetings involving the staff, the advisory groups, and agency personnel are held frequently for the purpose of reviewing project progress and providing guidance for continuing work. Finally, the projects engineer and the advisory 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 a special NCHRP report series. Each highway administrator receives a copy immediately on publication, and some 3,500 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, 43 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. Beginning with 1966, these reports have been supplemented by publication of an annual summary of progress that has been made available to both the sponsors and the public at large. Prior to 1969 the annual summary reported on a fiscal-year basis. It now reports on a calendar-year basis to permit inclusion of more up-to-date information that will remain current for a longer period of time. The tenth issue covers the Program from its inception through December 31, 1975 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 the research administered applies specifically to the AASHTO-sponsored research.

HOW NCHRP PROGRAMS ARE FORMULATED

Research problems from the American Association of State Highway and Transportation Officials 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 Administrative Practices.
- The chairmen of subcommittees under AASHTO's Standing Committee on Engineering and Operations.
- The Executive Committee of AASHTO.
- The Federal Highway Administrator.

The many problems received from these sources each year are forwarded to the Special AASHTO Select Committee on Research for consideration 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, this 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 status reports available on each project in the Program since FY '63. These reports include, among other things, statements of the anticipated project status after the currently allotted funds have been spent and the anticipated status after funds for project continuation have been expended. The committee review is also aided materially by reports from the NCHRP, TRB, and Fed-

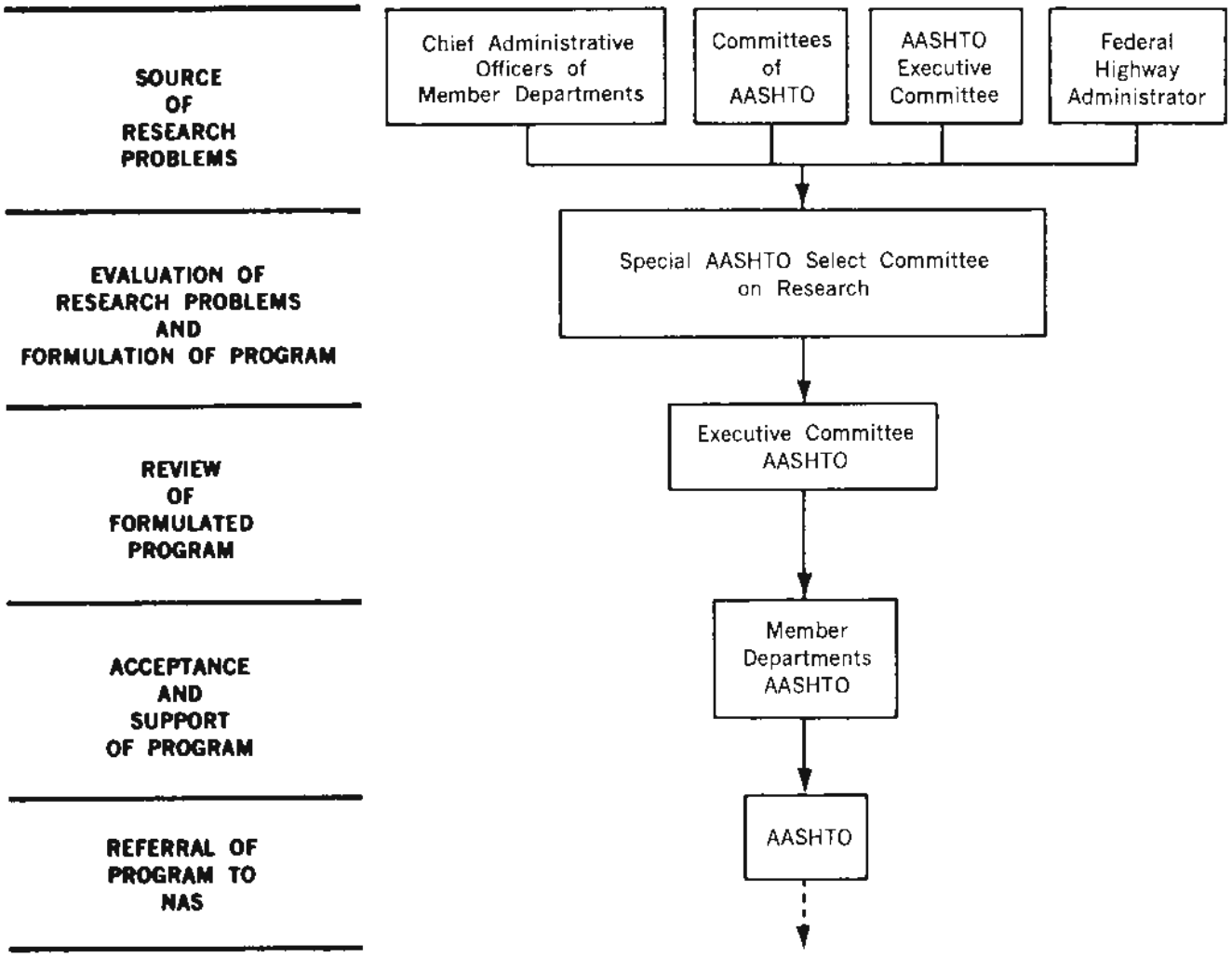


FIGURE 1

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

eral 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. Each problem is 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.
- The probability of success of completing the problem according to its scope, estimated cost, and time for completion.

The technical merits of the problems that survive this initial screening process are then evaluated in depth, and final priorities are placed on them. A research program is then formulated within the funds available for new problems.

The complete program, made up of continuations and new problems, is sent to the AASHTO Executive Committee for review, approval and/or modification, and acceptance. The Executive Committee acts during its annual winter meeting.

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. In so doing, a search is made of the relevant literature stored in the Board's automated Highway Research Information Service.

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 (see Table 2) and an increase in the levels of funding for individual projects. Since 1967, for example, each year's program has consisted of some 9 new problems with funding ranging between $100,000 and $300,000 and some 10 continuations—also funded in the same range—of projects begun in earlier years. 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 only a fraction of the problems submitted.

In 1975 AASHTO referred the fourteenth program (FY '76) of research problems. From all programs through FY '76, 239 research projects have resulted, on which contracts have been written with a total funding obligation of about $34.5 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 fifteenth group of research problems (FY '77 program) was selected in September 1975 and will be received in 1976 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. This action occurs at the same time that the States ballot to determine which new problems and continuations will be in the program.

The contract with the National Academy of Sciences 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 $3½ million is made available each year for NCHRP's contract research and for its administrative and technical operation. It is a significant indicator of the need for the NCHRP that all States have participated each year except for two of the early years. Even then, all but two States took part in the Program.

HOW THE NCHRP IS ORGANIZED TO ADMINISTER RESEARCH PROGRAMS

In line with its responsibility for administering the NCHRP, the Board has established an advisory committee to consider 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 Transportation Research Board Executive Committee.

In addition, the Board has established eight broad research fields under which advisory groups 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 Transportation Planning each project falling within the more specific subject areas of Traffic Planning and Urban Transportation—areas 7 and 8, respectively—is assigned an advisory group comprised of

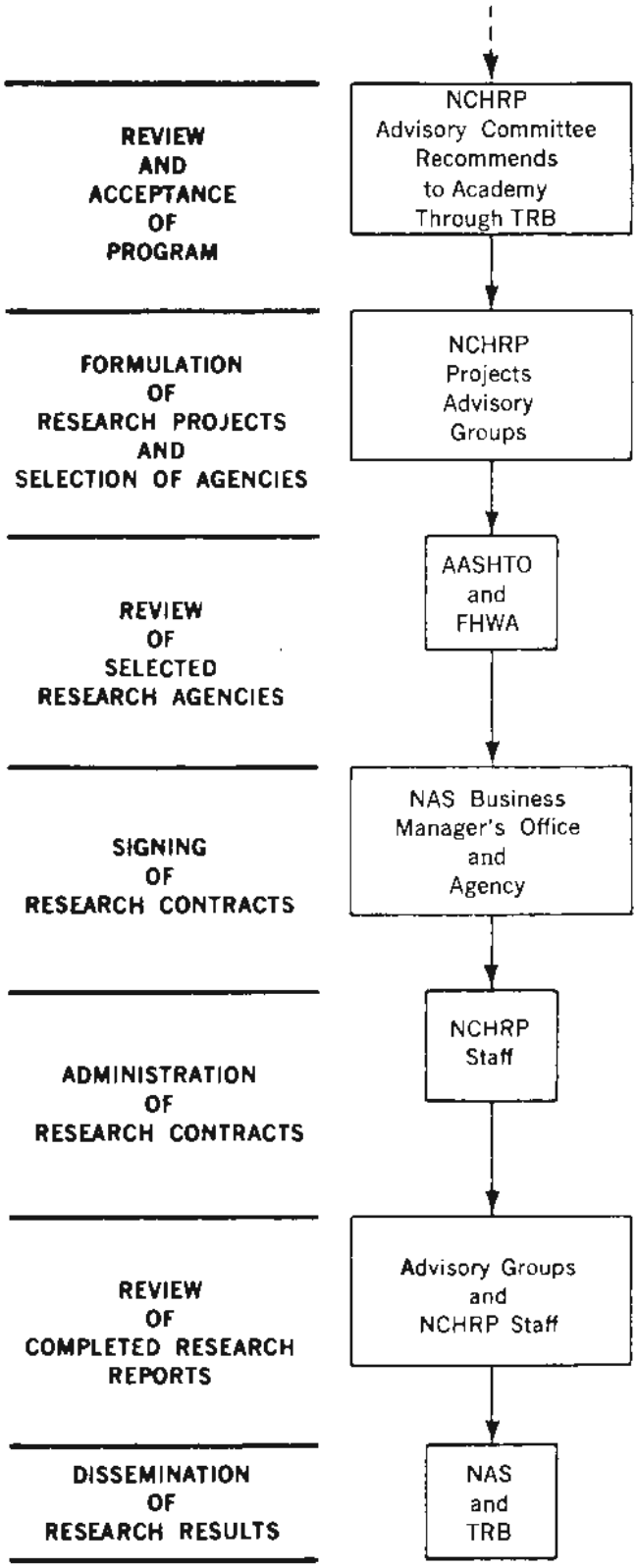


FIGURE 2

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

outstanding individuals who are very knowledgeable in the specifics of the particular project and who are looked to for guidance and counsel 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.

The distribution of all projects through FY 1976 within the fields of Figure 3 is as follows:

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
34	13.5	Socio-economic and environmental issues
28	15.1	Urban issues
6	4.0	Multimodal issues
41	23.0	Safety and accident prevention
18	0.8	Legal studies
11	13.3	Special projects (including in-house)
17	5.8	Improved materials quality and performance
12	3.7	Highway maintenance
22	6.4	Specifications, tests, and construction control
43	14.4	Structural design and performance

The membership of the advisory groups is only advisory to the Board; individuals 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 participation as advisors until the research agencies have been selected. If unsuccessful, they may return to full participation. Some 535 individuals serve without compensation on these advisory groups, and their total yearly contribution to the Program is estimated to be at least 3,500 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 advisory group membership, and 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 counsel and advice regarding technical aspects of the research.
- Reviewing and evaluating project reports as to the accomplishment of objectives and suitability for publication.

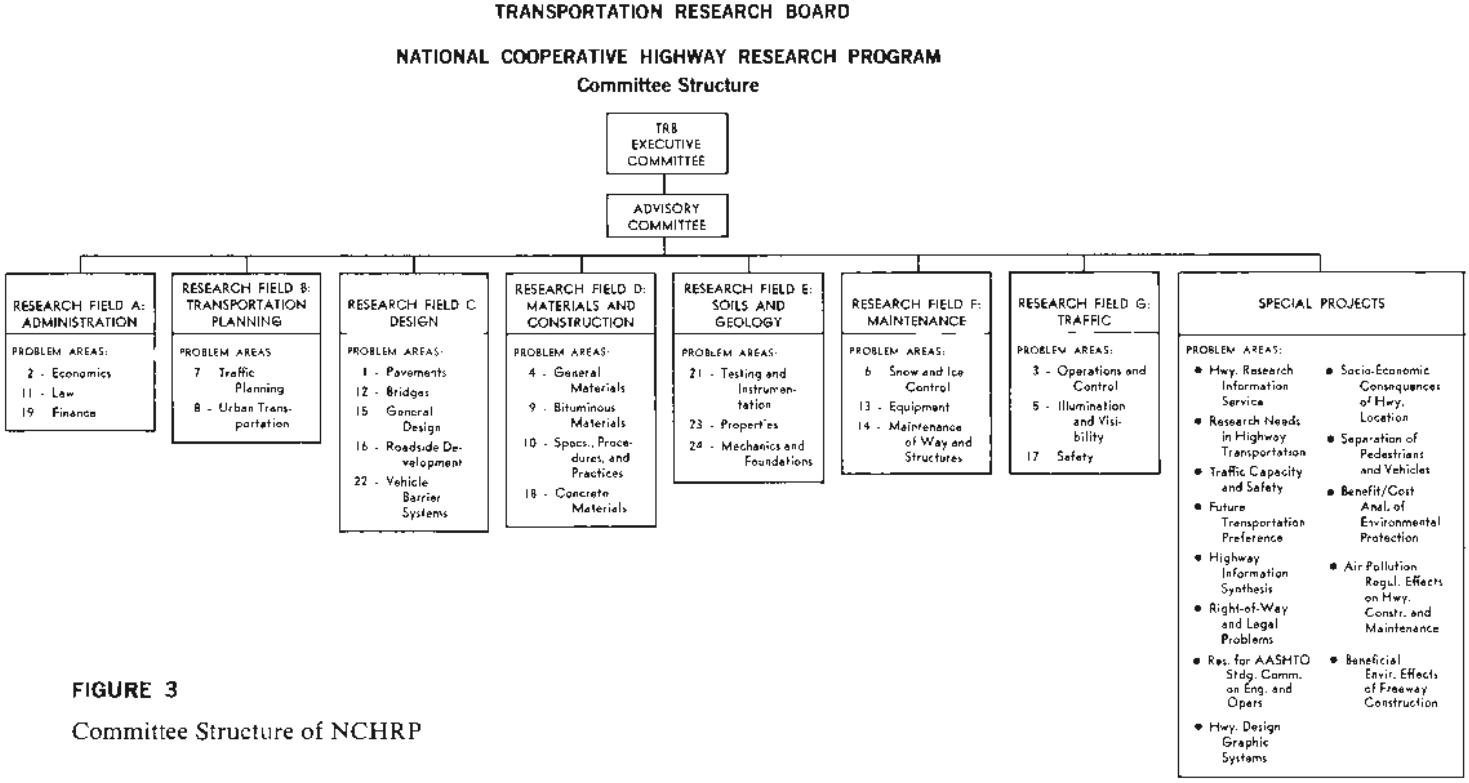


FIGURE 3

Committee Structure of NCHRP

• Making recommendations as to whether or not studies of problems included in prior fiscal year programs should be continued.

Following the NCHRP staff review made after program referral to the Academy, the recommended program is referred to the NCHRP advisory committee 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 problem solutions that can be practically applied. As the NCHRP officially gets each year's program under way, the advisory groups 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 interested individuals and research agencies. Because of deadlines the NCHRP must meet, proposals must be submitted according to fixed deadlines, and extensions simply cannot be granted. The subsequent proposal return has increased over the years from an average of 6 per project to a high of 17 per project (refer to Table 2). The range of proposals has been 2 to 35, and 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 ADVISORY GROUP MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	215	287
Federal Highway Administration	67	104
Special transportation and other governmental agencies	68	76
Educational institutions	77	103
Research institutes	5	6
Industry, consultants, and trade associations	87	118
Professional societies and service organizations	2	6
Transportation Research Board	14	85
All	535	785

TABLE 2

NUMBER OF PROPOSALS SUBMITTED

ITEM	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14	15	14	5
Proposals submitted	191	223	171	151	149	209	189	107	233	157	206	162	147	64
Proposals rec'd. per project (avg.)	6	8	12	9	12	13	10	12	17	11	15	11	11	13

TABLE 3

NUMBER OF AGENCIES SUBMITTING ONE OR MORE RESEARCH PROPOSALS

NO. OF PROPOSALS SUBMITTED	NUMBER OF AGENCIES SUBMITTING PROPOSALS													
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75
1	26	32	56	59	70	90	70	55	103	63	96	88	73	44
2	18	22	29	18	20	18	22	8	22	24	20	17	19	4
3	7	14	11	8	4	11	8	5	8	8	13	5	8	4
4	5	8	2	5	4	0	2	4	8	3	4	3	1	0
5	4	4	1	1	1	5	0	1	2	2	3	0	0	0
6	4	1	0	0	1	3	1	0	1	0	0	1	0	0
7	1	4	0	1	0	1	0	0	0	0	0	1	0	0
8	1	1	0	0	0	0	2	0	1	0	0	0	1	0
9	1	0	0	0	0	0	0	0	1	0	0	0	0	0
10	2	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	1	0	0	0	1	0	0	0	0	0	0	0
All	69	87	100	92	100	128	106	73	146	100	136	115	102	52

TABLE 4

TYPES OF AGENCIES SUBMITTING PROPOSALS

TYPE OF AGENCY	NO. OF AGENCIES SUBMITTING													
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75
Educational institutions	41	32	39	32	40	51	25	36	53	33	50	38	35	14
Research institutes	11	16	17	22	22	26	19	16	23	14	9	9	8	8
Industry, consultants, and trade associations	14	35	42	35	35	48	59	18	67	51	72	66	55	28
Professional societies and service organizations	2	0	1	2	0	0	0	0	0	0	0	0	0	0
State highway and transportation departments	0	3	1	0	0	2	3	1	2	1	3	2	2	1
Special transportation and other governmental agencies	1	1	0	1	3	1	0	2	1	1	2	0	2	1
All	69	87	100	92	100	128	106	73	146	100	136	115	102	52
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14	15	14	5

Contracts have been let to agencies headquartered in more than one-half of the States and the District of Columbia. Educational institutions have received about 37%; research institutes, 21%; industry and consultants, 38%; professional societies and service organizations, 2%; state highway and transportation departments and special transportation and other governmental agencies, 2%. 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 13 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 are given in the project statement. It 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 available, the proposal is rejected on receipt.

The three top proposals are chosen for each project, and an advisory group meeting is held to select an agency. The advisors review all known aspects of agency performance on other research projects under NCHRP or elsewhere. The successful proposals are retained by the group members for use in advisory duties during conduct of 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. It is also NAS policy that panel notes, deliberations, etc., are privileged and not releasable under any circumstances.

Following the selection meeting, a list of recommended research agencies is transmitted to the AASHTO Executive Committee and the Federal Highway Administration for their review and consideration. 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 advisory groups. 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 projects included in the 14 fiscal year programs conducted to date are listed in Table 5. There are 108 projects in traffic planning research, 115 in physical research, and 16 in the special projects area. The 239 projects are distributed among more than one-half of the States and the District of Columbia. To date, 205 of the projects have been completed. The distribution of all projects by agency type is given in Table 6.

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. The principal investigator, however, 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 to ensure that the referral to the National Academy of Sciences of an AASHTO-developed program for any given year meshes appropriately with the apportionment of Federal-aid funds for that year. This permits smooth progression from year to year throughout the planning and activation phases of each year's program.

TABLE 5

PROJECTS FOR FY '63 THROUGH FY '76 SUMMARY OF STATUS THROUGH DECEMBER 31, 1975

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OF 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	250,000
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structnres	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	300,000
	AREA TWO: ADMINISTRATION—ECONOMICS		
2-1	Criteria for Highway Benefit Analysis	U of Washington	101,948*
2-2	Guidelines for the Determination of Commnnity Conseqnences	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 (Indnced) 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
	AREA THREE: TRAFFIC—OPERATIONS AND CONTROL		
3-1	Development of Criteria for Evaluating Traffic Operations	Cornell Aero Lab	78,965* 79,913*
3-2	Surveillance Methods and Ways and Means of Communicating with Drivers	Cornell Aero Lab	246,756*
3-3	Sensing and Communication Between Vehicles	Ohio State U	163,190*
3-4	Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location	Airborne Instr	78,517* 49,474*
3-5	Improved Criteria for Designing and Timing Traffic Signal Systems	Planning Res	123,030* 48,155* 93,717*
3-6	Effect of Regulatory Devices on Intersectional Capacity and Operation	De Leuw, Cather	153,175*
3-7	Establishment of Standards for Highway Noise Levels	Bolt Beranek	144,920* 69,930* 49,927* 316,011

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS	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)
/15/63	2/28/65	Completed—Initial phase published as NCHRP Report 7; final report not published; summarized in Summary of Progress to June 30, 1967	1-2
/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)
0/1/63	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)
/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)
/31/64	1/31/67	Completed—Published as NCHRP Report 59	1-6
/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
0/1/66	6/30/67	Completed—Published as NCHRP Report 61	1-9
/12/66	3/11/68	Completed—Report included in NCHRP Reports 139,140	1-10
2/1/68	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	4/30/76	Research in progress	1-10B
/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
/25/69	6/8/73	Completed—Published as NCHRP Report 154	1-12
7/1/75	9/30/77	Research in progress	1-12A
/16/70	5/15/73	Completed—Published as NCHRP Report 151	1-12(2)
1/1/71	9/30/75	Report in review stage	1-12(3)
/19/71	8/20/74	Report in editorial and publication process	1-13
/15/72	5/31/73	Report in editorial and publication process	1-13(2)
/15/72	1/14/74	Report in editorial and publication process	1-14
8/1/72	8/31/75	Complete—Rep. not to be publ.; agency report available for loan	1-15
6/3/74	6/2/77	Research in progress	1-16
6/1/63	11/30/67	Completed—Rep. not publ.; sum. in Summary of Progress Through June 30, 1968	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
/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.; summarized in Summary of Progress to June 30, 1967	2-8
1/8/65	1/31/68	Completed—Published as NCHRP Report 75	2-9
1/1/66	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	Report in editorial and publication process	2-12
2/15/63	2/29/64	Completed—Report not published; summarized in Summary of Progress to June 30, 1967	3-1
7/2/64	2/28/66		
2/15/63	4/30/66	Completed—Published as NCHRP Reports 9, 28, 29	3-2
2/15/63	11/30/65	Completed—Published as NCHRP Report 51	3-3
3/1/63	3/31/65	Completed—Published as NCHRP Report 6	3-4
7/1/65	12/15/66	Completed—Published as NCHRP Report 40	3-4
3/1/63	12/31/65	Completed—Published as NCHRP Reports 3, 32	3-5
7/1/66	7/31/67	Completed—Published as NCHRP Report 73	3-5
8/1/68	12/31/69	Completed—Published as NCHRP Report 124	3-5
4/1/63	8/15/66	Completed—Published as NCHRP Reports 11, 41	3-6
2/1/64	4/30/67	Completed—Published as NCHRP Report 78	3-7
0/14/68	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	Report in editorial and publication process	3-7

TABLE 5 *(Continued)*

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OF CONTRACT COST
	AREA THREE *(Continued)*		
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, Commnnication, 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 Techniqnes 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	149,916
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 Compnter-Controlled Traffic	Stanford Res Inst	323,998 49,912
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 Snrveillance and Control Systems	JHK & Assoc	100,000
3-19	Grade Effects on Traffic Flow Stability and Capacity	Midwest Res Inst	220,443
3-20	Traffic Signal Warrants	KLD Associates	120,000* 80,000
3-21	Motorist Response to Highway Guide Signing	BioTechnology	272,071
3-22	Guidelines for Design and Operation of Ramp Control Systems	Stanford Res Inst	198,590
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	300,000
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	260,000
	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 Moistnre	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-Indnced Damage to Asphaltic Concrete	U of Idaho	190,177* 71.652
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah St Dept Hy	93,494
4-9	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah St Dept Hy	125,000
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
	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*

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS	PROJECT NO.
2/1/63	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
/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
/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
0/1/66	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
29/71	12/11/72	Completed—Rep. not publ.; summarized in Summary of Progress Through 1973	3-12
9/1/67	11/30/69	Completed—Published as NCHRP Report 93	3-13
0/1/67	1/10/70	Completed—Published as NCHRP Report 113	3-14
0/1/69	12/31/73	Completed—Published as NCHRP Report 159	3-15
/1/69	4/30/71	Completed—Rep. not publ.; summarized in Summary of Progress Through 1971	3-16
5/1/72	10/31/73	Report in editorial aud publication process	3-16
1/1/71	11/30/72	Completed—Published as NCHRP Report 145	3-17
/15/71	5/15/74	Completed—Report to be included in Phase II report	3-18(1)
/15/75	11/30/75	Contract to be exteuded	3-18(1)
9/1/71	6/30/75	Report in editorial aud publication process	3-18(2)
5/1/75	7/31/76	Research in progress	3-18(3)
9/1/71	8/31/74	Report in editorial and publication process	3-19
2/1/72	4/15/74	Completed—Report to be included in Phase II report	3-20
/1/74	7/31/76	Research iu progress	3-20
/1/74	1/31/76	Research in progress	3-21
15/74	12/31/75	Report in review stage	3-22
/8/74	7/7/76	Research in progress	3-23
9/1/74	11/30/76	Research in progress	3-24
15/75	9/16/77	Research in progress	3-25
5/1/63	10/31/66	Completed—Report not published; summarized in Summary of Progress Through June 30, 1968	4-1
15/63	11/30/66	Completed—Published as NCHRP Report 98	4-2
/1/63	9/30/64	Completed—Published as NCHRP Report 12	4-3(1)
/1/65	3/31/67	Completed—Published as NCHRP Report 65	4-3(1)
25/63	1/31/65	Completed—Published as HRB Special Report 80 and NCHRP Report 15	4-3(2)
/1/65	8/31/67	Completed—Published as NCHRP Report 66	4-3(2)
/1/63	4/15/64	Completed—Published as NCHRP Report 8	4-4
15/63	8/31/65	Completed—Report not published; summarized in Summary of Progress Through June 30, 1968	4-5
/1/65	11/30/66	Completed—Published as NCHRP Reports 74, 74A, 74B	4-6
9/1/67	2/28/70	Completed—Report to be included in Phase II Report	4-7
/1/71	8/31/73	Report in editorial and publication process	4-7
/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
/1/71	6/30/73	Report in editorial and publication process	4-8(2)
/1/71	3/31/74	Report in editorial and publication process	4-8(3)
5/1/75	1/31/82	Research in progress	4-8(3)
/1/68	6/30/71	Report in review stage	4-9
/1/72	12/31/77	Research in progress	4-9
15/69	3/31/71	Completed—Published as NCHRP Report 135	4-10
/1/72	11/30/73	Report in editorial and publication process	4-10A
16/74	3/15/77	Research in progress	4-11
15/63	5/31/66	Completed—Report included in NCHRP Report 60	5-2(1)
/1/67	7/31/67	Completed—Report included in NCHRP Report 60	5-2(1)
15/63	8/31/65	Completed—Report included in NCHRP Report 60	5-2(2)
20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3
20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
15/67	9/15/69	Completed—Published as NCHRP Report 85	5-5
/1/71	6/30/73	Report in editorial and publication process	5-5A
/1/71	12/31/74	Report in editorial aud publication process	5-5B
2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OF CONTRACT COST
	AREA FIVE (*Continued*)		
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	199,627
	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	Nouchemical Methods for Preventiug 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 Acceleratiug 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: TRANSPORTATION PLANNING—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 Rnral 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 Actnal 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 18,908
	AREA EIGHT: TRANSPORTATION PLANNING—URBAN TRANSPORTATION		
8-1	Social and Economic Factors Affecting Travel	Vogt, Ivers	94,558*
8-2	Factors Inflnencing 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 Evalnating 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*
8-7	Evaluation of Data Requirements and Collection Techniqnes for Transportation Planning	Creighton, Hamburg	190,000*
8-7A	Data Requirements and Transportation Planning Procedures in Small Urban Areas	U of Tennessee	99,968
8-8(1)	The Impact of Highways npon Environmental Values (Stndy Design)	M I T	29,654*
8-8(2)	The Impact of Highways upon Environmental Values (Stndy 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	99,753
8-12	Travel Estimation Procednres for Quick Response to Urban Policy Issnes	Metro Wash COG	39,895
8-12A	Travel Estimation Procedure for Quick Response to Urban Policy Issnes	Comsis Corp	160,000
8-13	Disaggregate Travel Demand Models	Chas River Assoc	100,000
8-14	New Approaches to Understanding Travel Behavior	Boston College	149,860
8-15	State and Regional Transportation Impact Identification and Measnrement	Bigelow-Crain	80,000
8-16	Guidelines for Public Transportation Levels of Service and Evaluation	U of Tennessee	480,000
8-17	Freight Data Requirements for Statewide Transportation Systems Planning	Creighton, Hamburg	225,000
8-18	Techniques for Evaluating Options in Statewide Transportation Planning/Programming	Plng Envr Int/AMV	300,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS	PROJECT NO.
9/1/70	5/31/73	Report in editorial and publication process	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
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.; summarized in Summary of Progress to June 30, 1967	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.; summarized in Summary of Progress to June 30, 1967	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	Init. phase completed—rep. to be incl. in Phase II rep.	6-11
9/12/72	9/11/74	Report in editorial and publication process	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
0/23/67	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	Report in review stage	7-9
4/1/74	3/31/75	Report iu review stage	7-10
4/1/75	11/15/75	Report in editorial and publication process	7-10
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.; summarized in Summary of Progress to June 30, 1967	8-3
2/1/65	8/1/67	Completed—Report included in NCHRP Report 96	8-4
0/14/68	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
9/13/68	8/28/70	Completed—Published as NCHRP Report 120	8-7
6/1/73	6/14/75	Report in editorial and publication stage	8-7A
9/16/68	3/14/69	Completed –Study design report not to be published	8-8(1)
9/9/68	3/7/69	Completed—Study design report 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	11/30/75	Report in review stage	8-11
9/3/74	12/31/75	Completed—No formal report to be published	8-12
1/1/75	1/31/77	Research in progress	8-12A
9/15/74	12/14/75	Phase I completed—No formal report to be published	8-13
—	—	Phase II in developmental process	8-13
1/1/75	6/30/76	Phase I report in editorial aud publication process	8-14
		Phase II contract pending	8-14
9/1/74	11/30/75	Phase I completed—Report in review stage	8-15
—	—	Phase II in developmental process	8-15
1/1/76	3/31/78	Research to begiu January 1, 1976	8-16
7/15/75	2/15/77	Research in progress	8-17
9/1/75	2/28/78	Research in progress	8-18

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	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	199,994
	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	199,572
	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 RI 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	100,000
	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* 100,000
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	174,699
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
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbus	200,000

STARTING DATE	COMPLETION DATE	PROJECT STATUS	PROJECT NO.
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
1/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	9-1
1/1 '65	10/31/67	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
1/1/71	6/30/73	Report in editorial and publication process	9-4
/15/75	12/14/77	Research in progress	9-4A
/15 63	11/14/64	Completed—Published as NCHRP Report 17	10-1
1/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
/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
/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	Report in editorial and publication process	10-8
1/1/69	2/28/74	Report in editorial and publication process	10-9
5/1/74	4/30/76	Research in progress	10-10
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)
0/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
/16/68	4/30/69	No final report—Project terminated	11-1(3)
2/1/68	5/31/69	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	11-1(4)
/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)
0/1/68	3/31/69	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	11-1(7)
/15/68	1/15/70	Completed—Published as NCHRP Report 134	11-1(8)
/15/69	12/1/69	Completed—Published as NCHRP Report 94	11-1(9)
/15/69	9/15/69	Completed—Published as NCHRP Report 107	11-1(10)
/24/69	8/25/69	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	11-1(11)
2/1/65	6/30/66	Completed—Published as NCHRP Report 72	11-2
1/1/66	12/15/67	Completed—Published as NCHRP Report 56	11-3
0/1/68	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
0/1/70	5/31/72	Completed—Published as NCHRP Report 142	11-5
4/1/74	7/31/75	Report in review stage	11-6
2/1/65	6/30/67	Report included in Project 12-6 report	12-1
5/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
15/65	3/14/69	Completed—Report available only to sponsors	12-3
15/65	3/31/68	Completed—Rep. not publ.; summarized in Summary of Progress Through 1969	12-4
15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5
2/1/67	4/30/72	Completed—Rep. not publ.; summarized in Summary of Progress Through 1975	12-6
0/1/66	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
8/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
/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
/1/70	12/31/73	Report in editorial and publication process	12-10
8/1/70	3/31/73	Report in editorial and publication process	12-11
15/73	4/15/77	Research in progress	12-11
0/1/70	10/31/75	Report in editorial and publication process	12-12
9/1/72	7/31/74	Report in editorial and publication process	12-13
8/1/75	7/31/78	Research in progress	12-13A
9/1/72	6/30/74	Report in editorial and publication process	12-14
9/1/72	4/30/75	Report in editorial and publication process	12-15
7/1/74	2/28/77	Research in progress	12-16

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	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-Shonlder Joint Design	Georgia Tech	99,754
14-4	Reconditioning Heavy-Dnty Freeways in Urban Areas	Texas A & M	99,665
	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 Strnctural 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*
	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 Constrnction	Utah State U	174,950
	AREA SEVENTEEN: TRAFFIC—SAFETY		
17-1	Development of Improved Methods for Redrction 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*
	AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS		
18-1	Revibration of Retarded Concrete for Continuons Bridge Decks	U of Illinois	103,895*
18-2	Use of Polymers in Highway Concrete	Lehigh U	300,000
	AREA NINETEEN: ADMINISTRATION—FINANCE		
19-1	Budgeting for State Highway Departments	Ernst & Ernst	45,000*
19-2(1)	Develop Performance Bndgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Bndgeting System to Serve Highway Maintenance Management	Ernst & Ernst	6,000*
19-2(3)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	6,000*
19-2(4)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	220,000*
19-3	Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways	Wilbnr 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†
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,631* 20,000†
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Commnnication, and Control—Summary Reporting	Patrick J. Athol	31,116*
20-3C	Summary of the Lodge Freeway Research	Asriel Taragin	10,375
20-3D	Summary of All Freeway Surveillance, Communication and Control Experience	To Be Determined	
20-4	Public Preference for Fnture Individual Transportation	Chilton Research National Analysts	195,260* 83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	300,000§
20-6	Right-of-Way and Legal Problems Arising out of Highway Programs	TRB	85,000§
20-7	Research for AASHTO Standing Committee on Engineering and Operations	†††	100,000§
20-8	Interactive Graphic Systems for Highway Design	Control Data	49,672*
20-9	Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation	RMC Res Corp	210,964
20-10	The Benefits of Separating Pedestrians and Vehicles	Stanford Res Inst	100,000
20-11	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Poly of New York	100,000*
20-11A	Toward Environmental Benefit/Cost Analysis—Measnrement Methodology	Cornell U	24,975
20-12	Effects of Air Pollution Regulations on Highway Construction and Maintenance	Howard, Needles et al	89,000
20-13	Beneficial Environmental Effects Associated with Freeway Constrnction	Penn State U	49,965

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS	PROJECT NO.
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
0/1/70	3/31/73	Completed—Published as NCHRP Report 161	14-2
/15/72	9/14/75	Report in editorial and publication process	14-3
/15/74	3/3/76	Research in progress	14-4
/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—Publ. as NCHRP Rep. 108; Ph. II rep. sum. in Sum. of Prog. Through 1975	15-2
0/1/67	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
/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
3/1/66	4/30/72	Initial phase publ. as NCHRP Report 91; Phase II rep. in edit. and publ. process	16-1
0/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
1/1/73	2/29/76	Research in progress	16-3
2/1/66	5/31/68	Completed—Pnblished as NCHRP Report 79	17-1
/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
9/1/67	12/1/69	Completed—Published as NCHRP Report 106	18-1
0/1/72	9/30/75	Report in editorial and publication process	18-2
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 to be published	19-2(1)
9/2/68	10/31/68	Completed—Working plan not to be 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)
/15/70	6/14/72	Completed—Published as NCHRP Report 141	19-3
/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
/15/66	1/31/69	Completed—Results to be summarized in Project 20-3C report	20-3
1/1/67	12/31/68		20-3
/20/68	5/31/71	Completed—Results to be 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
/15/75	7/15/76	Research in progress	20-3C
—	—	Project in developmental process	20-3D
5/2/67	1/21/69 (CRS)	Completed—Published as NCHRP Reports 49, 82	20-4
5/2/67	1/2/68 (NA)	Completed—Published as NCHRP Reports 49, 82	20-4
/15/67	§§	Research in progress: Topic reports published as NCHRP Syntheses 1 through 32	20-5
1/1/68	§§	Research in progress: Refer to Table 9 for pnblications	20-6
2/2/68	§	Research in progress: Completed task reports published as NCHRP Reports 148, 150, 157, 158; and as NCHRP Research Results Digests 55, 77	20-7
9/1/70	7/31/71	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	20-8
8/1/72	1/31/76	Research in progress	20-9
/26/74	2/25/76	Research in progress	20-10
9/1/72	5/31/74	Completed—Rep. not to be publ.; agency report available for purchase	20-11
9/1/75	5/31/76	Research in progress	20-11A
4/1/74	7/31/75	Report in editorial and publication process	20-12
9/3/74	8/2/75	Report in editorial and publication process	20-13

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	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	150,000
	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*
22-3	Field Evaluation of Vehicle Barrier Systems	Calspan Corp	25,000
22-3A	Field Evalnation of Vehicle Barrier Systems	Arthur L. Elliott	10,000*

* Final contract cost.
† 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.

TABLE 6

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '76 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS NO.	%
Educational institutions	89	37
Research institutes	50	21
Industry, consultants, and trade associations	90	38
Professional societies and service organizations	5	2
State highway and transportation departments	4	>1
Special transportation and other governmental agencies	1	<1
All	239	100

KEEPING TRACK OF RESEARCH IN PROGRESS

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the broad areas of physical research, traffic planning, and special projects research 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 projects 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 projects engineer and appropriate advisory group 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 up through formal publication of the final reports. At the milestones of the systematic process designed to accommodate these activities, NCHRP takes advantage of all 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 concentrating on:

- 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 under-

STARTING DATE	COMPLETION DATE	PROJECT STATUS	PROJECT NO.
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Completed—Report not to be publ.; to be included in Project 21-2(3) report	21-2
4/1/72	9/30/73	Completed—Report not to be publ.; to be included in Project 21-2(3) report	21-2(2)
9/3/74	12/2/76	Research in progress	21-2(3)
10/1/70	12/31/71	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	22-1
3/1/74	5/30/75	Report in editorial and publication process	22-1A
1/1/72	9/30/73	Init. phase completed—rep. to be incl. in report on Task 1, Phase II	22-2
10/1/73	3/31/75	Task 1 rep. in edit. and publ. process; Task 2 rep. publ. as NCHRP Report 153	22-2
1/1/74	2/15/75	Completed—Rep. not publ.; summarized in NCHRP Research Results Digest 76	22-3
7/1/74	12/31/74	Completed—Rep. not publ.; summarized in NCHRP Research Results Digest 76	22-3A

§ Continuing activity supported at the annual amount shown.
§§ Continuing activity supported in FY '76 at amount shown.
††† Texas A & M University Research Foundation to date.

standing 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 advisory group 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 advisory group as required.

- Carrying out project surveillance sufficient to keeping the research in line with the approved research plan, constantly keeping the researchers aware of the needs of the practicing engineer, and insuring that all project developments through final reporting center around these needs.

- Requiring research reports in a format that is designed specifically to first meet the needs of the busy administrator and the practicing engineer. Different treatment is given to the material that would be of interest to other researchers.

NCHRP Reporting of Research Results

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

Research agencies for the NCHRP are required to report their results in a form that succinctly summarizes the findings for the busy administrator and likewise informs the practicing engineer of the application of the findings. These objectives are accomplished through a "Summary of Findings," and a chapter on "Interpretation, Appraisal, and Application of Results." The detailed research techniques and analyses in which a researcher would be interested are presented in appendices and do not have to be labored through to extract the findings. The Program specifies style and organization of all reports to guide the researcher in his writing so that maximum use by the sponsors may be obtained.

Prior to publication, extraordinary measures are taken to ensure that useful research results are made immediately available to the appropriate operations personnel in the state organizations. One means consists of forwarding to them copies of the research agency drafts of final reports. According to the 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 pub-

lication 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 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 varions 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. Research findings not published in the NCHRP series are summarized in a subsequent *NCHRP Summary of Progress* report, issued annually each January. On an interim basis, the findings are sometimes reported in a *Research Results Digest*, described next.

Another means for bringing research findings before the practicing engineer was instituted in December 1968 with the first issue of *NCHRP Research Results Digest*—a series of flyers being published at frequent intervals. These Digests are being issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these 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.

In recent 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. Beyond that point, only final reporting remains, and it is up to the sponsor to implement the findings. Without steps in this direction, research with gold-plated results may just as well have been totally unsuccessful—the end result is the same. Only if the results get around and are used can it be said that AASHTO truly is capitalizing on its investment in a research mechanism that has been demonstrated to be cost effective.

In summary, then, it should be evident that the NCHRP normally possesses only indirect means for promoting implementation of research results; there is little opportunity for more direct discourse with the sponsor by which implementation may be promoted. Every possible opportunity is therefore taken all along the way to capitalize on the indirect means to the fullest extent. There has been steady improvement as regards the usefulness of NCHRP products, and this situation is expected to maintain its trend as a result of increased Program stability gained from experience. It is hoped that there will be a corresponding rise of user interest that will be reflected by increased utilization of NCHRP research results.

EXAMPLES OF UTILIZATION OF NCHRP RESEARCH RESULTS

Many instances have come to light regarding use of research results from NCHRP projects. There are undoubtedly many other uses of results that are unknown to the Program. 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 as below with the hope that widespread interest will result on the part of the member departments of AASHTO 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 of the rehabilitated AASHO Road Test project at Ottawa. Particular use made of recommendations for experimental designs, measurement programs, and data processing analysis.
1-2	Report 7	New York Dept. of Transp.	To develop a flexible pavement performance equation; in use as of June 1968.
		Tallamy, Byrd, et al.	In study of highway maintenance quality levels for Ohio Dept. of Hwys.
1-5(2)	Report 76	North Dakota State Highway Dept.	Major equipment purchase was based on successful use of similar equipment in conduct of project.
1-7	Report 37	Nat'l. Hwy. Safety Bur.	In preparation of a *Highway Safety Program Manual* for issuance to the States.
		92nd Congress, 1st Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
1-8	Agency final report	Consultant for USN and USAF	Development of a new approach to pavement design for heavy aircraft loadings; used for redesign of the Salt Lake City runway to accommodate B747 aircraft and in design of the runway, taxiways, and aprons at Air Force Plant No. 42 near Palmdale, Calif., where the design load is one million pounds (gross) from the B2707 (SST) configuration.
1-9	Report 61	California Div. of Hwys.	In evaluation of proposed State legislation regarding use of studded tires.
1-10	Agency final report	Consultant for USN and USAF	See Project 1-8.
1-11	Agency report	U.S. Forest Service	In preparation of an Engineering Technical Report evaluating several commonly accepted pavement design methods, as to their applicability for the 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.
1-12(2)	—	92nd Congress, 1st Sess.	See Project 1-12.
1-12(3)	—	92nd Congress, 1st Sess.	See Project 1-12.
	Agency report	New York Dept. of Transportation	Will lean heavily on the suggestions presented when purchasing or altering skid trailers and when modifying operational procedures.
1-14	Agency final report	Va. Dept. of Highways	Safety Committee reviewed agency recommendations for improvements at high accident site with resulting request for FHWA approval as an Interstate Safety Project.
2-5	Reports 13, 111	One State (unknown)	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.*
		Woodrow W. Rankin, I.T.E.	In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant and W. Grant Ireson	In textbook, *Principles of Engineering Economy.*
3-2	Reports 9, 29	Illinois Div. of Hwys., Bur. of Traffic	In a FAI 80 Motorist Communication project. Also, more emphasis is being placed on the influence of pedestrians on signal timing, because signals in the

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			small cities are almost always in the CBD where there are many pedestrians.
3-4	Reports 6, 40	California 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	Dist. of Columbia, Dept. of Hwys. and Traffic	Incremental travel cost technique applied to a comprehensive determination of the existing effectiveness of operation in the D.C. traffic signal system. Annual incremental travel costs in the D.C. system were estimated and used in a benefit/cost analysis of traffic signal system improvement alternatives.
		Minnesota Dept. of Hwys.	Steps taken toward implementation of the delay difference offset technique in an existing signal network.
		California 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 the open and closed window situation that consideration was given to installation of air conditioning and storm windows for school buildings adjacent to freeways.
		Georgia State Hwy. Dept.	Noise design guide used in design of the 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 Dept. of Hwys.	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 the 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

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			have been forecast in the instance of standard evaluations of major projects.
		Arizona cons. firm	In design and location of a 4.5-mile segment of I-10 (Papago Freeway) traversing a high-density area of downtown Phoenix. Recommendations made are expected to substantially reduce the noise levels in the areas adjacent to the Freeway.
		Natl. Assn. of Homebuilders	In development of a *Builders' Acoustical Manual* that includes guidelines for prediction of site noise due to traffic.
		Missouri State Hwy. Comm.	Highway traffic noise simulation program used to establish noise projections on new project designs.
		Federal Highway Administration	In developing highway noise level standards PPM 90-2, "Interim Noise Standards and Procedures for Implementing Section 109(I) 23 U.S.C."
		Louisiana Dept. of Highways	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, Tammen & Bergendoff	The model for predicting highway traffic noise was validated under contract to a state highway department.
		Express Hwy. Res. Foundation (Japan)	Abridgment (8 pp.) published in April 1972 issue of *Expressways and Automobiles* (in Japanese).
		Colorado Dept. of Highways	A projected noise study is based on a U.S. DOT program that was developed directly from this report, which is considered to represent the best study procedure from available empirical and theoretical research on highway noise.
		Minnesota Dept. of Highways	Predictions for use in design of I-35W noise barrier in south Minneapolis.
	Agency final report draft	Environmental Protection Agency	In evaluating alternatives for truck noise emission regulations.
	Agency final report	National Bureau of Standards	Published a form of the Noise Prediction Nomogram adapted to an "L-equivalent" measure.
3-8	Report 50	Orange Co. (Calif.) Traffic Eng. Council	Extensive use as the best available source of information for preparation of warrants for the 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 the portion dealing with crossings where flashing light signals—with or without gates—are not warranted.
3-9	Report 84	California Div. of Hwys.	Recommendations being used on the Freeway Surveillance and Control Project (Los Angeles), involving expenditure of about $8 million in three years.
3-12	Report 123	Transp. Systems Center	Information on fixed highway signing principles was 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.
3-13	Report 93	City of Waco, Tex.	Plans to incorporate in subdivision and zoning regulations many of the controls recommended as a means of attempting to protect facility capacity and safety.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
3-14	Film, "Relief for Tired Streets"	New York Dept. of Transportation	To encourage municipalities in the 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.
3-18(1)	Agency interim report	City of Lincoln, Nebraska	In design of a digital computer-controlled traffic control system to supervise 250-300 signalized intersections.
	Agency final report	New Zealand Ministry of Works	To reduce hardware costs by applying greater software capabilities to computer-controlled traffic signal operations.
		New York State Dept. of Transp.	As background and design evaluation for a centralized computer traffic surveillance and control system in the Northern Long Island Corridor.
3-20	Agency report	FHWA	To develop interest in warrant improvement within Signals Subcommittee of National Advisory Committee on Uniform Traffic Control Devices.
4-3	Reports 12, 15, 65, and 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."
4-11	Agency interim report	Federal 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.
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 Dept. of Hwys.	Reference source of current and complete information on individual delineation techniques.
	Report 130	Org. for Economic Coop. and Devel. Res. Group C-8	In preparing report on Visual Effectiveness and Durability of Road Markings, Reflectors, and Delineators.
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.
6-2	Report 4	California Div. of Hwys.	See Project 6-1.
6-3	Report 16	California 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."
6-4	Report 23	Iowa State Hwy. Comm.	Constructed a bridge with galvanized reinforcing bars in one-half of the deck. This follows the recommendations to the effect that more field evaluation is required of zinc, nickel, and asphalt-epoxy coatings.
6-5	Report 27	California Div. of Hwys.	See Project 6-1.
6-8	Report 1	California 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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
6-10	Agency reports	California Div. of Hwys.	In preparation of plans for two sections of US50 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.
7-4	Report 89	Illinois Dept. of Transp., Bur. of Planning	Findings have been found useful, and practice has been modified to conform with them.
7-7	Report 64	Ohio Dept. of Hwys.	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.
7-10	Agency interim report	Oregon County Transit Dist.	In preparation of an energy contingency plan.
8-3	Agency final report	Arizona Hwy. Dept.	Source material for decisions based on consumer sensitivity to the various factors considered in trip making.
8-4	Report 96	Univ. of Wisconsin, Dept. of Engineering	As a text in short course on Urban Transportation Planning.
8-5	Report 121	Univ. of Wisconsin, Dept. of Engineering	As a text in Traffic Engineering Seminar.
8-8(3)	Agency interim report	Iowa State Hwy. Comm.	In development of an action plan in conformance with FHWA PPM 90-4.
		Delaware Dept. of Hwys. and Transp.	In development of an action plan in conformance with FHWA PPM 90-4.
	Agency final report	New York DOT, Transp. Planning Div.	In preparation of a synthesis report giving background to regional personnel responsible for citizen participation. Also useful in development of NY 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 Research, South Africa	In developing similar procedures in South Africa.
9-3	Report 38	Ford Motor Co.	Saved countless hours of search and survey by state-of-the-art section on highway joint and crack sealing materials and methods. Useful in further understanding various design, construction, and maintenance problems, in analyzing specific failures, and in adapting future developments in highways to their industrial and other roadway problems.
10-1	Report 17	North Dakota State Univ.	Basic text for a course in statistical quality control taught to both undergraduates and a sizeable number of engineers, the majority of the latter being highway department employees.
		Illinois Div. of Hwys., Bur. of 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.
10-2	Report 34	Illinois Div. of Hwys., Bur. of 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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
10-6	Report 52	Illinois Div. of Hwys., Bur. of Res. and Devel.	Considering a trial of recommendation for use of nuclear pellet technique for measuring pavement thickness.
10-8	Agency final report	Pennsylvania Dept. of Transportation	The Ohio State ultrasonic gauge, several eddy current proximity gauges, and additional pachometers will be used with the new statistically based acceptance specifications to reduce over-all construction costs.
10-9	Res. Results Digest 48	U. of Minnesota and Minnesota Dept. of Hwys.	In seminars conducted throughout Minnesota to train city and county personnel in use of the pavement surface condition rating system.
11-1(6)	Report 92	New Mexico State Hwy. Comm.	In settling negotiations for purchase of an airport.
11-3	Report 56	Indiana State Hwy. Comm., Land Ac. Div.	Rated as "excellent." Requested extra copies for use in development of new work in area of responsibility.
		Illinois Div. of Hwys., Bur. of Rt.-of-Way	Most of the principles set forth have been in practice. Land Economic Study unit will conduct 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 Dept. of Transp., Bur. of Design	Findings have been found useful, and practice has been modified to conform with them.
	Report 147	AASHTO	Fatigue specification recommendations were adopted in total in the 1974 Interim AASHTO "Standard Specifications for Highway Bridges."
		American Railway Engineering 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.
13-1	Report 26	Delaware State Hwy. Dept.	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 Dept. of Hwys.	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 Hwy. 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

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			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.
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 Dept. of Hwys.	In evaluating acceptability of the Department's design criteria and standards.
	Report 115	Illinois Dept. of Transp., Bur. of Design	Findings have been found useful, and practice has been modified to conform with them.
	Report 118	New York State Dept. of Transp.	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 Dept. of Transp.	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 square miles 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 Dept. of Transp.	Channel design procedure applied to ditches along the Lake Wissota—Cadott Road in Chippewa County. These were previously subject to erosion, but none has occurred since use of riprap according to the procedure.
		Kansas State Hwy. Commission	As basis for publication, "Design of Stable Roadside Channels."
		Minnesota Dept. of Highways	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 State Dept. of Hwys.	Method to size riprap protection included in Ch. 8 of Design Manual.
	Report 108 and agency final report draft	Hydraulics Branch, Bridge Division, FHWA	As source documents for "Stable Channel Designs"; design procedures for riprap linings developed principally from Report 108.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
15-2	Report 108 and agency final report	Consultant, Madrid, Spain	Riprap design procedure applied to channels along motorways in Spain.
15-4	Report 136	Indiana State Highway 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 Engrg. and Opers.	Input (with Report 20, Proj. 5-4) to the 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.
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."
17-1	Report 79	Robley Winfrey	In development of a 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.
17-2A	Agency final report	South Dakota Dept. of Transportation, Div. of Hwys.	To assist in evaluating safety improvements accomplished under on ongoing safety program.
19-2(4)	Report 131	Office of Research and Development, FHWA	As a primary reference in training courses on Managing Highway Maintenance.
19-3	Report 141	Natl. Inst. for Road Research, South Africa	As source document in investigating certain aspects of vehicle sizes and weights on South African highways.
20-1	(HRIS)	Many diverse agencies	The Highway Research Information Service is known to be used widely by a number of organizations in addition to state highway departments. Recognition has been given to the periodic issues of *Highway Research in Progress* as being very useful and of great value to many other governmental agencies.
20-2	Report 55	Illinois Div. of Hwys., Bur. of Res. and Devel.	A committee within the Illinois Highway Research Council, having the assignment of developing a system of establishing research priorities for the Division's program, 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 4	California Div. of Hwys.	Serves as a basic document in the continuing development of Division practices and procedures to cope with the bridge deck deterioration problem. Also is used as a guide for those lines of research that will yield the highest return.
		U.S. Dept. of Transp.	In preparation of *Instructional Memorandum 40-2-70*.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		New Mexico State Hwy. Dept.	In revising the Department's *Bridge Construction Manual.*
	Synthesis 5	Center for Public Works Studies and Experimentation (Spain)	Translated into Spanish as an "Information Bulletin" of the Transport and Soil Mechanics Laboratory.
		Louisiana Dept. of Hwys.	As procedural guide to emergency measures to contain and/or control scour at bridge sites.
	Synthesis 7	92nd Congress, 1st Sess.	See Project 1-12.
	Synthesis 11	AASHTO	As a text in Highway Management Course (conducted by the Highway Management Institute at the Univ. of Mississippi).
	Synthesis 14	Texas Hwy. Dept.	Recommended to District offices as a reference to answer skid-resistance questions from both Departmental and non-Departmental personnel.
	Synthesis 18	Texas Hwy. Dept. and Texas Div., FHWA	As background information in plan preparation, plan review, construction supervision, construction inspection, and maintenance activity.
20-6	Res. Results Digest 11	Maryland State Roads Comm.	In a case before the September 1969 term of the State Court of Appeals.
	Res. Results Digest 11 and others	Colorado Dept. of Hwys.	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	Secretary of Transportation	Included in toto in 1970 Annual Report to the Congress in respect to progress made in the 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. Results Digest 25	Univ. of Wisconsin, Dept. of Engineering	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.
20-12	Agency final report	FHWA	In preparation of a "Handbook on Air Pollution for Construction and Maintenance."
22-2	Res. Results Digests 43, 53	California, Michigan, and states in FHWA Region 4	To specify breakaway cable terminals for both guardrails and median barriers on new installations.
		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."

* Project titles, as well as project status, are given in Table 5. Publication titles are given in Tables 7 and 9.

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 20-3, "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.

PERSONNEL

Robert E. Spicher, formerly a transportation planner with the Comsis Corporation in Washington, D.C., joined the staff of the National Cooperative Highway Research Program on March 1, 1975, as a Projects Engineer. Mr. Spicher will be working on the administration and supervision of a number of research projects in the areas of traffic and transportation.

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

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

He is a graduate of Drexel Institute of Technology and the Yale Bureau of Highway Traffic. He held membership in the Transportation Research Board and is now a member of the American Society of Civil Engineers, and the Institute of Traffic Engineers.

David K. Witheford, formerly Projects Engineer on the staff of the National Cooperative Highway Research Program, was named Assistant Program Director of NCHRP on March 1, 1975. In this capacity, Mr. Witheford will be responsible for assisting NCHRP Director Krieger W. Henderson, Jr., in all administrative and technical matters arising from day-to-day NCHRP management and will supervise the program when necessary. Mr. Witheford was Technical Director of the Eno Foundation before joining NCHRP in January 1973.

Born in Sheffield, England, Mr. Witheford graduated from Swarthmore College with a Bachelor's Degree in Civil Engineering, and is also an alumnus of Yale University's Bureau of Highway Traffic.

He was associated with the Delaware State Highway Department from 1949 until 1960, becoming Planning Engineer in 1957, in which capacity he supervised all Highway Planning Survey staff. In 1960 he was appointed Assistant Study Director of the Pittsburgh Area Transportation Study, leaving two years later to become a research associate in Yale University's Bureau of Highway Traffic.

Mr. Witheford was self-employed as a traffic and transportation consultant from 1965 until 1968, during which time he worked on several NCHRP projects.

He joined the Eno Foundation in 1968. As Technical Director, he was responsible for the technical program of the Foundation, for the production of *Traffic Quarterly* magazine, for research as needed, and for technical responses to international requests for information on transportation-related subjects.

He is the author (with George E. Kanaan) of "Zoning, Parking, and Traffic" and has written numerous technical reports, papers, and magazine articles. He is active in many professional and civic organizations.

Edythe T. Crump joined the National Cooperative Highway Research Program staff on April 15, 1975, as Assistant Technical Editor. Prior to joining NCHRP, she engaged in free-lance technical editing including the forthcoming three-volume treatise on Highway Law being developed under NCHRP Project 20-6.

A graduate of Texas Southern University, Houston, Mrs. Crump was employed in the technical publications support group at NASA's Johnson Spacecraft Center in Houston. Additional technical editing experience includes works for the Center for the Biology of Natural Systems at Washington University (St. Louis) and the American Petroleum Institute.

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 Gnidelines 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 Structnres (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
51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00

* Highway Research Board Special Report 80.

TABLE 7 (*Continued*)

Rep. No.	Title, Project, Pages, Price
52	Measnrement 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
105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00

TABLE 7 (*Continued*)

Rep. No.	Title, Project, Pages, Price
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). —— ——
162	Methods for Evaluating Highway Safety Improvements (Proj. 17-2A), —— ——

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
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), —— ——

TABLE 8

UNPUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM [a]

PROJECT SUMMARIES IN *SUMMARY OF PROGRESS REPORT* FOR PERIOD ENDING	
June 30, 1967	1-2, 2-8, 3-1, 6-6, 6-7A, 8-3
June 30, 1968	2-1, 4-1, 4-5
Dec. 31, 1969	12-4
Dec. 31, 1971	3-16
Dec. 31, 1972	9-2, 11-1(4), 11-1(7), 11-1(11), 20-8, 22-1
Dec. 31, 1973	3-12
Dec. 31, 1975	12-1/12-6, 15-2

[a] See Table 5 for project titles. For information on obtaining copies of research agency reports write to University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48103.

TABLE 9

NCHRP RESEARCH RESULTS DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE
3 [b]	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act
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
14	12-3	Waterproof Expansion Joints for Bridges
19 [b]	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968
20 [b]	19-1	Budgeting for State Highway Departments
22 [b]	20-6	Valuation in Eminent Domain as Affected by Zoning
25 [b]	20-6	Federal Environmental Legislation and Regulations as Affecting Highways
30	4-7	Fatigue Strength of High-Yield Reinforcing Bars
31 [b]	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way
32 [b]	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970
35	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices
39 [b]	20-6	Legal Effect of Representations as to Subsurface Conditions
40 [b]	20-6	Appeal Bodies for Highway Relocation Assistance
41 [b]	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases
42 [b]	20-6	Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation
43	22-2	Evaluation of Breakaway Cable Terminals for Guardrails
45 [b]	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned
46	3-18(1)	Control Logic for Traffic Signal Networks
47 [b]	20-6	Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation
48	10-9	Surface Condition Rating System for Bituminous Pavements
51	3-18(2)	Traffic Control in Oversaturated Street Networks
53	22-2	Development of a Breakaway Cable Terminal for Median Barriers
54 [b]	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation
55 [b]	20-7	Side-Friction Factors in the Design of Highway Curves (Task 4)
56	12-11	Waterproof Membranes for Protection of Concrete Bridge Decks
57	4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases
58	9-4	Minimizing Premature Cracking in Asphaltic Concrete Pavement
59	12-15	Classification of Welded Bridge Details for Fatigue Loading
60	12-12	Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings
61	1-12(3)	Wear-Resistant and Skid-Resistant Highway Pavement Surfaces
63	10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position
65	12-10	Design of Bent Caps for Concrete Box Girder Bridges
66	12-15	Nondestructive Methods of Fatigue Crack Detection in Steel Bridge Members
68 [b]	20-6	The Meaning of Highway Purpose
69	3-7	Establishment of Standards for Highway Noise Levels
72	1-14	Recommended Modification of Superelevation Practice for Long-Radius Curves
73	4-7	Fatigue Strength of High-Yield Reinforcing Bars
74	10-10	Electroslag Weldments in Bridges
75	21-2, 21-2(2)	Development of Prototype Soil Moisture Sensors
76 [b]	22-3, 22-3A	Field Evaluation of Vehicle Barrier Systems
77 [b]	20-7	Earth-Berm Vehicle Deflector (Task 3)
78	3-20	Traffic Signal Warrants—A Bibliography
79 [b]	20-6	Personal Liability of State Highway Department Officers and Employees
80 [b]	20-6	Liability of State Highway Departments for Design, Construction, and Maintenance Defects

[a] See Table 5 for project titles. Numbers missing from the series have been superseded by published reports. Digests are provided at a nominal cost depending on quantity. Make request to Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D. C. 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 will not be published in the regular NCHRP series, but a summary was included in the "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967.* A paper on this work has also been 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 has been 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
Effective Date:	February 1, 1974
Completion Date:	April 30, 1976
Funds:	$250,000

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 verify 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 to be 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 to be considered are:

(a) Cracking from repetitive traffic loading.

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

It is anticipated that the development of implementable structural subsystems will involve the following tasks:

1. Development of new or modified methodology, including appropriate computer programs, needed to integrate the various available analysis techniques into workable structural subsystems. The subsystems should be modular in form to permit a choice of analysis techniques for each distress mode.

2. Development, where required, of simplified test procedures for appropriate materials characterization needed for incorporation into the structural subsystems.

3. Incorporation into the structural subsystem concepts that account for observed variations in material properties, traffic, and environmental factors.

4. Verification of the ability of the structural subsystems to evaluate specific structural designs, such as those produced by other procedures, including comparisons of the evaluations using various subsystem components.

Research is proceeding in accordance with the research plan. Damage models are being developed for the three distress modes being considered. Emphasis is being placed on such practical considerations as computer capability, availability of input data, and material testing requirements.

Project 1-11 FY '68

Evaluation of AASHO Interim Guides for Design of Pavement Structures

Research Agency:	Materials Research & 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 exists 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, Washington, D. C.

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, are 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 essential findings of the study have been published as NCHRP Research Results Digest 50.

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: September 30, 1977
Funds: $199,955

Roadway accidents are known to involve extremely complex interrelationships between vehicles, drivers, traffic, weather, roadway geometry, and pavement surface characteristics. Accidents, for whatever cause, can result in death, human suffering—either physically or emotionally—and costly annual property damage. Because of the magnitude of the problem, extensive research in all its aspects has not only been conducted to date but also is continuing with the objective of bringing about still further improvements in highway safety.

One area of continuing research is that of pavement skid resistance. Although the inherent complexities in this area have long been recognized, the establishment of universal minimum pavement surface skid resistance (Skid Number) requirements is often considered to be the primary approach to solution of the problem. However, realistic skid resistance requirements should be based on actual traffic needs at each particular site. Research conducted under NCHRP Project 1-12, as described in *NCHRP Research Results Digest 50*, "Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites," indicates 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 is needed to provide highway agencies with additional tools for determining types of corrective actions needed at high or potentially high accident sites.

This project is directed toward the examination of methods 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 is to provide highway agencies with practical methods needed for determining where longitudinal acceleration demand exceeds available tire-pavement interface friction. It is anticipated that these methods will provide a basis for relating specific acceleration demand at particular sites to other factors such as geometric design features, driver behavior, tire frictional parameters, climate, traffic and pavement surface characteristics.

The accomplishment of the over-all objective is expected to involve the following tasks:

1. Improve, refine and simplify the data collection system developed under NCHRP Project 1-12, with special emphasis on improved service durability of the detection apparatus under heavy traffic and adverse weather conditions.
2. Calibrate the improved data collection system (a) by conducting field tests using accelerometers installed in automobiles or (b) by comparable direct methods.
3. Conduct field studies under dry- and wet-weather conditions to determine the relationships between longitudinal acceleration values, traffic conflicts, and frequency of skidding events. This should include a mathematical analysis to provide statistically valid results.
4. Prepare a procedural manual for implementation of the system, including detailed descriptions of the equipment, measurements, analyses, and limitations.

Research is in progress in accordance with the research plan.

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.

Research has been completed and the essential findings published as NCHRP Research Results Digest 49.

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 Invests.: 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 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 specific objectives of this project are:

Phase I:

1. Identify and evaluate, on the basis of previous and current research and experience, any procedures intended to result in the construction of improved wear- and skid-resistant pavement surfaces and the correction of worn or polished surfaces.
2. Develop recommendations for the implementation of the procedures identified under objective 1 that are found to be suitable for immediate practical application.
3. Identify and describe possibilities for new and innovative procedures for the construction of highly wear- and skid-resistant pavement surfaces and for correction of worn or polished surfaces.
4. Prepare recommendations for an experimental program to evaluate the promising procedures identified under objective 1 and the new and innovative procedures identified under objective 3 that are found to need further study.

Phase II:

5. Conduct the experimental program prepared under objective 4.
6. Develop recommendations for the implementation of the procedures found by the experimental program to be suitable for practical application.

Phase I of the study has been completed with reasonable accomplishment of objectives, and the interim report covering this phase has been reviewed and approved by the project advisory panel. Tentative performance criteria for procedures and techniques intended to improve wear resistance and skid resistance of pavement surfaces have been prepared. Ten pavement systems have been identified as being suitable for immediate practical application to correct worn or polished surfaces and for construction of new wear- and skid-resistant surfaces. These are described and recommendations for their use are included in the interim report. The essential findings from the interim report pertaining to pavement systems suitable for immediate application have been published as NCHRP Research Results Digest 61.

The interim report also contains a list of candidate pavement surfaces in need of further evaluation to determine their suitability to resist wear and polishing and a recommended experimental program for the conduct of Phase II of the study. As the result of advisory panel review, the experimental program has been revised. The primary feature of the approved experimental program is a simulated field evaluation of 36 pavement surfaces exposed to both conventional and studded tire traffic in the Amoco Oil Co. circular test track. The experimental work has been completed, the data analyzed, and the final report submitted. It is in the review stage.

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.

Research has been completed, and the final report is in the NCHRP editorial and publication process.

Project 1-13(2) FY '72

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

Research Agency:	University of Michigan
Principal Invest.:	John A. Green, Jay S. Creswell, Duane 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 final report is in the NCHRP editorial and publication process.

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 essential findings of the study have been published as NCHRP Research Results Digest 72, "Recommended Modification of Superelevation Practice for Long-Radius Curves."

The project report is in the NCHRP editorial and publication process.

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.

The general objective of this project was to aid in overcoming the problems that have been noted so that the potential of CRCP can be more fully realized. The specific objectives were to:

1. Review presently available methods for designing continuously reinforced concrete highway pavements to determine those design variables that require further refinement or inclusion.
2. Utilize in-service pavements and laboratory studies to relate design variables to performance considering traffic loads, deflections, material properties, environment, and slab support.
3. Develop more precise design procedures for continuously reinforced concrete pavement systems.

Project work included general condition surveys of CRCP performance in a large group of states and diag-

nostic 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 project report will not be published in the NCHRP series; however, the essential findings will be published in the NCHRP Research Results Digest series. Copies of the agency report are available on a loan basis upon request to the Program Director.

Project 1-16 FY '74

Evaluation of Winter-Driving Traction Aids

Research Agency: Pennsylvania State Univ.
Principal Invest.: Prof. W. E. Meyer
Effective Date: June 3, 1974
Completion Date: June 2, 1977
Funds: $300,000

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.

The objectives of this project are to:

1. Select methods and develop criteria to be used as a standardized procedure for effectively evaluating winter-driving traction aids for passenger cars, multi-purpose passenger vehicles, and light trucks with regard to:
   (a) Vehicle performance (traction, braking, control).
   (b) Pavement surface characteristics (physical properties of ice and snow).
   (c) Bare-pavement wear.
2. Conduct an experimental program to evaluate the performance of available winter-driving traction aids on ice and snow, using the standardized procedure for evaluating vehicle performance.
3. Provide a limited evaluation of any possible adverse effects of these aids on vehicle performance on other than snow- and ice-covered pavements.
4. Prepare an over-all cost-benefit type of ranking for winter-driving traction aids, singularly and in combinations where appropriate, considering such factors as performance on snow and ice, pavement wear, economics, user convenience, practicality, durability, and reliability.

Research is in progress. Standardized procedures for evaluating the performance of winter-driving traction aids have been selected. The experimental program is being conducted on an indoor ice skating rink, outdoor ice surfaces, and outdoor snow-covered surfaces.

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 will not be published in the NCHRP report series; however, a summary is included in *NCHRP Summary of Progress Through June 30, 1968.*

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 Commission for cargo vehicles and for intercity buses. Detailed methodology of the cost-savings model is presented so that other researchers can make similar estimates under known local conditions. Also, an updating technique has been developed and the 1962 costs were projected to 1965 utilizing equipment costs and driver 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 Dates:	June 1, 1963	June 1, 1965
Completion Dates:	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 Dates:	July 1, 1967	Aug. 11, 1969

Completion Dates:	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 will not be published in the NCHRP

report series; however, a summary is included under "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967.*

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 have 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

Highway User Economic Analysis

Research Agency: Stanford Research Institute
Principal Invest.: D. G. Andersen
Effective Date: April 1, 1974
Completion Date: October 31, 1975
Funds: $90,074

There is continuing need for simple and practical methods for analyses of highway improvements based on costs and benefits to road users. Such analyses can provide economic factors bearing on the choice between alternative locations or designs for highway improvement projects. These cost and benefit analyses are needed, together with other major factors (social and environmental effects, funding programs, etc.) to arrive at project decisions for a given section of highway.

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 will include a selected analysis methodology based on sound economic theory and 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 were developed 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.

Current practice was reviewed in the literature and through questionnaires to all state transportation and highway agencies. An unpublished summary is contained in a report entitled "Current Practice in Highway User Economic Analysis," available on loan by request to NCHRP.

The project report is in the NCHRP editorial and publication process.

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 Dates:	Feb. 15, 1963	July 2, 1964
Completion Dates:	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, a summary of the report is available in *Highway Research Record No. 211* and also in the *NCHRP Summary of Progress to June 30, 1967.*

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 inter-vehicular 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 tri-light system denoting brake and accelerator action and an acceleration information display of horizontal rows of green and red lights to indicate the magnitude of the vehicle's acceleration or deceleration. Studies of lane changing decisions were also made. Taxonomics 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 Dates:	March 1, 1963	July 1, 1965
Completion Dates:	March 31, 1965	Dec. 15, 1966
Funds:	$78,517	$49,474

This study was directed toward evaluation of 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 advisory 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 Dates:	3/1/63	7/1/66	8/1/68
Completion Dates:	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

This project was for the purpose of identifying 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 Dates:	2/1/64	10/14/68	4/1/71	9/1/72
Completion Dates:	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 NCHRP Program Director.

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

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

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

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

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

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

The research has been completed and the project final report has been provided in six volumes. Other 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, and copies of the computer program can be supplied upon request to the Program Director. The reports, which are in the editorial and publication process, can also be provided on a loan basis.

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 Dates:	Dec. 1, 1963	Apr. 1, 1965
Completion Dates:	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, and where appropriate highway design criteria were suggested.

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

The final report has been published as:

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

Project 3-11 FY '67

Optimizing Street Operations Through Traffic Regulations and Control

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

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

A base-condition traffic operations profile was established for each city and used for subsequent comparisons as changes in traffic regulations and control were implemented and evaluated through a series of test stages. Operational techniques ranging from relatively simple, but effective, signal timing to extensive left-turn prohibitions and one-way operations, were evaluated. Angle parking, no-stopping towaway, and unbalanced traffic flow were also evaluated throughout an area of urban streets. Average speeds, stops, delays, and a variety of other measures were used to determine the relative magnitude of operational 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	4/1/68	3/29/71
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 will not be published in the NCHRP report series; however, a summary of the report is included in the *NCHRP Summary of Progress Through 1973*.

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:	$149,916

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 NCHRP.

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, a summary

of the Phase I report is included in *NCHRP Summary of Progress Through 1971*.

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 is in the NCHRP editorial and publication process. Copies of the report are available on a loan basis upon request to the Program Director.

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 itself to 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."

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	Nov. 30, 1975
Funds:	$323,998	$49,912

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 effort is to study traffic flow and control interaction, and develop an advanced control concept, strategy, and computer program. The research is to include development of an operational control program for calculating offset patterns for a network of signalized intersections that has the capability for independent and variable split adjustment. The program is to be tested and evaluated on an installed system with actual traffic and be applicable to both undersaturated and oversaturated conditions.

The research has proceeded in three phases: Phase I, planning and initial evaluation; Phase II, control program coding and software integration; Phase III, implementation and evaluation. A final report describing the ASCOT program system has been submitted and is available on a loan basis upon request to the NCHRP Program Director.

Additional research is in progress to make improvements to the offset-optimization logic and to test the performance of the system with different levels of network traffic volume surveillance. To accommodate this work the contract is to be extended.

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; 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 is in the NCHRP editorial and publication process. During this period, copies of the report are available on a loan basis upon request to the NCHRP Program Director.

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: July 31, 1976
Funds: $100,000

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 are 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. Many other factors undoubtedly have an important effect on control system requirements.

The research effort is to consist of the following major tasks:

1. Identify and define the range of traffic surveillance and control system alternatives to which the cost-effectiveness methodology is to be applied. This range should be as broad and flexible as possible to accommodate the evaluation of alternative control schemes that may be developed in the next few years in addition to those already in existence. The alternatives should include at least nonresponsive time-of-day control; selection of prestored timing plan to match traffic patterns; fully adaptive real-time traffic-responsive control; and on-line timing plan optimization, with or without short-term traffic-responsive variable-split control.

2. Develop and describe in detail a systematic cost-effectiveness evaluation methodology. The approach should be through a "total-system cost analysis" concept that accounts for all pertinent elements of cost, including at least capital costs; operations and maintenance costs (including those for all equipment, facilities, personnel, and administrative functions); traffic operations costs (directly and indirectly incurred by road users); and other community costs or impacts.

3. Exercise the cost-effectiveness methodology for more than one sample problem of signalized network design in order to demonstrate its usefulness and practicality.

4. Prepare a final technical report documenting all the procedures and results of the research project, and develop a users' manual thoroughly instructing traffic engineers in the application of the cost-effectiveness methodology.

Through December 1975, the research agency had completed the first of the tasks above and had assembled all the information needed for developing the methodology.

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 is in the NCHRP editorial and publication process. Copies of the agency draft are available on a loan basis upon request to the NCHRP Program Director.

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	July 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.

A report on the work completed through early 1974 has been submitted and is available on a loan basis upon request to the Program Director of NCHRP. A continuation of the research to extend the coverage of the warrants to additional intersection configurations is in progress.

Project 3-21 FY '74

Motorist Response to Highway Guide Signing

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

Much recent research has dealt with evaluating the effects of guide signs (i.e., those described in Sections 2E and 2F of MUTCD) on the motorist. However, the collective value of this research has been limited by a lack of validated measures of driver response to various signing alternatives. There is a critical need for the development and validation of new measures, as well as validation of those that have been used in the past. The validated measures are required so that: (1) sign evaluation studies conducted by diverse organizations will have a common base and will be interpretable in terms that are widely acceptable, and (2) signing standards can be developed on the basis of definitive research results.

The objectives of this project, which will be conducted in two phases, are:

1. To review and describe all known measures of driver response to guide signing.
2. To suggest and describe additional measures that may have practical application.
3. To critique candidate measures and describe their interrelationships.
4. To identify the most promising measures and suggest methods of validating each.
5. To proceed in Phase II with the development and validation of a method, or methods, to evaluate motorist response to guide signing.

The research has been completed, and the final report on the project is in the review stage. Copies of the Phase I report, submitted in 1974, are available on a loan basis upon request to the NCHRP Program Director.

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:	$198,590

A considerable investment will be made in ramp control systems during the next decade by many governmental units that are now beginning to undertake their design and construction in order to reduce accidents and delay. However, there are not yet adequate design guidelines for installing and operating such systems. Such guidelines are currently required to facilitate the selection of the most cost-effective ramp control systems and to prevent their early obsolescence.

The objectives of this project, therefore, 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. 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.

Research activities included: (a) visits to a number of ramp-metering installations; (b) study of control device configurations, selection criteria, and system hierarchies; (c) development of a user-oriented manual to assist traffic engineers in the selection of ramp control systems. The user manual and the research report are in the review stage.

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 7, 1976
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 is the preparation of such guidelines for optimum traffic control signal design configurations at intersections and mid-block crossing locations. The optimizing process must at least include considerations of costs and user response in terms of observance, safety, and efficiency. The details of operation of traffic control signals are felt to be beyond the scope of this project. As a result, operations need only be considered to the extent that special configurations may be required for special operation techniques, such as separate left-turn phases.

The research will include at least 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.

An interim report describing several analytical and accident studies completed through mid-1975, and also containing an annotated bibliography, has been submitted. Copies may be obtained on a loan basis upon request to the Program Director of NCHRP.

Project 3-24 FY '75

Determine the Luminous Requirements for Retroreflective Highway Signing

Research Agency: Highway Safety Research Institute
University of Michigan
Principal Invest.: Dr. Paul L. Olson
Effective Date: September 1, 1974
Completion Date: November 30, 1976
Funds: $100,000

This project is being conducted in two phases, with the following objectives:

Phase I

1. Review and summarize the literature and research findings relevant to the relationship between reflectivity and sign legibility. This review is to consider factors such as (a) sign characteristics, (b) sign location, (c) ambient illumination conditions, (d) traffic characteristics, (e) road geometry, (f) vehicle headlighting variables, (g) environmental conditions, (h) driver characteristics.

2. Survey available retroreflective materials and describe their characteristics on the basis of available information.

3. Summarize current traffic engineering practices in regard to use of retroreflective signing materials.

4. Identify and describe problems pertinent to this investigation arising from activities conducted in Objectives 1, 2, and 3; specifically, (a) outline the information necessary to specify the luminosity values needed for proper traffic engineering decisions, (b) indicate those problem

areas in which the necessary information is still lacking, (c) rank these problem areas in order of their relative criticality to proper conclusion of the current investigation, and (d) indicate the relative probability of obtaining research solutions to these problem areas within the time and budget constraints of the current investigation.

5. Prepare a Phase I report detailing accomplishments to date and describing a comprehensive research plan for Phase II to solve each of those problems identified as being both critical to the investigation and researchable within time and budget constraints.

Phase II

1. Conduct the approved field and/or laboratory research in order to develop the ranges of acceptable luminosity values to include:

(a) A laboratory investigation to determine the effect of background and legend luminance and other variables on visibility distance.

(b) A laboratory investigation to equate the photometric and legibility characteristics of button and sheeting legend materials.

(c) Development of a computer model to predict legibility distance of various combinations of signing materials under a wide variety of roadway conditions.

(d) A field study to validate the computer model, by comparing actual and predicted visibility distances to signs installed along roads.

2. Present the values in a form usable by the engineer in conducting a signing program.

Phase I is completed and the research team is now conducting the laboratory experiments and validation studies.

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:	September 16, 1977
Funds:	$260,000

The current highway accident toll in the United States is approximately 50,000 deaths, 2 million injuries, and more than $10 billion in costs for some 17 million accidents annually. Even with the best economic conditions, funds are invariably insufficient to finance all improvements needed to reduce this toll. It is imperative, therefore, to avoid design standards that may not be cost effective in reducing accidents.

To maximize accident reduction with the limited available funds, design standards should be flexible. The design should be tailored for each project, route segment, or subsystem to produce significant accident reductions per dollar expended. In this fashion, the cumulative accident reduction of many such improvements will greatly exceed the reduction possible from a relatively few improvements designed according to a rigid set of high standards that ignore costs.

Currently available data provide gross measures of the over-all safety and service benefits of highway facilities. However, the data are limited or lacking to evaluate the standards for specific situations and design elements in terms of accident frequency and severity. What is needed is an optimization of geometric design standards for highway facilities, both urban and rural, that reflects a regard for economy without sacrificing traffic safety. Such standards could be applied to the upgrading of existing highways, which will constitute the bulk of the highway construction program in the foreseeable future.

This research project covers applicable design elements on various highway facilities, including both high and low volumes and urban and rural conditions. The general objectives are: (1) to quantify the effect of varying the magnitude, size, or dimension of each roadway and roadside design element (and/or combination of elements where they are interactive) on accident frequency and severity; and (2) to develop methodology to measure the cost-effectiveness of the various levels of each element.

Because of the large number of variables involved in the geometric cross section and longitudinal design, as well as environmental and traffic factors, it is realized that all possible factors and combinations of factors cannot be considered within the time and funding constraints for this project. Therefore, this research is being conducted in two phases.

Phase I consists of an exploratory effort to identify those areas that offer promise as the most fruitful to pursue in more detail. The probable gross effects of various design elements on accidents and costs are being assessed, and those elements with greatest promise will receive further study in Phase II. An interim report summarizing the results of Phase I is being prepared.

Phase II will consist of: (1) quantifying the effect on accident frequency and severity for individual design elements and any interactions thereof and (2) developing methodology for, and examples of, cost-effectiveness analyses. Developing values for accident costs, as well as construction, maintenance, and operational costs, will not be a task for this project.

Westat, Inc., and Auburn University are serving as subcontractors on this project.

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.

Research has been completed. The project report will not be published in the regular NCHRP Report series, but a summary is included in the *NCHRP Summary of Progress Through June 30, 1968.*

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 Evaluatiug 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 Dates:	Mar. 1, 1963	July 1, 1965
Completion Dates:	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 Dates:	Mar. 25, 1963	July 1, 1965
Completion Dates:	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 iu 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.

Research has been completed. The project report will not be published in the regular NCHRP report series, but a summary is included in the *NCHRP Summary of Progress Through June 30, 1968.*

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 or Phases I and II into a single final report. A total of 353 fatigue tests was conducted in the two phases of work.

The study has been completed. On the basis of the ob-

served behavior, a fatigue design provision was developed for deformed reinforcing bars suggesting a limitation on the service load stress range.

The final report is in the NCHRP editorial and publication process. The essential findings have been published in NCHRP Research Results Digest 73, "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 Institote
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 are:

1. To evaluate current and proposed procedures and criteria for the setting of density standards to control compaction during construction of granular base and subbase courses.
2. To develop new or revised procedures and criteria, whose employment would permit the setting of more appropriate density standards.
3. To illustrate, from available published and unpublished data, specific examples of inadequate standards, the consequences of such inadequacy, and the manner in which the new or revised procedures and criteria would have avoided such consequences.
4. To illustrate, with respect to specific cases where satisfactory pavement performance has been obtained, that the new or revised procedures and criteria would have yielded equally 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. Development of design procedures or acceptance plans to control compaction during construction is not included.

The research program conducted by the agency to meet these objectives included:

1. A literature survey.
2. An information survey of all State highway departments, to determine current practice regarding granular base and subbase compaction specifications.
3. Interviews with personnel of 30 State highway departments.
4. Laboratory tests involving numerous combinations of the following parameters: (a) six methods of compaction, (b) four aggregate types, (c) six gradations and, (d) two moisture conditions. Four replicates were tested for each combination of parameters.
5. Prototype tests in large-scale laboratory test pits (8 ft x 12 ft in plan view) with a 12-ton vibratory roller to obtain the "ultimate" density.

Research has been completed and the final report is in the NCHRP editorial and publication process. The essential findings from this final report have been summarized in NCHRP Research Results Digest 57, "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 in 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 is in the editorial and publication process.

The objective of the Phase II research is to provide field verification of, or suitable modifications thereto, the test system tentatively proposed under Phase I for predicting the susceptibility of asphaltic concrete mixtures to moisture damage. Cooperative arrangements have been made with seven state highway and transportation agencies and with Region 10 of the Federal Highway Administration for experimental construction, testing, and performance observations over a five-year period to evaluate the proposed test system. Experimental construction and research were started in the fall of 1975 by some of the participating agencies; the remainder are expected to begin active participation during the 1976 construction season.

Project 4-9 FY '69

Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices

Research Agency:	Utah State Highway Department	
Principal Invest.:	Dale E. Peterson	
Effective Date:	Oct. 1, 1968	Oct. 1, 1972
Completion Date:	June 30, 1971	Dec. 31, 1977
Funds:	$93,494	$125,000

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.

Phase I of this project, through a review and analysis of existing information and an extensive laboratory testing program, has successfully provided urgently needed tentative guide specifications, inclusive of performance criteria, for preformed elastomeric joint seals for use in portland cement concrete pavement joints. This information was reported in NCHRP Research Results Digest 35, "Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices" (Feb. 1972). The primary experimental program for Phase I was conducted by the Utah State Department of Highways, with analytical assistance from the University of Utah.

The tentative guide specifications provided by Phase I are well suited to interim service. For full acceptance, a field research program is needed to validate the soundness of, or provide appropriate modifications for, the tentative specifications that have been established. This program is being conducted as Phase II of the project.

In Phase II, an experimental program of field study has been designed and instituted to test the tentative specifications. Installation of preformed elastomeric sealers in sawed transverse joints on construction projects in seven states has been accomplished. Planning, supplemental specifications, and evaluative observations during the installations were provided as part of the project effort. Samples of the sealers were retained at the construction stage and subjected to laboratory test. Samples are also being removed periodically following construction and tested in the

laboratory. Force-deflection tests are the primary method of sample evaluation. Observations of field performance are being made at the time of post-construction sampling. Six-, 12-, 18-, and 24-month samplings and observations following construction have been completed. An interim report containing findings after two years of exposure of the experimental sections has been received and is undergoing review.

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, have been 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 has involved the following tasks:

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 final report is in the NCHRP editorial and publication process.

Project 4-11 FY '75

Buried Plastic Pipe for Drainage of Transportation Facilities

Research Agency: Simpson Gumpertz & Heger
Principal Invest: Frank J. Heger
Effective Date: September 16, 1974

Completion Date: March 15, 1977
Funds: $200,000

A number of pipe products, made of plastics as defined in ASTM D883, have become available to the transportation industry within the past few years and appear to have good potential for economical use as underdrains, storm sewers, culverts, and other drainage structures. However, due to the lack of experience with these products in transportation facilities, use in this field has been limited. Understandably, there has been a reluctance to use them in place of, or as alternates to, more conventional pipe products whose in-service behavior has been established by many years of experience in a wide range of applications. Accordingly, it is necessary to undertake an evaluation of the theoretical considerations and field performance of buried plastic pipe for use in transportation facilities.

Objectives:

The over-all objective of this project is to develop and evaluate design, installation, and performance criteria for the use of buried plastic pipe products in transportation facilities.

The specific objectives of Phase I are to:

1. Identify the types, sizes, and physical and chemical characteristics of plastic pipe products currently available and considered suitable for use as underdrains, storm sewers, culverts, and other drainage structures.
2. Based on available research and experience with buried plastic pipe: (a) evaluate the current state of the art; (b) appraise the performance with regard to abrasion, frost action, temperature variations, and other environmental considerations; and (c) prepare tentative guidelines for recommended design and installation procedures.
3. Outline an experimental program, (intended to be performed under Phase II) to improve the understanding of (a) the time-dependent soil-structure interaction of buried plastic pipe subjected to earth and live loads and (b) any other performance factors that appear to need further study.

The specific objectives of Phase II are to:

4. Conduct the experimental program outlined in Objective 3, subject to approval by the NCHRP.
5. Analyze and interpret the information obtained from the experimental program, synthesize the data with other available information, and evaluate the tentative guidelines prepared under Objective 2.
6. As part of the final report, prepare a manual on the use of buried plastic pipe for drainage of transportation facilities, with particular attention to permissible loads and deflections, use limitations, material specifications, acceptance tests, construction and maintenance techniques, and inspection criteria.

Phase I has been completed and an interim report containing the findings has been submitted, reviewed, revised, and distributed to the sponsoring agencies.

Phase II of the study has been approved and research is under way.

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 Dates:	Feb. 15, 1963	Feb. 1, 1967
Completion Dates:	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 performauce. 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 Dates:	Mar. 1, 1965 July 15, 1967

Completion Dates:	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 ntilizing 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 was produced describing the results of the research. Loan copies of the film are available from the NCHRP Program Director.

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 research has been completed, and the final report is in the NCHRP editorial and publication process. Copies are available on a loan basis on request to the Program Director.

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 is in the NCHRP editorial and publication process. Prior to its publication, copies of the report are available on a loan basis on request to the NCHRP Program Director.

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 project final report has been accepted for publication and is in the editorial publication process. In the meantime, loan copies are available from the NCHRP Program Director.

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:	$199,627

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."

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 relatedness 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.

Research has been completed. The project report will not be published in the regular NCHRP report series, but a summary is included in the *NCHRP Summary of Progress to June 30, 1967.*

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.

Research has been completed. The project report will not be published in the regular NCHRP report series, but a summary is included in the *NCHRP Summary of Progress to June 30, 1967.*

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 evaluate the specific problems associated with snow removal and ice control operations at interchanges and to recommend methods for alleviating the problems. The investigation has been completed and both physical and operational factors that influence winter maintenance operations at interchanges have been listed in the project report. Design considerations and operational procedures aimed at alleviating the problem have been described in a manual submitted as part of the final report.

The project report has been published as:

NCHRP Report 127, "Snow Removal and Ice Control Techniques at Interchanges."

Project 6-11 FY '71

Economic Evaluation of the Effects of Ice and Frost on Bridge Decks

Research Agency:	Midwest Research Institute	
Principal Invest.:	Robert R. Blackburn	
Effective Date:	Sept. 1, 1970	Sept. 12, 1972
Completion Date:	Nov. 30, 1971	Sept. 11, 1974
Funds:	$50,000	$50,000

Ice or frost on bridge decks while the approach pavements remain ice- or frost-free is a known safety hazard. Although little hard evidence has been presented to indicate the extent of the problem, maintenance practice and research on various preventive or remedial techniques often assumes it to be significant. This project was undertaken to fill a need to quantify the problem as a basis for rational decisions concerning the economics of design and maintenance practices.

Phase I of the project consisted of a literature search, a survey of selected state highway departments, the formulation of a cost-benefit methodology, a preliminary model parametric analysis, the collection of cost data on preventive and remedial techniques in current use, the development of a subsidiary net cost model, the formulation and evaluation of a bridge classification model, and the computation of illustrative examples of the cost-benefit methodology.

The application of the methodology developed in Phase I to sample cases identified data that were lacking. Furthermore, the resulting models were found not to be in a convenient form for ready implementation. Phase II of the project was designed to overcome the deficiencies. The continued research was directed at evaluating and implementing the methodology developed so that it could be used more readily by a highway administrator to determine the added design or extra maintenance cost justified to prevent or remedy ice or frost on bridge decks. The cost-benefit methodology developed consists of a cost model and a benefit model. A bridge characterization model was also developed for predicting the annual number of ice and snow accidents to be expected on a bridge, given various characteristics of the bridge. The use of the methodology and bridge model appears promising; however, anyone wishing to apply the process will need to develop a more precise accident data base with regard to bridge and road surface conditions (frost, localized ice, etc.) for the particular area of interest beyond that now being collected. The data base can be generated using data collection procedures developed in the study.

Research has been completed and the final report is in the NCHRP editorial and publication process.

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 Dates:	Feb. 1, 1964	Apr. 1, 1966
Completion Dates:	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 Dates:	Feb. 1, 1964	May 1, 1965
Completion Dates:	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 weighing vehicles in motion with review and study of existing or new equipment. The ultimate aim was to obtain load magnitudes automatically in a way similar to obtaining traffic volumes by traffic counters.

Franklin Institute's approach to this problem served to complement the studies performed by others rather than to duplicate existing research. The data processing system in block form only was developed on the project. It was planned that no full-scale or field testing would be performed under this contract. Study was primarily given to methods that will allow static weights of the axle to be calculated from a limited number of dynamic load observations.

The methods for estimating the static axle weight from sampled force studied include averaging, dynamic models, the interlacing polynomials, and regression analysis. A preliminary system for the detection and the analysis of weighing vehicles in motion was synthesized.

The project report has been published as:

NCHRP Report 71, "Analytical Study of Weighing Methods for Highway Vehicles in Motion."

Project 7-4 FY '64, FY '65, and FY '67

Factors and Trends in Trip Lengths

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	Alan M. Voorhees	
	Salvatore Bellomo	
Effective Dates:	Feb. 1, 1964	Oct. 23, 1967
Completion Dates:	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 15 to 20 years ago.

A computer program was assembled to assign traffic to a network using four different capacity restraint methods. An analysis of statistical inferences from different network loadings was conducted.

The project report has been published as:

NCHRP Report 58, "Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use."

Project 7-6 FY '66

Multiple Use of Lands Within Highway Rights-of-Way

Research Agency:	Barton-Aschman Associates
Principal Invest.:	Harvey R. Joyner
Effective Date:	February 1, 1966
Completion Date:	February 28, 1967
Funds:	$24,220

Controlled-access highways in urban and rural areas include land which was necessarily acquired to provide space for the present and future safe design and operation of the facility but which is not now used. This project assembled information that illustrates what has been and what might be accomplished with these plots of land in the interest of both the highway user and the adjacent community.

The researchers reviewed the literature and prepared an annotated bibliography on the subject. A questionnaire was sent to the highway departments and several cities in the U.S. as well as abroad to survey existing uses being made of highway rights-of-way. Personal visits to various sites were made to acquire more information on the effects of various uses. Policies and legal requirements were reviewed and recommendations made for the use of land within the highway rights-of-way.

The project report has been published as:

NCHRP Report 53, "Multiple Use of Lands Within Highway Rights-of-Way."

Project 7-7 FY '66

Motorists' Needs and Services on Interstate Highways

Research Agency:	Airborne Instruments Laboratory
Principal Invest.:	Martin A. Warskow
Effective Date:	January 1, 1966
Completion Date:	December 31, 1967
Funds:	$99,267

This project was concerned with the needs and desires of motorists traveling on the Interstate Highway System, how these needs and desires are being satisfied, and what additional service provisions should be made. Legal and financial implications for providing various services were studied.

The researchers analyzed three basic classes of services: emergency services, which include out-of-fuel, mechanical failures, accidents, and medical needs; normal necessities, which include need for fuel, food, lodging, and directional information; and supplemental services, which include information on choice of lodging, fuel, and food facilities as to quality, location, brand, etc.

A national questionnaire was mailed to a sample of registered motorists to determine motorists' desires. Emergency service data were collected from various sources. A series of road trips was conducted in seven states in various parts of the country to experience a variety of the geographic aspects of this study. In each state, the researchers visited the local auto club, the state highway officials, and the state police to obtain various types of data.

The project report has been published as:

NCHRP Report 64, "Motorists' Needs and Services on Interstate Highways."

Project 7-8 FY '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 techniques provide estimates of weekend recreational traffic as measured by numbers of individual vehicles.

The principal development is 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 major contribution of RTPM to the state of the highway planning art is its documentation and treatment of the recreational demand-supply interactions that generate weekend recreational traffic. These interactions are complex, in that recreational participants' final trip destination and timing decisions are based on the specific nature of the recreational activities undertaken, the availability and locations of recreational resources, and the amounts and lengths of recreational time available. RTPM has been designed to provide a high degree of flexibility in terms of user-specified inputs and outputs. Users can specify the geographical area to be covered; the years, seasons, days, and hourly periods for which estimates are to be developed; and the extent and complexity of the highway network incorporated into any analysis. The degree of detail available in the output is limited mainly by the availability of input data describing recreational behavior.

In the most general sense, RTPM provides estimates of

weekend recreational traffic, as measured by numbers of individual vehicles. Output may be more specifically described in terms of user-specified highway parameters and time parameters

Research has been completed except for computer program improvements. The contract termination date will be advanced.

Project 7-10 FY '74 and FY '75

Peak-Period Traffic Congestion

Research Agency:	Reinak-Rosenbloom	
Principal Invest.:	Sandra Rosenbloom	
Effective Date:	Apr. 1, 1974	Apr. 1, 1975
Completion Date:	Mar. 31, 1975	Nov. 15, 1975
Funds:	$49,624	$18,908

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 is 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.

Approaches to ameliorate peak-period traffic congestion have been classified as social, socioeconomic, sociotechnical, and technical. They have been summarized in a state-of-the-art report. Experience with each approach has been described under the following categories: concepts, costs, time frame, funding source, political feasibility, and impact. The unedited agency draft is available at a cost of $8.50. Checks should be made payable to the Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, DC, 20418.

Mutually supportive techniques and incompatible techniques were identified. As a result, eight recommended packages of techniques to ameliorate peak-period traffic congestion were developed. These packages carry the following titles: (1) Work Hour Changes, (2) Pricing Techniques, (3) Restricting Access, (4) Changing Land Uses, (5) Prearranged Ride Sharing, (6) Communications Substitutes for Travel, (7) Travel Engineering Techniques, and (8) Transit Treatments.

To highlight existing deficiencies and knowledge, ten problem statements have been developed.

Research has been completed and the project report is in the NCHRP editorial and publication process.

AREA 8: URBAN TRANSPORTATION

Project 8-1 FY '64

Social and Economic Factors Affecting Travel

Research Agency:	Vogt, Ivers and Associates
Principal Invest.:	Robert S. Vogt
Effective Date:	February 1, 1964
Completion Date:	September 23, 1966
Funds:	$94,558

The purpose of this research was to develop means of estimating intercity travel using known traffic volumes and available economic and social data between selected cities and testing it by application to other pairs of cities between which travel is also known. A review was made of the adequacy of current processes of estimating urban travel using social and economic factors and the applicability of these techniques in estimating intercity travel. This study also researched whether useful and reliable work can be done by using urban transportation study techniques and applying them to other travel areas.

Knowledge gained by this research is useful to transportation planners and design engineers. Extensive use of electronic computers and existing computer programs to extract and classify summarized pertinent origin-destination data from existing studies has been accomplished.

A nationwide network has been produced for trip distribution purposes. More than 3,000 centroids representing each county or county equivalent with basic population, employment, income, bank deposit, and other social-economic information have been assigned. The centroids are connected by links representing the highway system. External O-D data were acquired and processed for 22 cities in Tennessee, Wisconsin, and Missouri. From these data, regression analyses were run to test various equation forms and the correlation between variables, combination of variables, and transformation of variables for total trips and for trips by purpose. The trips predicted from the regression equations have been compared to actual survey trips.

The project report has been published as:

NCHRP Report 70, "Social and Economic Factors Affecting Travel."

Project 8-2 FY '64 and FY '65

Factors Influencing Modal Trip Assignment

Research Agency:	IIT Research Institute
Principal Invest.:	Dr. F. C. Bock
Effective Date:	February 1, 1964
Completion Date:	August 31, 1966
Funds:	$298,033

The intent of this research was to improve methods of assigning urban area traffic to the various modes of travel. It involved the identifying of factors underlying choice of travel mode, the determination of the relationships of these factors, and also the development of a method of analysis and forecasting. Methods were tested and found to be

practicable for use under real-life conditions. Such methods would be applicable in making better trip assignments in urban transportation systems.

The project report contains a survey of existing modal split models, and analysis of five 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 compnted 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, but a summary is included in the *NCHRP Summary of Progress to June 30, 1967.*

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 advisory 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 Dates: April 1, 1965 Aug. 7, 1967

Completion Dates:	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 tarnsportation 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: $99,968

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 are time consuming and costly and have inordinate data requirements. The complexity and expense of these procedures is 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 under network analysis, corridor growth traffic forecasting models, use of work trip 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 is in the NCHRP editorial and publication process.

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 has been completed and the report has been received, but will not be 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 has been completed and the report has been received, but will not be 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.* This report is structured to assist in the revision and implementation of Action Plans. The overview discussion of the ten elements is roughly analogous in scope and level of detail to the FHWA Process Guidelines. The remaining sections of the report correspond in many ways to the content of an Action Plan.

Project 8-9 FY '72

Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems

Research Agency: Creighton, Hamburg
Principal Invest.: F. F. Frye
Effective Date: September 1, 1971
Completion Date: January 31, 1973
Funds: $100,000

Economic evaluation of proposed new highway facilities traditionally has been on a cost-benefit basis, as is common with other public works projects. On the other hand, evaluation of proposed new transit facilities, as an action of a private company or a public utility, has too often been on a cashbox-revenue return basis. From the point of view of public investment, it is necessary to view these expenditures within a comparable evaluation framework so that the measures of benefits and costs are interchangeable. Such a framework for the economic evaluation of multimodal passenger transportation systems has immediate applicability to urban 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.

Research has been completed. It 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 '74

Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility

Research Agency: DACP, Inc.
Principal Invest.: Jonathan S. Lane
Effective Date: September 16, 1974
Completion Date: November 30, 1975
Funds: $99,753

To fully assess the impacts associated with a proposed transportation improvement, it is necessary to be able to compare the transportation, social, economic, and environmental consequences of this investment to the alternative consequences of not making any significant transportation investment, which may result in a relative decline in levels of transportation service. Such an evaluation is now required by Federal law. However, available evaluation techniques and procedures do not appear to be well suited to specify and measure either short- or long-term social and economic consequences of not constructing a ground transportation facility. Research is needed to gain valid and usable techniques for such an evaluation. Because environmental and systems performance measures are well documented, the major emphasis needs to be on the social and economic consequences of not constructing a ground transportation facility (NCTF).

The general objective of this research was to strengthen techniques for the evaluation of the NCTF alternative. The research recognized that the primary application of the resulting techniques is for transportation planning and project decision-making purposes, including major highways and transit facilities, and explored their application in concert with comprehensive planning. It specified a product that can reasonably be expected from the application of these techniques, reflecting time and cost factors consistent with the scale of the project in question.

Research on the first phase of this project has been completed. Interim guidelines for the analysis of the NCTF alternative have been developed as a result of considerable research into the experience to date in analyzing and portraying the social and economic consequences of the NCTF alternative. The guidelines represent the conceptualization of the practical approach to determine the social, economic, and environmental consequences resulting from either a decision not to construct the transportation facility or a decision to delay the facility. Deficiencies in current analyses of the NCTF alternative have been identified and formalized in the preparation of potential research plans for a possible Phase II.

The final report describing the research findings and incorporating the guidelines is in the review stage.

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

Urban travel estimating procedures currently in use were designed primarily to evaluate regional transportation systems and to provide design volumes. Most initial studies or major updates proceeded on a two- to three-year time schedule, and even today the situation is not much

better. Increasing input to the planning process from citizens and local elected officials, preparation of environmental impact statements, corridor hearings, and consideration of low-capital and no-build options all demand that the planning process be able to provide analytical support to decision-makers in a very short time frame. For example, policy committees are frequently asking that alternatives be considered between meetings or before a public hearing within one month. Most present procedures are just inappropriate to permit an analytical response to the issues raised within the time constraints. There is need for a conceptual evaluation of travel estimation procedures (available and soon to be available) as to their capability to satisfy the requirements of policy issues and to establish the character of more streamlined approaches.

To meet the outlined need, the over-all objective is provision of field-tested, operational, travel estimation procedures for quick response to urban policy issues. It is planned that research to satisfy this objective will be conducted by separately funded phases over a period of several years. The following specific objectives and tasks were accomplished in Phase I:

A. Urban policy issues for which travel estimates are required were identified and categorized. It is recognized that travel estimates are utilized by transportation planners responding to public and private bodies, a few of which are business groups, planning commissions, A-95 review bodies, city councils, mayors, EPA, and transportation commissions. Questions asked by these bodies are different, depending on the questioner and the issue being examined. Therefore, the demands on the travel estimation procedures are different.

Task 1. Criteria for classifying policy issues that require travel estimation input were developed.

Task 2. Policy issues were compiled and cataloged according to the developed classification, and the requirements each places on the travel estimation procedures were identified.

B. Travel estimation procedures were evaluated as to their ability to satisfy the requirements of policy issues. The evaluation criteria are based on the policy issue analysis and may include timeliness, needed accuracy, cost, utility, etc. The conceptual evaluation provided the basis for selecting the most appropriate areas for detailed testing and expansion of capabilities.

Task 1. Travel estimation procedures for quick response to urban policy issues were listed.

Task 2. A classification of travel estimation procedures as they relate to Objective A was developed, and criteria were established to evaluate the procedures.

Task 3. The procedures were described and cataloged according to the developed classification.

Task 4. Travel estimation procedures were evaluated in terms of the criteria developed in Task 2 of this objective.

C. A set of recommendations for subsequent phases of the project was developed.

The final report for Phase I will not be published, but the major findings will be included in the report to be prepared during Phase II. In the interim, a summary of the descriptions of individual travel estimation procedures can be obtained from NCHRP.

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:	January 31, 1977
Funds:	$160,000

The continuation phase of Project 8-12 will provide a manual (guide) of travel estimation techniques having quick response capabilities. The techniques will be applicable for use by transportation and/or land-use planners to respond to issues identified in Phase I, 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 to be addressed; e.g., the applicability of techniques to regions, subregions, corridors. Specific objectives are as follows:

1. Provide and fully describe for each major element of travel demand analysis a manual technique, set of factors, or other appropriate tool to enable the user to carry out a simplified analysis without the necessity of referring to other sources.

2. Develop manual techniques to fill the identified gaps in the available methods; limited to providing the means to assess the interrelationship between alternative land-use configurations and transportation facilities.

3. Include by reference additional data and techniques, both manual and computerized, that are presently available or under development. Include adequate documentation for the user to assess the analytical advantages and disadvantages, degree of complexity, application time, and cost of each technique referenced. Illustrate, by means of discussion and detailed examples, how existing and forthcoming manual techniques and UTP models and computer programs may be chained, modified if necessary, and applied to provide a quick, easy, and inexpensive-to-use planning tool with inputs and outputs that can be readily understood and dealt with by urban planning professions in nontransportation areas of specialization.

4. Identify areas of potential high payoff for development efforts beyond the scope of the current study.

Research has recently been initiated on the continuation phase.

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:	December 14, 1975
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.

Recent research indicates that travel choice models based on individual and household level data can be formulated which show how travel is influenced by changes in policy. These "disaggregate" models appear to have the potential to address subregional and project planning issues as well, and reduce data requirements. Disaggregate models developed to date further indicate considerable promise of transferability between urban areas.

Research is now necessary to develop prototype disaggregate behavioral travel demand models with coefficients estimated by use of data from a large urban area to demonstrate the usefulness of such models in the planning, design, and operation of transportation systems on both regional and subregional levels.

To meet the described need, the over-all objective of this research is 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 is anticipated that such models will form the basis of improved travel demand estimation procedures.

For this research models will be developed using existing urban transportation study survey data, suitably augmented, to describe the travel choice environment.

The specific objectives of Phase I are as follows:

1. Review existing research relating to the theory, development, and application of disaggregate behavioral travel demand models.

2. Identify a desired set of variables that should be included in travel demand models and that are relevant to current transportation planning and policy questions.

3. Develop policy-sensitive travel demand forecasting models consistent with travel choice theory using data at the level of households or individual travelers. The coefficients of the models should be estimated using existing urban transportation study survey data, suitably augmented, to describe the travel choice environment. The survey data used should come from an urban area that has extensive public transportation service.

4. Evaluate the resulting models from the standpoints of: (a) adherence of the parameters and model structure to travel choice behavior; (b) the nature of the data required to develop and apply the models; (c) the kinds and probable levels of accuracy of outputs; (d) the relative complexity of estimating the coefficients of the models; and (e) the time, costs, and other application problems associated with using the models.

5. Identify anticipated improvements resulting from application of the research results as compared to conventional urban transportation planning methods.

6. Make recommendations for the staged improvement of the models developed in Phase I, outlining:

   (a) Additional data requirements and collection procedures necessary to such improvements.
   (b) Additional model development necessary.
   (c) Several specific application areas.
   (d) A program for implementing these models in operational urban transportation studies.

7. Recommend major conceptual and other improvements and suggest potentially feasible means of achieving those improvements.

The preliminary draft final report for Phase I has been submitted and reviewed by the advisory panel. The scope of work for the Phase II effort is now being developed.

Project 8-14 FY '75

New Approaches to Understanding Travel Behavior

Research Agency:	Boston College
Principal Invest:	Marc A. Fried
Effective Date:	January 1, 1975
Completion Date:	June 30, 1976
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.

Research is therefore needed to develop a strong theoretical structure for representing travel behavior, to provide a strong conceptualization of this theory, to determine the appropriate variables and means of their measurement, and to enable rigorous testing of travel behavior hypotheses. It is expected that such theory will lead directly to the specification of new operational travel demand models suitable for use in situations of changing transportation systems, policies, and problems.

The over-all objective of this research is 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.

Development of the theory will be based on, but not necessarily be limited to, a careful review and categorization or existing conceptualizations of household allocations of resources, such as time and money, in assigning priorities to activities and expenditures. Conceptualizations of consumer decision processes will also be reviewed and categorized.

A careful review and evaluation has been made of current theories of travel demand in transportation planning, economics, sociology, geography, psychology, and other fields as they relate to basic causes of individual travel. The most promising theoretical elements have been selected. As of December 31, 1975, work is progressing on the merging of these elements into new approaches that permit an understanding of how different travelers respond to a wide array of future transportation conditions.

The approaches will be designed to trace through the process by which changes in transportation conditions will affect long-term decisions such as residential location and automobile purchases as well as shorter-term decisions such as when, where, and by what means to make a trip. A detailed plan to test and implement these approaches is to be prepared.

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:	November 30, 1975
Funds:	$80,000, Phase I

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 highlight 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 and to document those methodologies within a single volume. To achieve the stated objective, the research is being conducted in two phases.

The research is directed primarily at statewide and regional-scale planning, program development, and policy analyses involving movement of passengers and commodities rather than urban area (3-c), intra-urban, or detailed project studies. It is recognized, however, that many of the techniques will be applicable to these other scales and levels of analyses.

The investigation emphasizes methodologies broadly applicable to all transport modes, including both line-haul and terminal facilities for surface and air transport. Options include all levels of capital investment (such as new construction, low-capital strategies, abandonment, and no-build), operational improvements and assistance, pricing, and regulation.

The states have and are formulating organizational and procedural mechanisms (such as the Action Plans now being developed) for considering the effects of alternative courses of action throughout all stages of project development. Phase I of this project documents technical methodologies to assist the states in their decision-making processes. Specific identification and measurement techniques were examined in contrast to issues of impact evaluation and design of the over-all planning and policy-making process.

The Phase I 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. Consideration was given in each of the described methodologies to identifying distributional effects.

Phase I tasks included:

A. Identify pressing transportation policy and planning issues on a statewide and regional scale for which social, economic, and environmental impact analyses are required by transportation planners.

B. Identify and describe briefly, with representative examples, possible significant direct and indirect social, economic, and environmental impacts of proposed statewide and/or regional transportation alternatives.

C. Identify currently available alternative methodologies for assessing the impacts identified in Task B. Evaluate these methodologies in the context of their responsiveness to the issues identified in Task A, and the resources and skills necessary to utilize these methodologies.

D. Suggest revisions and research priorities for the deficiencies determined in the evaluation of current methodologies.

E. Develop preliminary operational guidelines for use by transportation agency personnel in impact identification, measurement, and analysis for transportation.

F. Prepare an interim report on the findings and guidelines related to Tasks A through E, including a Phase II research plan to provide near-term solutions to the identified deficiencies in current methodologies.

The interim report for Phase I has been prepared and reviewed by the advisory panel. The scope of work for the Phase II effort is now being developed.

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: March 31, 1978
Funds: $480,000

Public transportation has traditionally been provided by fixed-route service financially supported through revenues from passengers. Reduced patronage resulting primarily from increased use of automobiles, plus higher operating costs, have caused growing deficits. Public concern about energy, environment, auto dependency, and congestion have obliged government to underwrite these deficits in most urban areas. The rising amounts of required public moneys, 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 could be provided. Public officials need guidelines on these issues in order to establish appropriate public policies in areas such as (a) special needs of various market segments, (b) resource allocation issues, and (c) institutional issues.

The general objective of this research is to determine the nature of the relationships between public transportation service, the urban environment, and user segments, and subsequently to develop guidelines for use by decision-makers in evaluating short-term (approx. 5 years), alternative public transportation systems. It is anticipated that this objective will be met by research to be conducted in two phases.

The specific objectives of Phase I are:

1. Determine system attributes required to attract use from different market segments in various urban environments.
2. Determine system types that best satisfy these attribute requirements at various levels of service and financial support.
3. Determine expected costs and potential revenues of various types of service from different market segments in various urban environments.
4. Describe other significant impacts and institutional factors that may be caused by or result from implementation of various systems and service.

The specific objective for Phase II requires development of guidelines for use by public officials and handbooks for use by the nonprofessional decision-maker for each of the following purposes:

1. To compare public transportation systems and services among similar communities.
2. To evaluate, select, and implement alternative types of systems and services in various urban environments.
3. To evaluate the effectiveness of the systems and services provided.

Research is to begin January 1, 1976.

Project 8-17 FY '76

Freight Data Requirements for Statewide Transportation Systems Planning

Research Agency: Creighton, Hamburg
Principal Investigator: Frederick W. Memmott
Richard B. Blackwell
Effective Date: July 15, 1975
Completion Date: February 15, 1977
Funds: $225,000

Many state departments of transportation (and other state and regional agencies) are now concerned with preparing, or assisting in the preparation of, statewide "master plans" for highway, rail, air, pipeline, and water facilities needed to serve existing and future freight flows. Because this is a relatively new focus, the DOTs often are not familiar with the kinds of freight data needed for such planning. Furthermore, little is known about currently available data, its reliability, its compatibility among different sources, its temporal continuity, its units of aggregation, its costs, and so forth. Such data are believed to be necessary to the planning processes.

There is a need to define and rank essential data and to begin building a core of knowledge and understanding about goods transport, especially the identification of existing freight data source material upon which future transportation plans can be based. Also, there is a need to develop methods for assembling basic freight data.

The general objective of this research is 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 is being conducted in two phases. Specific tasks for Phase I are to:

1. Identify the types of freight data necessary for statewide transportation systems planning purposes. Recommend what type of data and the scale of detail that will be required in view of the current and proposed planning methodologies.
2. Rank these data requirements in terms of their relative importance to statewide transportation systems planning.
3. Given the data requirements, catalogue and determine the existence of available data in reference to the planning data requirements determined in Task 1. Investigate the institutional problems and constraints in the use of freight data (e.g., disclosure restrictions, proprietary nature of shipper and carrier data, and joint use and reciprocity agreements among private and public parties).

4. Identify deficiencies in existing freight data and evaluate the criticality of such deficiencies to statewide transportation systems planning.

5. Develop and evaluate alternative strategies for resolving such deficiencies. These strategies may range from creative use of existing data to extensive collection of primary data.

Specific tasks for Phase II include:

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. Such a manual should include specification of data acquisition, processing, verification, and maintenance procedures.

2. Provide illustrative, realistic examples of how to apply these techniques to typical problems encountered in statewide transportation systems planning.

Tasks 1, 2, and 3 are essentially completed. An interim report describing the Phase I findings will be prepared prior to development of the manual in Phase II. The firm of R. L. Banks Associates is serving as a subcontractor on this project.

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:	February 28, 1978
Funds:	$300,000

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. Such techniques do not begin to cover the range of options that face today's decision makers; neither do they enable quick response. Several issues have evolved that place today's transportation decision makers in the position of making trade-offs and choices from among a range of options and values not previously considered. These issues include new environmental concerns, changing social equity concerns, major decreases in available revenue, increased costs due to inflation, unified transportation funds and multimodal financial programming, energy shortages and energy cost increases, public interest in pricing mechanisms (e.g., tolls and fares) to influence travel, and federal interest in "low capital-intensive" options.

More specific examples of such policy issues are:

1. Subsidy of the transportation needs of the elderly, students, and the handicapped.
2. Public transportation in rural areas.
3. State transit operating subsidies.
4. Public acquisition of airports, railroads, and other rights-of-way.
5. Funds for maintenance versus capital investments.
6. Subsidy of air commuter and air-taxi service.
7. Rail service versus highway construction.
8. Impact analysis (air, water, noise, energy, social, economics, land use).
9. Funding mechanisms (bonding versus revenue financing).
10. Practical considerations of new technology.

The general objective of this research is to provide transportation planning methodologies that will be policy-sensitive, allowing the testing and evaluation of options in a fashion that will produce timely results for decision-making. This research addresses reasonable-cost, sketch-planning-type techniques having an application to issues of statewide transportation planning as part of the programming process. This research is being conducted in two phases.

Specific tasks of Phase I are to:

1. Identify and classify major transportation issues facing decision-makers at the statewide level.
2. Identify and categorize data and methodologies available to meet the needs of decision makers in addressing transportation issues identified in Task 1.
3. Evaluate and document methodologies most likely to provide early usefulness.
4. Develop a study design to test several high-priority methodologies (identified in Task 3) in states willing to participate and commit resources. At least four states should be identified as candidates in the study design.

The specific tasks of Phase II are to:

1. Develop a draft procedural manual for test application of techniques identified in Phase I.
2. Conduct the testing in the approved study design developed in Phase I, Task 4.
3. Document the results of the testing and revise manuals developed in Phase II, Task 1.
4. Based on the experience gained in Phase II, Task 2, and deficiencies recognized in Phase I, Task 3, evaluate the importance of the deficiencies and suggest new methodologies where appropriate.

Research accomplished to date has been concerned with the identification and classification of transportation issues and related methodologies. An interim report will be prepared at the end of Phase I. The firm of System Design Concepts is serving as a subcontractor.

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.

Research has been completed. The project report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972.*

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. Tentative recommendations have been prepared to minimize cracking of asphaltic concrete pavements and a plan has been prepared for verifying or modifying these tentative recommendations. The essential findings of the study have been published as NCHRP Research Results Digest 58. The project report is in the NCHRP editorial and publication process.

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:	December 14, 1977
Funds:	$199,994

Cracking of the surface course is generally considered to be the most significant manifestation of asphaltic concrete pavement distress. 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. Premature cracking (that occurring at an early life or after less accumulated traffic than anticipated during design) is particularly troublesome. Considerable research effort has been and continues to be directed toward development of more mechanistic procedures for flexible pavement design to reduce cracking that will be applicable to all locations, environments, and traffic loadings.

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 are (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. It is expected that the researchers will use the recommendations of Project 9-4 as a basis for the verification procedure.

It is anticipated that the following tasks will be required to accomplish these objectives:

1. Prepare a plan for obtaining the subjective information on factors affecting distress of asphaltic pavements from experienced engineers, including a suitable questionnaire and interview procedure.
2. Implement the plan prepared under Task 1 to collect the subjective information in two climatic regions of the contiguous United States and develop "priors" for at least cracking from repetitive traffic loading.
3. Develop the framework for acquisition of "data" compatible with mechanistic models for asphaltic pavements. The framework must accommodate objective field measurements on existing pavements and test roads and be suitable for combining with the "priors" obtained from Steps 1 and 2 describing (a) what should be measured, (b) how it should be measured, and (c) how it should be analyzed when it has been obtained.
4. For pilot implementation of the verification procedure for a specific distress mode, collect field data on cracking from repetitive loading of pavements in the same two climatic regions in which the interviews were conducted.
5. Complete the analysis by combining the "priors" and the "data" to illustrate the methodology.

Research is in progress.

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 Material Research & 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 Dates:	Oct. 22, 1963	Oct. 15, 1964
Completion Dates:	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. Tu 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 Dates:	Feb. 1, 1964	May 1, 1965
Completion Dates:	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 Dates:	Jan. 15, 1964	Apr. 1, 1965
Completion Dates:	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, snbbases, 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 ntilizing 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. Research has been completed and the objectives have been met. Procedures have been developed for optimization of nuclear backscatter-type density gauge calibration, a quality 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.

The essential findings of the study have been published as NCHRP Research Results Digest 63. The final report is in the NCHRP editorial and publication process.

Project 10-9 FY '70

Criteria for Need of Seal Coats for Bituminous Pavements

Research Agency:	University of Minnesota
Principal Invest.:	E. L. Skok
Effective Date:	November 1, 1969
Completion Date:	February 28, 1974
Funds:	$50,000

In order to most economically maintain bituminous-surfaced pavements in serviceable condition, seal coats may be periodically required. Determinations of the need for seal coats, the type required, and the proper time to apply

are important. Premature sealing results in a needlessly early expenditure of funds, while tardy action may result in excessive deterioration or unsafe conditions and greater total maintenance expenditures. Currently available methods of rating pavements for the need of sealing are not totally adequate. They are time consuming, require the use of costly equipment and highly skilled personnel, rely on the judgment of experienced personnel, or are not reproducible. Methods and criteria for determining when sealcoat applications should be made are needed.

The objectives of this project were to develop, and evaluate in the field, guidelines for the programming of seal coats on bituminous pavements.

Research has been completed. The essential findings of the study, including a "Surface Condition Rating System for Bituminous Pavements," have been published as NCHRP Research Results Digest 48. The final report is in the editorial and publication process.

Project 10-10 FY '74

Acceptance Criteria for Electroslag Weldments in Bridges

Research Agency: United States Steel Corporation
Principal Invest.: W. P. Benter, Jr.
Effective Date: May 1, 1974
Completion Date: April 30, 1976
Funds: $199,572

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 is to develop and verify acceptance criteria for the use of electroslag butt welds in bridges. Research is to be conducted in two phases. The specific objective of Phase I is to define necessary acceptance specifications based on the most complete study, using laboratory specimens from full-size welds, that current knowledge and testing equipment can provide within the allotted funds. The specific objective of Phase II is to verify the findings of Phase I by conducting dynamic tests of full-size bridge girders.

Accomplishment of Phase I objectives will include the following tasks:

1. A thorough review of domestic and foreign literature on the subject.
2. Preparation of a state-of-the-art report on electroslag welding.
3. Testing of laboratory specimens taken from full-scale welds. Variables include welding procedures and equipment, grades of steel, and plate thicknesses. The testing is to determine toughness, fatigne, tensile, and metallurgical properties.
4. Development of tentative acceptance tests and criteria for electroslag butt welds based on the results of previous tasks.
5. Submission of an interim report summarizing the findings of the Phase I work and containing a detailed work plan for conduct of Phase II.

The report prepared under task 2 has been published as NCHRP Research Results Digest 74, "Electroslag Weldments in Bridges."

Phase II will consist of fabricating and dynamically testing full-size girders to determine fatigue and fracture behavior of electroslag butt welds in girder flanges in accordance with the detailed work plan submitted under Phase I.

The final report is to include recommended specifications and acceptance tests for electroslag butt welds for bridges based on the results of both Phase I and Phase II.

Through December 30, 1975, Phase I research has been completed, and the preliminary draft of the interim report is nearing completion.

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 will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*.

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 was 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 will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972.*

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 they may be removed by the condemnee. In this area, the courts have also recognized a different rule than exists between landlord and tenant and mortgagor and mortgagee in regard to such fixtures.

The objective of the research was to review all appellate cases in the trade fixture area and to cite and compare these with selected typical landlord-tenant and mortgagor-mortgagee cases to illustrate the different rules of law applicable. Appropriate jury instructions, based on the decided cases, were developed as to the acquisition and valuation criteria that have been judicially prescribed. Comments were made on the valuation techniques involved, particularly as to how they may differ, if they do, from conventional methods of fixture valuation. Existing legal and appraisal literature was reviewed and cited, particularly law review articles, *ALR* annotations, and *The Appraisal Journal.*

The project report has been published as:

NCHRP Report 94, "Valuation and Condemnation Problems Involving Trade Fixtures."

Project 11-1(10) FY '68

Compensability and Valuation Aspects of Residential Displacement in Highway Programs

Research Agency: Ross, Hardies, O'Keefe, Babcock, McDugald & Parsons
Principal Invest.: Fred P. Bosselman
Effective Date: March 15, 1969
Completion Date: September 15, 1969
Funds: $5,000

Serious practical problems arise when highway construction unavoidably necessitates substantial displacement of residential units, both in urban and rural areas. Relocation of displaced residents is, in varying degrees, becoming a responsibility of public agencies. However, up to the present time alternative means and procedures for performing this responsibility have been limited, and it is evident that new and greater efforts in this activity must be made. Significant legal and valuation problems must be solved if legislators and administrators are to have guidelines for development of new methods of improving reloca-

tion 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 will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972.*

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 different 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, (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:	$100,000

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 the final report is in the review stage. Loan copies of the agency's final report will be available from the NCHRP Program Director early in 1976.

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 the causes and magnitudes of fabrication and environmental stresses, of the possible existence of permanent deformations in existing bridges due to current specifications, and of 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 will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1975.*

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 on this project will not be published in the NCHRP series. A snmmary is included in the *NCHRP Summary of Progress Through December 31, 1969.*

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:	Septeinber 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, will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1975.*

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 Dates:	Oct. 1, 1966	July 1, 1970
Completion Dates:	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 Dates:	Mar. 1, 1968	Jan. 2, 1970
Completion Dates:	Feb. 28, 1969	June 30, 1971
Funds:	$28,793	$69,753

Highway bridge railing systems have evolved through need and experience and with design information not fully substantiated by research. In recent years many full-scale crash tests on railings have been conducted providing much useful information, but still there is need for a better definition of service requirements. Of prime importance is a need for developing a fundamental concept of the purpose that railings are expected to serve under various site conditions, with due consideration being given to a balance between safety, appearance, and economy. Design criteria, when established, can then be correlated with existing research data for development of specifications for the design of various railing configurations and materials.

The Phase I research effort to develop tentative service requirements has been completed, and the results have been published as:

NCHRP Report 86, "Tentative Service Requirements for Bridge Rail Systems."

The Phase II effort had as its objective the quantification of the service requirements to produce design criteria for bridge rail systems. This objective was to be pursued by further establishing the validity of a simple mathematical model developed under Phase I; by conducting parameter studies using the mathematical model to evaluate simulated vehicle-barrier collisions; by developing tables, curves, or nomographs for use by design engineers; and by refining the limits of tolerable deceleration on the basis of more recent information.

The agency devoted study to the trends of automobile weights and dimensions; the evaluation of accident causation factors that may have a significant influence on the frequency of bridge rail-vehicle collisions; the analysis of structural response and failure mechanisms of concrete parapets; the relationship between barrier strength and rigidity versus vehicle damage and accelerations transmitted to the passengers; the effects of barrier design on the dynamic response of a vehicle; the required barrier height for certain selected vehicles; and analysis of crash-tested bridge rail designs by a mathematical model for purposes of further validating the model and theoretically estimating the efficiency of the design.

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

NCHRP Report 149, "Bridge Rail Design—Factors, Trends and Guidelines."

Project 12-9 FY '67

Elastomeric Bearing Research

Research Agency:	Battelle Memorial Institute
Principal Invest.:	J. C. Minor
Effective Date:	September 1, 1967
Completion Date:	January 31, 1970
Funds:	$84,800

The development of new elastomers and elastomeric bearing systems is proceeding at a rapid rate. The ability of these bearings and bearing systems to absorb the various loads and movements occurring in bridges in a more efficient manner and at a significantly lower cost than mechanical bearing systems justifies an effort to improve current designs. Toward this objective, this project contemplated research on elastomeric bearings and bearing systems using materials as defined in the AASHTO specifications for elastomeric bearing pads.

The major objectives of the project were to evaluate (1) effect of geometry on compressive strain, compressive set, shear modulus, and rotational modulus for hardness between 50 and 70 durometer and sizes from 50 to 200 sq in., and the effect of lamination on these values; (2) relative performance of glued laminated pads compared to fully vulcanized units, including an effective test of the adhesion between layers; (3) relative performance of molded pads versus pads sawed from larger sheets with an evaluation of the sawing process and determination of an acceptable cut surface; and (4) evaluation of the aging and low-temperature (to −40 F) characteristics of the various pads.

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

NCHRP Report 109, "Elastomeric Bearing Research."

Project 12-10 FY '70

Analysis and Design of Bridge Bents

Research Agency:	Portland Cement Association
Principal Invest.:	Dr. James E. Carpenter
Effective Date:	January 1, 1970
Completion Date:	December 31, 1973
Funds:	$297,900

The present strong emphasis on safe and aesthetic design of reinforced concrete highway bridges has resulted in substructure configurations that depart widely from the traditional footing-column-cap frame design. Aesthetic considerations often dictate the concealment of massive concrete caps and elimination of numerous vertical columns; however, design procedures in current use are not applicable to these new configurations. There is a general feeling that current procedures result in overdesigned structures containing much more steel than is necessary. Therefore, an urgent need exists for the development of appropriate design procedures.

Although the ultimate need is to establish valid design procedures that are applicable to many configurations of bridge bents, this project was limited to investigation of bent caps concealed in straight, continuous, reinforced concrete bridges.

Design procedures were developed by (1) constructing and testing adequately-scaled reinforced concrete models of representative bents and (2) developing a mathematical model to correlate with the experimental results. The design procedures may be corroborated by data taken from full-size bridges instrumented during construction, but not as a part of this project.

Research was based on prototypes representative of popular box-girder designs. The accomplishment of the research included: (1) reviewing the technical literature; (2) determining a desigu 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 one-fifth 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 bridges and of stress distribution in the bent cap accompanied the experimental work.

Research has been completed, and the final report is in the NCHRP editorial and publication process. The essential findings from this final report have been summarized in NCHRP Research Results Digest 65, "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 & Development	
Principal Invest.:	C. J. Van Til B. J. Carr	C. J. Van Til
Effective Dates:	Aug. 1, 1970	July 15, 1973
Completion Dates:	Mar. 31, 1973	Apr. 15, 1977
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 subject. 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 is to develop, or discover, one or more effective waterproofing membrane systems for use on concrete bridge decks.

The objective is being 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, now in progress, is 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 report for Phase I is in the NCHRP editorial and publication process.

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. Construction activity is now complete. Semiannual observations of performance of the installed systems are in progress.

Project 12-12 FY '71

Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings

Research Agency:	United States Steel Corporation
Principal Invest.:	C. G. Schilling K. H. Klippstein
Effective Date:	October 1, 1970
Completion Date:	October 31, 1975
Funds:	$310,000

Highway bridges are subjected to a great variety of forces that range from constant dead load, through slowly changing forces due to creep of materials and temperature differentials, to an almost infinite variety of live loads caused by moving vehicles. Currently, most bridges are designed to carry a static load produced by a design truck, with certain empirical allowances being made for dynamic effects. On the basis of these loads and an assumed frequency of occurrences, the design considers the static and fatigue properties of the material used. Not much is known about the actual service life of the bridge and the actual service loads.

The first major problem in predicting the life of highway bridges is to determine, from a heterogeneous spectrum of frequencies and amplitudes, the loading conditions to which the structure is subjected during its lifetime. Others have conducted field tests to develop this information.

This project was directed to the next major problem: to determine the behavior of welded highway bridge steels (specifically, A36 and A514) under variable-cycle fatigue loads and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The primary objective of this project is 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 is in the NCHRP editorial and publication process. NCHRP Research Results Digest 60, "Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings," containing some of the findings was published in April 1974.

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:	$174,699

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 final report is in the NCHRP editorial and publication process.

Project 12-13A FY '73

Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks

Research Agency:	Portland Cement Association
Principal Invest.:	William F. Perenchio
Effective Date:	August 1, 1975
Completion Date:	July 31, 1978
Funds:	$75,000

Many reinforced concrete bridge decks experience damage because of corrosion of the reinforcing steel. One 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. 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.

Research conducted under NCHRP Project 12-13 had as its primary objective the development of one or more technically and economically feasible cathodic protection systems for reinforced concrete bridge decks. The essential findings, including a proposed sacrificial anode system, are included in the final report for NCHRP Project 12-13. A field study program is now needed to evaluate the performance of the sacrificial anode approach to cathodic protection.

The objective of this research is to field evaluate the effectiveness of a zinc anode galvanic protective system applied to the surface of a bridge deck exhibiting active reinforcing steel corrosion. The research is to consist of the design and installation of two or more variations of the zinc anode galvanic protective system on a bridge deck in regular service. A two-year performance monitoring program is to be conducted, as is a program to obtain cost and life data. One experimental area is to include a system in which the size and spacing of the zinc anodes are to be determined from a computer program developed for this purpose in NCHRP Project 12-13. A second experimental area is to contain zinc anodes placed over each reinforcement bar in the top layer of reinforcement. A third experimental area is reserved for an innovative system that will be the option of the research agency. Asphaltic concrete will be placed over the electrical elements to protect them and to serve as a wearing course.

The research agency has entered into an agreement with the Illinois Division of Highways under which the experimental installations are to be placed in a bridge deck rehabilitation construction contract. The agency's research work plan has been submitted and approved. Construction plans and specifications for the experimental installations have been prepared and the construction is soon to be placed under contract.

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 final report is in the NCHRP editorial and publication process. Meanwhile, loan copies are available from the Program Director.

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.

To identify fatigue failures, a review of available methods for the detection of fatigue cracks is needed. Typical details that are most susceptible to fatigue cracking must also be identified. Methods are 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 first phase of research 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.

Interim reports on the accomplishments under objectives 1 and 2 were published as NCHRP Research Results Digest 59, "Classification of Welded Bridge Details for Fatigue Loading," and NCHRP Research Results Digest 66, "Nondestructive Methods of Fatigue Crack Detection in Steel Bridge Members."

Phase 1 research has been completed, and the final report is in the NCHRP editorial and publication process. A proposal for a second phase of research is now being reviewed by the project advisory panel.

Project 12-16 FY '75

Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel

Research Agency: Battelle Columbus Laboratory

Principal Invest.: Dr. John E. Slater
Dr. David R. Lankard

Effective Date: September 1, 1974

Completion Date: February 28, 1977

Funds: $200,000

This study is 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. The effect of chlorides is to cause a change in this alkaline environment, thus allowing the corrosion reaction to take place. Only a small amount of chloride is necessary to cause the reaction to start, but 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 agravate 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 is 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 will include preliminary field survey, laboratory evaluation, and field investigation of repair methods currently used throughout the United States. The major emphasis of the project is on commonly used methods but some methods that have been used experimentally in the field are also being 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 is 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 includes 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 include electrical measurements, chloride analyses, and other corrosion detecting procedures.

The field investigation will verify 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 will be studied. In addition to visual examination, emphasis will be placed on techniques that indicate corrosion behavior (such as electrical measurements and chloride analyses).

Through December 31, 1975, the preliminary field survey has been completed. All specimens for the laboratory evaluation have been prepared. Measurements are about 50 percent complete, and data analysis has begun. The field investigation is expected to begin in mid-1976.

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: September 14, 1975
Funds: $99,754

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. Because some water is therefore likely to enter through the joint at some time during the pavement life, provisions also 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.

The objectives of this project were to:

1. Determine the most suitable currently available procedures (including methods and materials for sealing the joint, subsurface drainage, and other methods for minimizing the effects of water) for alleviating the problems associated with the joint between a portland cement concrete pavement and a bituminous surfaced shoulder, taking into account the variations in such factors as climate, subgrade, roadway pavement design, shoulder design, and traffic.
2. Develop and experimentally evaluate improved systems for minimizing the passage of water through the pavement-shoulder joint.
3. Prepare a plan for a field study program that could be undertaken by highway agencies to evaluate promising procedures for sealing the pavement-shoulder joint.

The research was conducted jointly with the University of Michigan.

The study was approached through a series of visits in a number of states to discuss and observe pavement-shoulder joint performance, a program of movement measurements at pavement-shoulder joints in Georgia and Michigan, and laboratory studies of sealer performance and of the performance of drainage-layer materials.

The products of the research were a series of recommendations for pavement-shoulder joint design and construction, sealant specifications, shoulder design, and underdrainage facilities. Guidelines were offered for a test program to evaluate several promising shoulder and sealant systems developed in the project.

Research has been completed, and the final report is in the NCHRP editorial and publication process.

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 3, 1976
Funds: $99,665

In the next decade, a 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 state.

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 is the 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, are required characteristics. The methods and procedures will be 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. This project is aimed at situations where the disruption of traffic flow justifies exceptional measures.

This study is planned for accomplishment in two phases, with only Phase I being addressed initially. This phase was

directed at formulation of one or more potential pavement rehabilitation systems meeting the criteria outlined, and development (at least conceptually) of field techniques and equipment for application of the system(s). Work included a state-of-the-art study, visits to several sites of expressway rehabilitation activity, and the gathering of information on potential rehabilitation processes, equipment, and materials. A small laboratory study was made to complement existing data on materials with information germane to the project. The final report has been received and is in the review stage. Field evaluation will be conducted as Phase II of the project.

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 Dates:	July 1, 1967	May 1, 1970
Completion Dates:	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 that summarizes the Phase I research is available on loan.

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."

Additional work is under contract and, for administrative reasons, has been designated Project 22-2, "Traffic Barrier Performance and Design." 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 Procedures 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 essential findings of the field evaluation phase have been published as NCHRP Research Results Digest 67, "Field Evaluation of Tentative Design Procedure for Riprap-Lined Channels," and a summary is included in the *NCHRP Summary of Progress Through 1975*.

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:	$150,000

Conventional luminaire support poles are, of necessity, mounted close to the traveled roadway. In this location, 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."

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 report covering the experimental phase of the project is in the NCHRP editorial and publication process.

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:	November 1, 1973
Completion Date:	February 29, 1976
Funds:	$174,950

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.

The objectives of this project were to:

1. Assess the effectiveness of the control of erosion from highway construction.
2. Develop a manual of recommended techniques and design criteria for the control of erosion, using hydrologic, hydraulic, agronomic, pedologic, and economic principles.
3. Identify research needs in the subject area.

The research was conducted jointly with the U.S. Forest Service.

Work on the project included a search and cataloguing of published literature on erosion control, and an extensive questionnaire survey of erosion control practice. Visits were made to highway construction sites throughout the country during the summer of 1974 to observe and evaluate erosion control practices. The Universal Soil Loss Equation was established as the project base for estimating soil loss. Existing maps that divide the country into areas of varying soil erosion potential were used in application of the universal equation. An erosion control manual was developed for immediate interim use by highway and transportation agencies.

Research has been completed, and the final report has been submitted.

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."

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 has been reported to provide 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 is in the NCHRP editorial and publication process.

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 Dates:	Dec. 15, 1966	Jan. 1, 1967
Completion Dates:	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 Surveillence, Information, and Control System," has been accepted. It, along with the 1967 reports, will not be published but will be included in the work described under Project 20-3B.

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.

* 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.

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 Dates:	Nov. 20, 1968	Jan. 1, 1969
Completion Dates:	May 31, 1971	Dec. 31, 1969
Funds:	$505,631	$20,000 †

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 are being studied for the heavily traveled corridor of the John C. Lodge Freeway in Detroit.

The research program conducted during 1967 and 1968 by the Texas Transportation Institute is described 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 necessity to utilize existing equipment and facilities as fully as possible and to carry previous research activity to a logical conclusion placed some constraints upon the nature of the topics selected for study. The topics included (1) detection of capacity-reducing incidents, (2) improved ramp control techniques and environmental effects, (3) pilot studies of freeway-frontage road informational system, (4) an experiment in traffic routing within the freeway corridor, and (5) observation of freeway operations.

Draft reports on the topics of the 1969 research work have been accepted by the advisory committee.

The 1970 research had the general objective of improving and refining the existing system aimed at 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 have been 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 have been accepted and are available on a loan basis on request to the Program Director. They, along with the 1969 reports, will not be published but will be included in the work described under Project 20-3B.

† 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.

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 TRB advisory committee 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. Arrangements for obtaining the desired summary reports have been initiated under NCHRP Projects 20-3C and 20-3D.

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:	$10,375

This project was established with the objective of preparing a report summarizing the main findings of freeway surveillance and control on the John C. Lodge Freeway in Detroit. The end product is to be one report describing the history and technical activities of the research conducted

by the State of Michigan and under the National Proving Ground and NCHRP Projects 20-3 and 20-3A. The report will cover the objectives, organization, and data, as well as the results, conclusions, and recommendations associated with each stage of the research. References to all published and unpublished reports and file documents pertinent to the background of the report will be appropriately cited.

Project 20-3D FY '70

Summary of All Freeway Surveillance, Communication and Control Experience

Research Agency:
Principal Invest.: *To Be Determined*
Effective Date:
Completion Date:
Funds:

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. The project will draw on both published research reports and other experience available from relevant research projects. The final report is intended, therefore, to synthesize past and present practices and to provide judgmental values on their merits and successes in order to aid highway administrators in decisions related to freeway operation problems.

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 Dates:	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 FY '76

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 32 published syntheses of highway practice that have been prepared under this project are listed in Table 7.

The following topic reports have been completed and are in the NCHRP editorial and publication process: "Acquisition and Utilization of Geotechnical Information;" "Durability of Drainage Pipe."

The following reports are in the review stage: "Intersection Design and Control of Off-Ramp Terminals;" "New Applications of Instrumentation and Equipment for Testing Highway Materials;" "State Utility Accommodation Policies and Practices."

The following topics are in the research stage: "Pile Foundations;" "Adverse-Weather Construction Methods;" "Statistically Oriented End Result Specifications;" "Rapid-Setting Materials for Patching of Concrete;" "Lime-Fly Ash Stabilized Bases;" "Transportation Demand and Requirements for the Poor, Aged, and Disadvantaged;" "Bridge Bearing Design and Performance;" "Consolidation of Concrete;" "Staffing and Management Required for Social, Economic, and Environmental Impact Assessments;" "Recording and Reporting Methods for Highway Maintenance Expenditures;" "Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation;" "Rehabilitation of PCC Pavement Joints;" "Priority Planning and Project Selection Systems;" "Effect of Bridge Painting Practices on Environment;" "Selection of Transit Routes;" "Conversion of Streets to Pedestrian Malls."

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.:	John C. Vance
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

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 acquisitiou 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 advisory 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 (Postponed)
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 (In progress)
Study No. 13—Appeal Bodies for Relocation Assistance (Research Results Digest No. 40)
Study No. 14—Admissibility and Use of Severance Studies in Condemuation 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, 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" (Cancelled)

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 (Cancelled)

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 68)

Study No. 28—Valuation of Outdoor Advertising Rights

Study No. 29—Valuation of Scenic Easements (Cancelled)

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

Study No. 35—Model Airspace Act: A Vehicle for Joint Development

Study No. 36—Formation of the Contract

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

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

Studies 23 through 35 were initiated pursuant to authorization of a two-volume text on eminent domain by Advisory Committee SP20-6 on March 24, 1972. All of these papers have been completed and a limited selected distribution of Volumes I and II will be made early in 1976.

Continuation funding of $185,000 in the FY '74 program is being used to produce a third volume of the textbook on highway law, covering areas outside the field of eminent domain. Such areas include, but are not limited to, highway contract law, tort liability of highway department officers and employees, liability of highway and transportation departments for design and maintenance defects, environmental law, relocation assistance, control of highway access, and the legal interrelationships of the Federal and state governments.

Through December 31, 1975, papers on Studies No. 11, 17, and 36 through 44 have been written, reviewed, and revised. They will be included in Volume III, which is expected to be published in the latter half of 1976.

Future work on this continuing project will include updating and supplementing the textbook.

Project 20-7 FY '69 and continuing

Research for AASHTO Standing Committee on Engineering and Operations

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 Engineering and Operations is called continually to rule on engineering and operations policies as a guide for state highway and transportation departments to follow. The Committee desires to attain 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

* Texas A&M University, California Department of Transportation, and Stanford Research Institute (Project 2-12) to date.

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 tasks undertaken in this project and the status of each are 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, and the final report is in the NCHRP editorial and publication process. A bridge hazard index is proposed for assessing the degree of hazard of narrow bridges. Guidelines are offered for remedial treatments at narrow bridges.

Task 8, "Energy and Transportation Systems" (California Department of Transportation). This study is 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. Contract negotiations have been completed and research has started.

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 will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972.*

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: January 31, 1976
Funds: $210,964

Residential dislocation is one of the major direct consequences of urban highway projects. Geographic and socioeconomic characteristics are of critical importance in predicting the impact of such dislocation on both the dislocatees themselves and on residents remaining in the area from which the dislocation occurs. There is a critical need:

1. For improved methodologies to serve as a basis for highway route location and design decisions and to conform to study and reporting requirements of pertinent federal legislation and regulations.
2. To identify the needs for further equity adjustments in relocation assistance activities and programs.

The objectives of this research are (1) to identify the relevant variables and develop techniques for using these variables in predicting the dislocation consequences of alternate route and design proposals, and (2) to identify related legislative or regulatory constraints and recommend legislation and policy and program modifications to assure equity to the displacees.

Early in the project, a preliminary hypothesis was established which identified problems, variables and predictive techniques to be examined in case studies. Subsequently, compensation issues were identified. Home interview data have been collected from displacees before and after moving at six sites geographically distributed throughout the United States. These data have been coded and techniques have been developed to display the consequences of highway-induced residential dislocation. A manual has been developed, incorporating the techniques, to predict in advance the consequences of highway-induced residential dislocation.

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: February 25, 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 is a need to identify and measure benefits of separating pedestrians and vehicular traffic.

The general objective of this research is 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. Specific objectives are as follows:

1. Identify direct and indirect benefits of separating pedestrians from roadway vehicular traffic, including transportation, social, economic, and environmental benefits for both the user and the community. Separation types could include, but not be limited to: (1) mall, (2) overpass, (3) underpass, (4) skyway, (5) grade-separated network, (6) barrier, (7) sidewalk, (8) signalization, (9) cross-walk, and (10) sanction.
2. Define population segments (including the young, elderly, disadvantaged, merchants, cyclists, and others) likely to benefit from pedestrian-vehicular separation.
3. Adopt or develop measurement techniques, understood by the public and decision makers, to quantify benefits for population segments defined in Objective 2. Provide documentation, where possible, and discuss deficiencies in data and techniques.
4. Adopt or develop, where possible, criteria for converting measured benefits to dollar values.
5. Develop techniques for the practitioner comparable, but not limited to, conventional cost-benefit techniques, to use in the evaluation and design of proposals for separation.
6. Test the techniques developed in Objective 5 for a potential and an existing pedestrian separation. It is anticipated that this testing may require the collection of field data.

To December 31, 1975, benefit factors have been identified and measurement techniques proposed. These factors fall under four principal categories as follows: 1) Transportation, 2) Safety/Health/Environment, 3) Residential/Business, and 4) Environmental/Institutional. A methodology has been developed to weight the benefits identified according to the values held by decision makers and/or the community at large. The methodology and the proposed factors have been field tested at sites in Seattle, Washington; Brooklyn, New York; and Ottawa, Ontario.

Research has been completed and the final report is in the review stage.

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 will not be published, but the agency's unedited final draft may be purchased from the Transportation Research Board at a cost of $15.00. Checks should be mailed to the Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. The findings from this research will be summarized in two Research Results Digests entitled (1) "A Preliminary Energy Model" and (2) "Environmental Elements Impacting Factors and Threshold Levels."

Project 20-11A FY '74

Toward Environmental Benefit/Cost Analysis—Measurement Methodology

Research Agency:	Cornell University
Principal Invest.:	Dr. Arnim H. Meyburg
Effective Date:	September 1, 1975
Completion Date:	May 31, 1976
Funds:	$24,975

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. The task has proved to be difficult, due to the diversity of disciplines involved. The aspect of diversity of impacts is accentuated with large projects such as most transportation facilities. Consequently there exists a need for a comprehensive approach to environmental impact assessment, a multidisciplinary approach embracing a wide array of physical, natural, and social science concerns, capable of dealing with the extensive networks of interactions that constitute the environment of any project.

A start has been made in developing a usable methodology in assessing environmental impacts of transportation facilities using the energy flow concept. It is recognized that similar research may be under way in other fields. Further development of the concept for transportation facilities planning should reflect the state of the art in all relevant fields. Research is needed to identify, summarize, and evaluate parallel research to determine areas of research having the highest potential for further study.

The general objective of this research is 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 are included:

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, including a review focusing on each program's attributes as a method for assessing environmental impacts of transportation facilities; it also considers the potential applications of combined findings from two or more different programs.
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 to date has been concentrated on Tasks 1 and 2.

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:	$89,000

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 is in the NCHRP editorial and publication process.

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 nrban and rural freeways. A literature search, analysis, and evaluation was accomplished. The investigators were concerned with studies such as, but not limited to:

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 is in the NCHRP editorial and publication process.

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 service behavior. Despite recognition of the importance of the relationship between the presence of water and service behavior, the engineer has been hampered in his effort to provide predictable performance by the lack of instrumentation and techniques for adequate water or moisture measurement. The economic significance of the problem in highway construction and maintenance is particularly evidenced by the large financial investment aimed at removal of excess water which causes loss of supporting capacity of subgrade soils and aggregate bases, embankment instability, and deterioration of pavements.

The objective of this project was to evaluate, on the basis of a comprehensive literature review, the suitability of existing instrumentation and techniques to measure the amount and state of water in highway components such as embankments, subgrades, base courses, and structures.

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

NCHRP report 138, "Instrumentation for Measurement of Moisture—Literature Review and Recommended Research."

Project 21-2 FY '71

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency: Southwest Research Institute
Principal Invest.: Dr. C. G. Gardner
Effective Date: February 1, 1972
Completion Date: January 31, 1974
Funds: $64,976

There is an immediate need for reliable instrumentation to measure the moisture in situ in soil and untreated granular materials used in such highway substructures as subgrades, embankments, slopes, backfills, and base courses.

It is recognized that the moisture sensor is the critical component of any moisture measurement instrument or technique. For this reason, this project is to concentrate on the development of new and innovative, or modification of currently available, sensors for moisture measurement.

The objectives of this project were to design, build prototype models, and conduct laboratory verification programs for one or more sensors capable of measuring moisture in granular and soil materials that would be suitable for highway needs. During the initial phase of the study nuclear magnetic resonance (NMR) and microwave absorption approaches were investigated independently. In general, satisfactory performance was achieved using the NMR approach but considerable difficulty was encountered with the microwave technique. As a result, the experimental verification phase was limited to the NMR sensor.

Research has been completed, and an NMR sensor has been developed for measurement of moisture in fine-grained soils. The prototype model has undergone laboratory testing and is considered suitable for further development and field evaluation.

The technology on which the prototype sensor is based is described in a paper by Gardner & Matzkanin, published in TRB Record 532. The essential findings of the study have been published in NCHRP Research Results Digest 75. Information contained in the project report is expected to be published ultimately 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, bnild a prototype model, and conduct a laboratory verification program for a sensor capable of measuring moisture in granular and soil materials that would be suitable for highway needs.

Research has been completed, and a sensor has been developed based on the use of electrical capacitance as a measure of soil moisture. The prototype model has undergone laboratory testing and is considered suitable for further development and field evaluation.

The technology on which the prototype sensor is based is described in a paper by Selig, Wobschall, Mansukhani, and Motiwala, published in TRB Record 532. The essential findings of the study have been published in NCHRP Research Results Digest 75. Information contained in the project report is expected to be published ultimately 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 2, 1976
Funds: $150,000

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 and capacitance technology have been developed under these projects and subjected to laboratory testing.

The objective of this project is the further refinement and field evaluation of the two prototype moisture sensors developed under Projects 21-2 and 21-2(2). The research program will consist of the following tasks:

1. Further development and fabrication of refined sensors of both electrical capacitance and NMR types plus ancillary readout instrumentation for field installation and evaluation.

2. Field installation, data collection, and evaluation of the fabricated sensors in New York, Texas, and two additional states, with sensors to remain implanted for at least one year.

3. Simulated field installation and evaluation of the fabricated sensors in parallel under a wider range of soil,

compaction, moisture, and contamination conditions than can be encountered in actual field installations.

To facilitate administration and management of the research, the contract has been executed with Southwest Research Institute, with the State University of New York at Buffalo as a substantial subcontractor and Dr. E. T. Selig as co-principal investigator.

Several improvements and refinements of the prototype NMR and dielectric sensors have been made and readout instruments have been designed and fabricated for both sensor types. Both sensor types depend on empirical calibration for particular soil conditions. Both use rather complex electronic systems as readout instruments but each readout instrument is portable and can be used with several sensors at one site and can be moved from site to site. The readout is a digital value that can be converted to amount of water per unit volume from a table or chart. This can be converted to percent water on a dry weight basis using the dry density of the soil. The sensors have been installed in the fine-grain subgrade soil under in-service pavements in Arizona and Pennsylvania. Data collection will be over a 12-month period. Technical performance and practicality of the sensors will be evaluated. Simulated field installation and evaluation work will be conducted in the SUNY laboratories.

AREA 22: VEHICLE BARRIER SYSTEMS

Project 22-1 FY '69

Concepts for Improved Traffic Barrier Systems

Research Agency:	Walter W. White
Principal Invest.:	Walter W. White
	Marvin A. Shulman
Effective Date:	October 1, 1970
Completion Date:	December 31, 1971
Funds:	$25,000

Conventional traffic barrier systems are presently being applied widely by highway and bridge engineers. All of these existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized, longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails. The system should present a reasonably consistent appearance to the motorist as he moves along the highway and over structures, although parameters (such as height, post spacing, section properties, and anchorage) may vary to suit the application. Emphasis should be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

The objective of the research was to produce one or more traffic barrier system designs, described with sketches and narrative to the degree necessary to convey understanding, that offer promise of: preventing penetration by a standard-size U.S. automobile weighing 4,000 to 5,000 lb and impacting at 25° and 65 mph; smoothly redirecting errant vehicles relatively parallel to traffic flow; providing a range of controlled dynamic deflections by varying design parameters; retaining longitudinal continuity following a collision; permitting adequate visibility; being capable of quick and easy repair; performing satisfactorily in various foundation conditions; limiting decelerations at the center of gravity of the vehicle to 5g lateral, 10g 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 will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*.

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 final report is in the NCHRP editorial and publication process.

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 Dates:	Jan. 1, 1972	Oct. 1, 1973
Completion Dates:	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 advisory 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 advisory 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. A summary of the tests results and other information on this terminal are contained in NCHRP Research Results Digest 43 (October 1972). 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. The results of this effort are reported in NCHRP Research Results Digest No. 53 (December 1973). Publication of an NCHRP report covering the findings of this first phase of research was postponed pending completion of additional work on the BCT in Phase II.

Phase II research has been completed. It 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.

A final report covering development of the BCT under both phases of research is in the NCHRP editorial and publication process. Meanwhile, copies of the uncorrected drafts of the agency's final reports may be obtained on a loan basis by request to the NCHRP Program Director.

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 22-3 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." Copies of the uncorrected draft of the agency's report may be obtained on a loan basis by request to the NCHRP Program Director.

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." Copies of the uncorrected draft of the agency's report may be obtained on a loan basis by request to the NCHRP Program Director.

SUMMARIES OF UNPUBLISHED REPORTS

Research reports emanating from NCHRP projects normally are published in the *NCHRP Report* or *Synthesis of Highway Practice* series of the Transportation Research Board. When a final report is not published in this manner, a summary is included in an issue of the annual *NCHRP Summary of Progress* to provide adequate circulation of the outcome of the research. Two such summaries are included herein.

The opinions and conclusions expressed or implied in these summaries are those of the research agencies that performed the research. They are not necessarily those of the Transportation Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, or the individual States participating in the Program.

Persons having deeper interest in the subject matter of either of these projects can obtain information on securing copies of the agencies' reports by writing to University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48103.

Projects 12-1 and 12-6 FY '65 and '67

Permanent Deflections and Loss of Camber in Steel Bridge Beams

By: J. W. Baldwin, Jr.
D. L. Guell
Research Agency: University of Missouri

Introduction and Research Approach

Description of the Problem

Observations of bridges in the AASHO Road Test indicated that permanent deformations and loss of camber occurred in the steel beams even when the stress level computed from measured strain was below the known yield point of the steel. This finding raised a question as to what stresses, in addition to those caused by loading, were present in the beams so that the total stress exceeded the yield point. Furthermore, there are questions as to what extent similar conditions exist in typical highway bridges and whether they are significantly influenced by the choice of a cambering method.

Objective and Scope

The findings presented in this report are the results of two research projects: Project 12-1, "Deformation of Steel Beams Related to Permitted Highway Bridge Overloads," and Project 12-6, "Prediction of Permanent Camber of Bridges."

The complete documentation of the research is contained in Appendices II through V of the agency report, which are not published herein. The appendices are available from University Microfilms.* The material for Project 12-1 is documented in Appendix II, "Permanent Deflections in Highway Bridge Beams." Project 12-6 research is documented in Appendix III, "Effect of Cambering Method on Loss of Camber in Wide-Flange Steel Beams; Appendix IV, "Flame Cambering of Wide-Flange Steel Beams; and Appendix V, "Temperature Prediction in Flame Cambering of Wide-Flange Steel Beams."

The scope of both projects included:

1. A survey of available field data concerning evidence of permanent deformations in existing highway bridges.
2. A survey of available data on residual stresses in rolled beams.
3. A survey of existing practices for cambering beams and a categorization of cambering methods.
4. For composite construction, the determination of the effects of slip in the shear connection, shrinkage of the concrete slab, and creep in the concrete slab.
5. The determination of the magnitude and distribution of residual stresses, and the variation of yield point in steel beams as rolled and delivered to the fabricator without camber.
6. The determination of the effect of certain cambering methods on residual stresses.
7. The determination of permanent deformation in steel beams, with and without camber, subjected to repeated loads of various levels lower than those causing computed yield point stress. The number of cycles of load applied was to approximate six months of service load on a bridge.
8. The development of a method of analysis to predict the permanent deformation of steel beams.

Project 12-1 included analytical and experimental studies of one as-received and one cold-cambered noncomposite 27 WF 94 beam 36 ft in length and one concrete-on-steel composite beam 36 ft in length.

* University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48103.

Project 12-6 involved analytical and experimental studies of noncomposite beams in the as-received condition as well as beams cambered by four different methods—cold cambering and three methods of flame cambering. The flame-cambering methods are referred to as continuous heating, wedge heating, and spot heating. Two different beam sections (27 WF 94 and 27 WF 160) were examined. These shapes were selected because they are representative of beams used in highway bridges and they present a wide difference in flange thickness. Beams were coded according to size and method of cambering as given in Table 1.

TABLE 1

TEST BEAM DESIGNATIONS

BEAM		
27WF160	27WF94	DESCRIPTION
AC1	BC1	Cold cambered and used for residual stress and yield point determination
AC2	BC2	Loaded as received, cold cambered, and reloaded
AF1	BF1	Flame cambered by continuous heating and loaded
AF2	BF2	Flame cambered by wedge heating and loaded
AF3	BF3	Flame cambered by spot heating and loaded

Experimental Study

Residual Stresses and Yield Point.—The initial step in the experimental work was to determine the residual stress and yield point distributions in test beams as they were received from the mill. Because these determinations are destructive in nature, distributions obtained for each beam size were assumed to exist for all beams of a single size and heat of steel. Residual stresses and yield point were also determined after cambering and again after load testing.

Static Test Series, Project 12-1.—Three beams were tested under static loading. The first test incorporated only the study of permanent deflections in noncomposite beams resulting from a combination of loading stresses and residual stresses as received from the mill. This phase included testing a 27 WF 94 steel beam 36 ft in length. The test procedure also served as a method of cold bending the beam for later testing.

The second test included consideration of residual stresses resulting from cold bending during fabrication. This test was accomplished by reverse loading the same 27 WF 94 beam that had been subjected to controlled cold bending during the first-phase test.

Effects of residual stresses on permanent deflections in composite beams were considered in a third test. A 36-ft composite section, which consisted of the 27 WF 94 steel beam employed in the first and second phases and a 6-in. by 60-in. concrete slab, was tested.

Cambering, Project 12-6.—All beams used for cambering and repeated-load testing for Project 12-6 were 36 ft long and were simply supported during both operations. In addition to these beams, each of the flame-cambered beams was accompanied by a 9-ft-long companion segment. These segments were cambered by the various methods and used to determine the residual stresses produced by the cambering technique.

Each long beam was instrumented to determine curvature and deflection during cambering. The flame-cambered beams were also wired with thermocouples to record temperature history during and after heating.

Mechanical Cambering.—The beams were cold cambered by simply supporting them at the ends and jacking against them with hydraulic rams. The two rams were spaced 5 ft 11 in. apart and positioned symmetrically about midspan.

Flame Cambering.—For the flame-cambering tests, care was taken to duplicate as nearly as possible the conditions found in practice. Continuous-heating equipment was borrowed from a fabricating shop for use in the laboratory. Instructions related to torch size and speed and gas pressure were obtained from the shop foreman. Cambering both by wedge heating and by spot heating was carried out in the laboratory by an experienced industry technician, whose specialty was flame cambering by those particular methods.

For the continuous-heating method of flame cambering, three torches were mounted on a motor-driven carriage that traveled on the top flange. The torches were spaced to apply heat to the entire flange width and each beam was heated over its entire length. The average speed was 12 in. per minute for AF1 and 16 in. per minute for BF1. Temperature-indicating crayons and thermocouples indicated that the surface temperature of the steel reached approximately 1,200 F.

For wedge heating, five sections along the length of each beam were heated. At each section a wedge-shaped area of the web was heated first, with the apex of the wedge at the bottom flange. After a short pause (approximately 3 min) to allow cooling, a rectangular area on the top flange directly over the wedge was heated. The area was approximately 5 in. long and covered the full width of the flange. Approximate heating times at each section were 6 min for the web area and 7 min for the flange. Temperature-indicating crayons showed that the surface of the flange remained above 1,200 F for as long as 7 min after heating had stopped. It was estimated (by the color of the steel) that the temperature was as high as 1,700 F.

Again for spot heating, five sections along the length of each beam were heated. At each section a rectangular area approximately 3 in. wide by 16 in. long on the top flange directly over the web was heated first. The width of this area did not cover the full flange width but was limited to about 3 in. Immediately after the flange was heated, a triangular area of the web was heated. This area was approximately 10 in. in both length and depth. Maximum

temperatures were approximately the same as those for wedge heating.

Repeated-Load Tests.—The load tests for Project 12-6 were repeated applications of design load and allowable overload. (Section 1.2.4 of AASHTO's *Standard Specification for Highway Bridges* specifies the allowable overload stress to be 150 percent of design load stress, which is 20,000 psi.). All load tests were conducted at 0.25 cycles per second using two hydraulic rams applied at the third points of the beam. During load tests, instrumentation on the beams measured beam load, deflection, curvature, and strain.

Beams AC2 and BC2 were first load tested as received; they were then cold cambered and load tested again. The test sequence was to apply:

1. Successively increasing increments of load to design load.
2. Approximately 200 cycles of design load.
3. Successively increasing increments of load to attain 1 cycle of allowable overload.
4. Approximately 20,000 cycles of design load.
5. Approximately 1,000 cycles of overload.

During steps 1 and 3, the beam was held at each load level to allow the deflection to stabilize. Because time was allowed for complete yielding during step 1, no additional loss of camber occurred during step 2. Similarly, no additional loss of camber occurred during steps 4 and 5 once 3 had been completed. Because of the desire to observe the effect of the repeated loading, the aforementioned loading sequence was altered for the remaining beams. The new sequence adopted was 2, 1, 4, 5, and 3.

Theoretical Analyses

One of the objectives of the research reported herein was to develop a rational method of analysis in order to predict the behavior of beams, both noncomposite and composite, uncambered and cambered. To achieve this objective, three theoretical analyses were developed. In order of their application to the cambering problem, they are:

1. "Temperature Prediction in Flame Cambering of Wide-Flange Steel Beams." A computer program was developed to predict the temperature field, as a function of time, in a beam during flame cambering.
2. "Flame Cambering of Wide-Flange Steel Beams." A computer program was developed to determine the induced curvature and stresses due to a given temperature history.
3. "Permanent Deflections Resulting From Residual Stresses." A computer program was developed to predict permanent deflection or loss of camber resulting from known residual stresses and a given loading.

The results of the first program were used as input to the second in order to predict residual curvature and stresses resulting from each method of flame cambering described earlier. The residual stresses thus obtained were used in the third program to determine loss of camber. In the case of uncambered beams, only the third program is needed. Because this program uses residual stresses as input, either theoretically or experimentally determined residual stresses can be used. A rather complicated combination of programs, described in Appendix II, was used in the analysis of the composite beam.

TABLE 2

COMPOSITE BEAM ANALYSIS

FACTOR	CASE 1	2	3	4	5
Initial stress	No	Yes	Yes	Yes	Yes
Slip	No	No	Yes	Yes	Yes
Strain softening (%)	No	No	No	10	50
Total midspan deflection at design loan (in.)	0.50	0.50	0.50	0.52	0.60
Permanent midspan deflection at design load (in.)	0.00	0.00	0.00	0.02	0.09
Total midspan deflection at nominal yield (in.)	0.97	1.03	1.08	1.14	1.30
Permanent midspan deflection at nominal yield (in.)	0.00	0.06	0.11	0.17	0.33

Findings

Permanent Deflections

Test Results, Project 12-1.—Measured residual stress and yield point distributions for the steel beam in the as-received condition are shown in Figures 1 and 2. Computed initial stresses in the composite test beam are presented in Figure 3.

Both experimental and predicted results for moment versus curvature and load versus deflection for the phase-one test are shown in Figures 4 and 5. Good agreement between the experimental and predicted values is observed.

Results of load versus deflection and permanent deflection for the phase-two test are shown in Figure 6. When both residual stresses and the Bauschinger effect are accounted for, the comparison between theoretical and experimental results is very good.

For the composite phase-three test, five theoretical cases were considered. These cases involved various degrees of composite action, initial stress, and strain softening as given in Table 2. The results of moment versus curvature and load versus deflection are shown in Figures 7 and 8. The agreement between the predicted (case 5) and measured deflections is excellent up to a load approximately 15 percent greater than the nominal yield load. Above this load, the measured deflection was less than the predicted value. During this loading, the bottom fibers of the steel beam were subjected to strains in excess of the yield strain for the third time. Although this may have caused some strain hardening in these fibers, it is also quite possible that the discrepancy between predicted and observed values was the

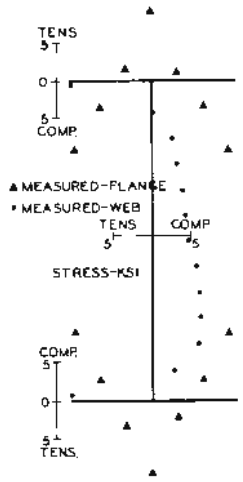


Figure 1. Residual stresses for the as-received test beam.

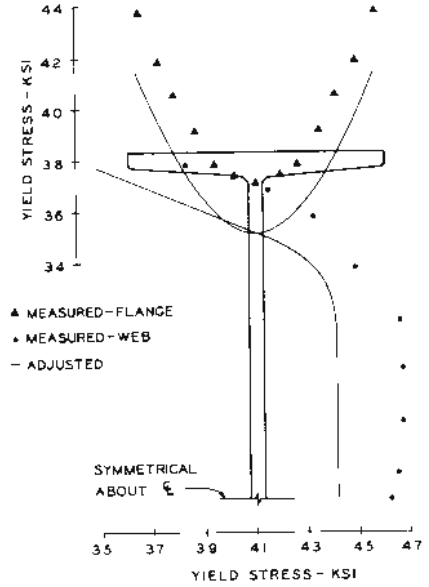


Figure 2. Yield point distribution for the as-received test beam.

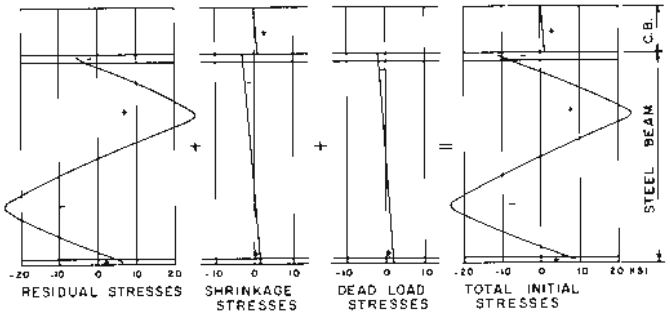


Figure 3. Computed initial stresses in composite test beam.

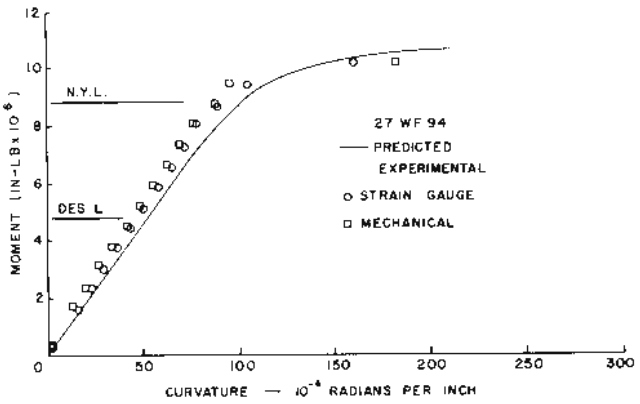


Figure 4. Moment vs curvature in the as-received test beam.

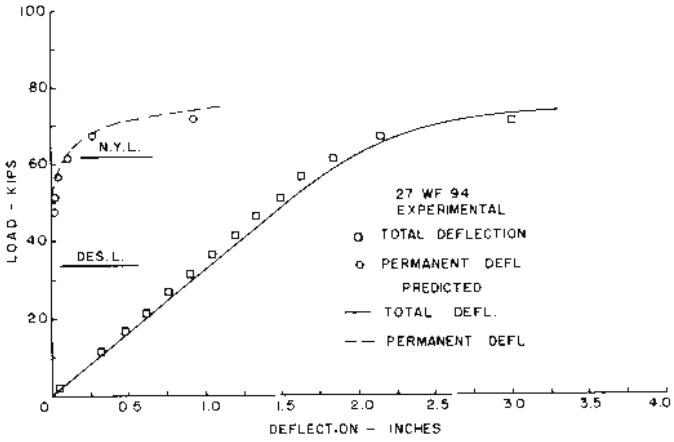


Figure 5. Load vs deflection in the as-received test beam.

result of assuming a strain softening ratio * of 50 percent for all fibers in the steel beams when the upper two-thirds of the beam were not actually being subjected to reversed yielding.

A plot of load versus permanent deflection is shown in Figure 9. Again, agreement between predicted (case 5) and measured deflection is quite good up to loads approximately 15 percent greater than nominal yield load.

* A detailed description of the strain softening ratio is given in Chapter II of Appendix II.

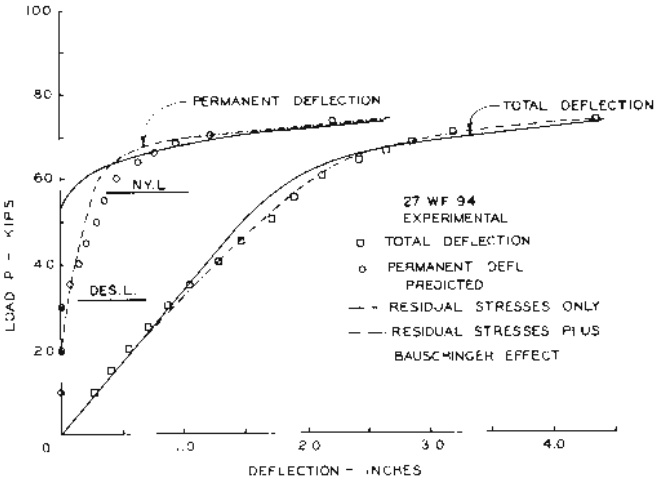


Figure 6. Load vs deflection in the cold-bent test beam.

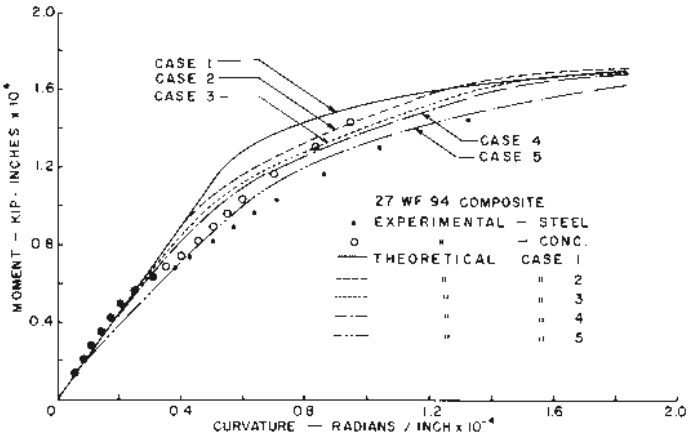


Figure 7. Load vs midspan curvature in the composite test beam.

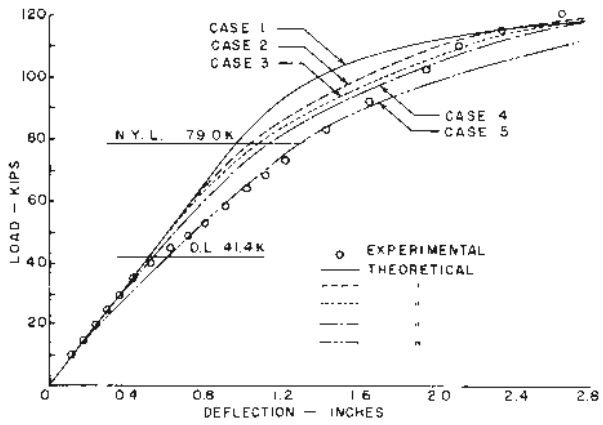


Figure 8. Load vs midspan deflection in the composite test beam.

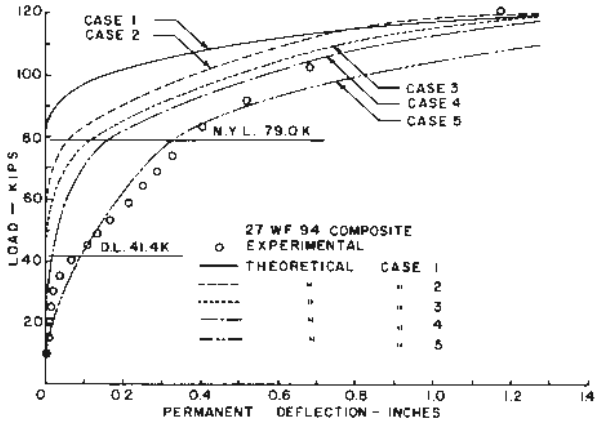


Figure 9. Load vs midspan permanent deflection in the composite test beam.

Figures 8 and 9 allow a comparison of the contributions of slip, residual stress, and strain softening. Table 2 also gives this comparison in tabular form. These comparisons make it clear that, up to nominal yield load, the elastic action is by far the largest contributor to total deflection with strain softening, residual stresses, and slip following in descending order of importance. Permanent deflection remaining after removal of the nominal yield load was approximately 34 percent of the elastic deflection under nominal yield load. Even though the test beam had substantially fewer shear connectors than required by the 1965 AASHO code, slip contributed very little to the permanent deflection.

Field Studies.—In an effort to obtain field data to which the results of the laboratory study could be compared, a questionnaire was sent to state and province bridge officials in the United States and Canada; city engineers or planners for cities in the United States having a population of 250,000 or over; members of the AASHTO operating subcommittee on bridges and structures; and bridge engineers for the major railroads in the United States and Canada. The initial questionnaire was a simple business-reply card with a place for the respondent to check whether or not his department had data concerning permanent deflections in bridge stringers and whether they would be willing to furnish this information. Of the 190 questionnaires mailed, 90 were returned. Of these, only 15 replies were affirmative. Follow-up of these 15 replies produced only two useful sources of information.

One source of information was an agreement with the Highway Division, Department of Transportation of the State of Hawaii, to instrument a bridge under construction and to follow-up measurements for a period of 6 months after the bridge was open to traffic. The other source of information was the California Division of Highways, which furnished data on 12 bridges. Data related primarily to slab shrinkage and agreed quite well with predicted values.

Effects of Cambering

Survey of Cambering Methods.—The original research plan for Project 12-6 called for a questionnaire in order to determine the method of cambering most commonly used by producers and the major fabricators. However, initial site visits and telephone inquiries revealed little if any standardization of flame-cambering methods. It seems that each shop foreman and each iron worker has his own special technique and his own set of terms to describe the process. Therefore, the development of a simple survey questionnaire was not feasible. However, discussions with a number of individuals who practice flame cambering revealed that most techniques are derived from combinations or variations of the three basic processes referred to herein as continuous heating, wedge heating, and spot heating.

Site visits revealed a low degree of quality control in current practices. For example, although cold cambering of beams is a rather simple process that is easily described, cold-cambered beams exhibit considerable variation in amount of camber. In addition, some beams become overcambered and, subsequently, are reverse loaded to reduce the over-camber; others are deformed only once. As a result, adjacent beams in a bridge can exhibit greatly different properties in regard to loss of camber.

Yield Point and Residual Stress, Project 12-6.—Typical as-received yield point variations are shown in Figure 10. Table 3 summarizes the results of the yield point deter-

minations before and after cambering. Although the cambered AC1 beam exhibits a somewhat higher yield point than the as-received beam, Table 3 does not indicate any other significant change in yield point resulting from any of the cambering methods investigated.

Results of the as-received residual stress determinations for the two beam sizes are shown in Figure 11. Some representative plots of experimental and theoretical residual stresses resulting from cambering of the Project 12-6 beams are shown in Figures 12 and 13. It was found that all four methods of cambering produced undesirable tensile residual stresses in at least part of the flange that carries tension under service conditions. Residual stress patterns varied considerably depending on the cambering method used and, in some cases, substantial discrepancies existed between the theoretical and experimental values. Both predicted and measured residual stresses exceeded 60 percent of the yield point in at least one location in all flame-cambered beams.

Part of the discrepancy between experimental and predicted results is attributed to the failure of the analysis to correctly predict the complete temperature-time relationship of every beam fiber during both heating and cooling. The residual stress field induced by heat is very sensitive not only to the maximum temperature but also to the temperature-time relationship for every beam fiber during both heating and cooling.

In predicting the temperature-time relationship for the wedge-heating technique, the flange heating pattern was simulated as a uniform heat flux applied over the top flange. This pattern did not yield good residual stress predictions. Subsequent examination of the moving pictures filmed during cambering indicated that there was a significantly different heating pattern. Thus the simulation was not valid, and large discrepancies are to be expected. The actual heating sequence was so complex and so dependent on visual feedback to the operator that it was impossible to model accurately.

Another factor that affected the accuracy of the predicted residual stresses was the assumption that plane sections before heating remain plane during heating and after cooling. Figure 14 shows typical plots of the average-strain distributions for three of the beams. Examination of the graphs shows that the assumption was good for continuous heating, fair but not completely correct for wedge heating, and considerably in error for spot heating.

In the cases of spot heating and wedge heating, the accuracy of observed residual stresses was also affected by the highly localized nature of the heating. The experimental residual stresses shown in Figures 12 and 13 were determined from strains measured over a 10-in. gauge length and represent the average residual stress over that length. In cases where only a part of this length was heated, it is highly likely that the maximum stress was considerably higher than the average.

The residual stress distribution remaining after completion of the loading sequence was experimentally determined for all beams except BC2, which was badly deformed by a malfunctioning ram. Predictions were made for the residual stresses after loading based on both the measured camber-induced residual stresses and the calculated camber-induced residual stresses. Figure 15 gives example plots showing comparisons of the experimental and predicted residual stresses with the beam oriented in the loading position (reversed from the cambering position).

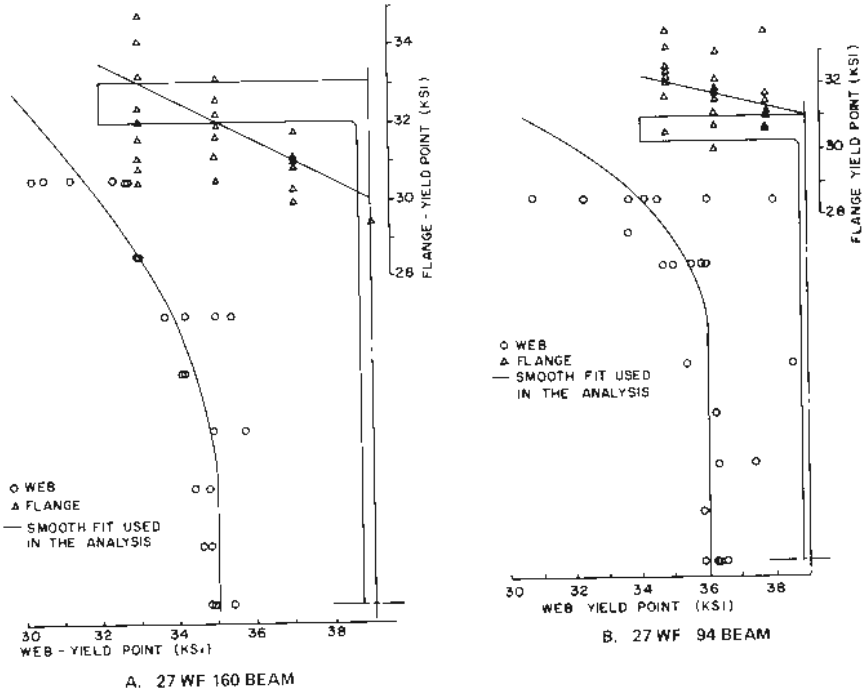


Figure 10. Yield point distributions for as-received test beams.

Camber and Loss of Camber, Project 12-6.—Experimental and predicted results for the camber are given in Table 4. The use of a deflection control method for cold-cambering beams in the laboratory resulted in good agreement between experimental and predicted values of camber for beams AC2 and BC2. The accuracy of the predicted camber for the flame-cambered beams was, in general, not as good as for cold cambering. Differences occurring between the wedge- and spot-heated beams are believed to be due to the difficulty in accurately modeling the heating process for these techniques of flame cambering. Also involved is the determination of the exact effective length of the heated zone.

Experimental and predicted loss of camber due to design load and permitted overload are also given in Table 4. The predicted loss of camber was determined using both experimental and theoretically predicted residual stresses resulting from cambering. A typical graph of the loss of camber with cycles of design load and overload is shown in Figure 16. In all cases, it was found that for any load level no additional loss of camber occurred after a (static) cycle

TABLE 3

YIELD POINT STRESS[a] IN TEST BEAMS

BEAM	LOCATION (SEE DRAWING) 1	2	3	4
AC1	30.7	30.2	32.7	34.9
As Received	30.8	30.9		
	31.5	31.0		
AC1	33.1	31.8	31.3	34.8
Cambered	32.0	31.1	32.8	
	34.1	29.9		
	34.7	31.0		
AF1				
Cambered	32.4	30.4	30.6	35.4
AF2				
Cambered	30.4	29.9	30.3	—
AF3				
Cambered	31.0	30.2	32.4	—
BC1	32.3	30.7	33.6	36.5
As Received	32.0	31.5	34.1	35.9
BC1	32.4	31.1	32.3	36.2
Cambered	32.2	31.4	30.7	36.3
	31.6	31.7		
BF1				
Cambered	33.6	30.6	36.0	—
BF2				
Cambered	33.2	33.6	34.5	—
BF3				
Cambered	30.5	34.6	38.0	—

[a] In ksi.

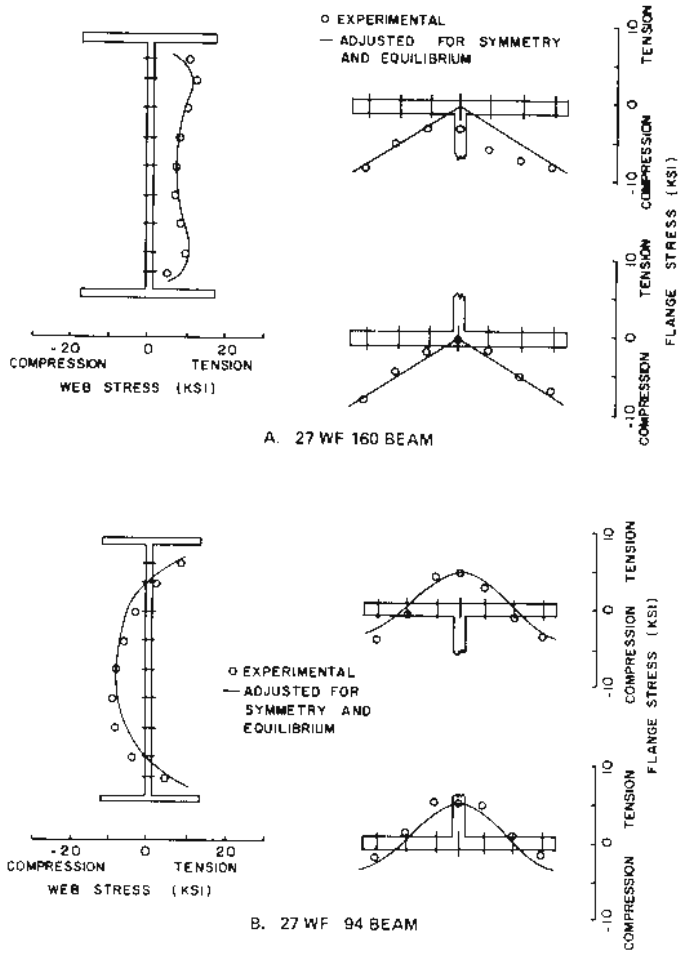
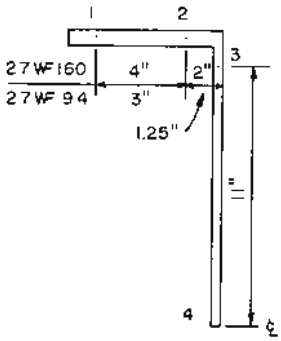


Figure 11. Residual stress for as-received test beams.



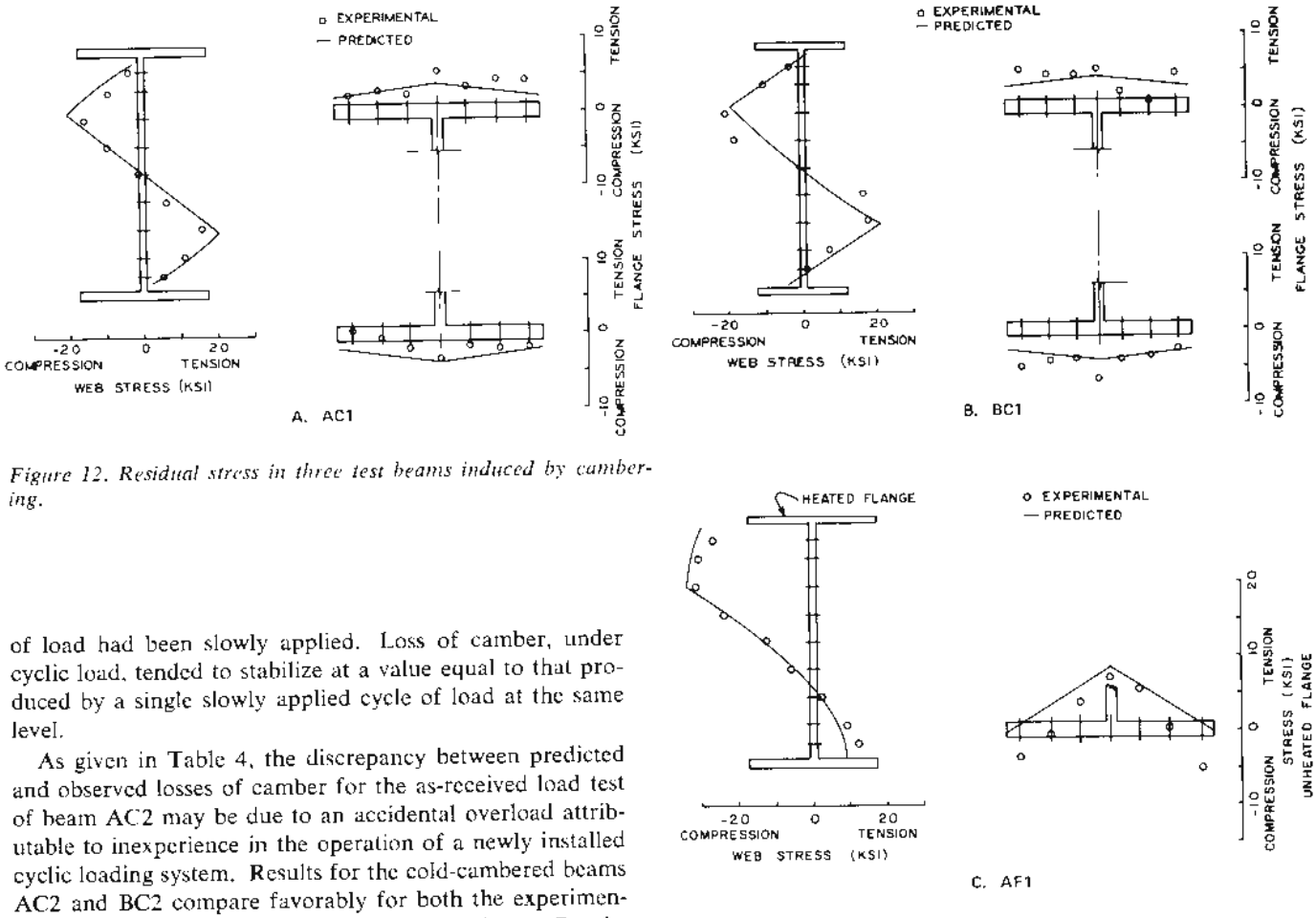


Figure 12. Residual stress in three test beams induced by cambering.

of load had been slowly applied. Loss of camber, under cyclic load, tended to stabilize at a value equal to that produced by a single slowly applied cycle of load at the same level.

As given in Table 4, the discrepancy between predicted and observed losses of camber for the as-received load test of beam AC2 may be due to an accidental overload attributable to inexperience in the operation of a newly installed cyclic loading system. Results for the cold-cambered beams AC2 and BC2 compare favorably for both the experimental and predicted residual stress distributions. Results showed that the experimentally determined curvature for

TABLE 4

LOSS OF CAMBER IN TEST BEAMS

	CAMBER (IN.)		LOSS OF CAMBER (IN.)					
					PREDICTED			
					EXPERIMENTALLY DETERMINED RESIDUAL STRESSES		ANALYTICALLY DETERMINED RESIDUAL STRESSES	
			EXPERIMENTAL					
BEAM	EXPERIMENTAL	PREDICTED	DESIGN LOAD	OVERLOAD	DESIGN LOAD	OVERLOAD	DESIGN LOAD	OVERLOAD
AC2 as received	—	—	0.021	0.309	0.000	0.180	—	—
AC2 cambered	1.675	1.593	0.261	0.741	0.284	0.735	0.289	0.755
AF1	1.820	1.810	0.137	0.555	0.292	0.769	0.319	0.860
AF2	1.623	1.184	0.028	0.302	0.005	0.282	0.084	0.339
AF3	1.647	0.543	0.063	0.248	0.046	0.278	0.058	0.273
BC2 as received	—	—	0.021	0.309	0.000	0.180	—	—
BC2 cambered	1.534	1.500	0.211	0.625	0.258	0.678	0.266	0.660
BF1	1.535	2.790	0.418	0.961	0.572	1.164	0.861	1.520
BF2	1.694	0.606	0.041	0.388	0.000	0.194	0.092	0.232
BF3	1.592	0.624	0.050	0.298	0.034	0.165	0.051	0.155

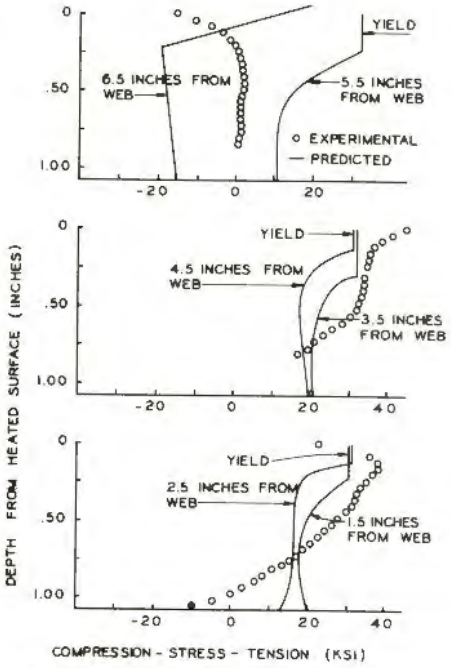


Figure 13. Residual stress induced by cambering in heated flange of beam AF1.

the companion beam segments was greater than that of the parent beam for the beams cambered by continuous heating. Thus the measured residual stresses were larger in the companion beams and the predicted loss of camber based on these measured residual stresses was greater than that observed in the test beam. Because of the wide variations in curvature at the heated regions in a beam subjected to wedge or spot heating, the experimentally determined residual stresses from the companion beam segments represented a rather crude approximation of the actual residual stresses in the parent beams. Thus, close comparisons for loss of camber were not achieved, but a relative order to the loss of camber was obtained. In all cases the losses of camber resulting from wedge and spot heating were very nearly equal, and specimens cambered by either method exhibited much lower loss of camber than those cambered by either continuous heating or cold bending.

Microstructure.—When it was realized that flange temperatures were well above the recrystallization temperature during the wedge- and spot-heating procedures, there was concern about the possibility of grain growth in the steel. A total of 24 metallographic specimens were cut, polished, etched, and photographed under a metallurgical microscope to determine grain size. Half of these specimens were cut from heated zones and half from unheated zones in the test beams.

Although there was considerable random variation in the grain size, there was no indication that any of the flame-cambering methods significantly affected the grain structure of the steel. Tension tests of coupons cut from the heated zones indicated that there was also no appreciable change in the mechanical properties of the steel.

Interpretation, Appraisal, and Application

General

The findings of this study make clear that, in addition to the normally computed effects of loading, the following factors may produce permanent deflections in highway bridges:

1. Effective static yield point of material below nominal yield point.

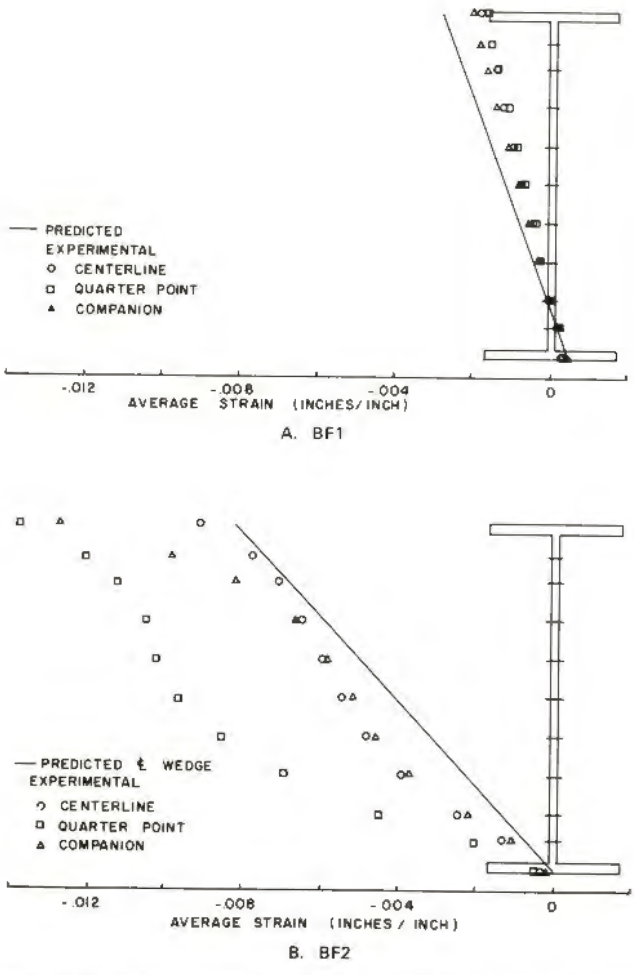


Figure 14. Average-strain distributions resulting from flame cambering.

2. Cooling residual stresses.
3. Cold-bending residual stresses.
4. Strain softening (Bauschinger effect).
5. Shrinkage of concrete deck slab.
6. Slip in the shear connection.

From a research standpoint, all of these factors can be predicted with a reasonable degree of accuracy when sufficient information is available about the fabrication history of the beam and when sufficient effort is devoted to measurement of material properties. From a practical design standpoint, however, accurate prediction of the permanent deflections resulting from these factors is very difficult. Some of the needed information simply does not exist at the time a beam is designed, and the net effect of some factors is not great enough to justify the cost of measurements and analyses. However, a knowledge of the bounds on deflections, which can be caused by various factors, combined with engineering judgment should produce estimates of permanent deflections entirely satisfactory for design purposes.

The field survey undertaken as part of this project indidates that, quantitatively, very little is known about the occurrence of permanent deflections in the field. There is doubt as to whether permanent deflection or loss of camber has been a problem in any bridges to date. During the past few years, however, there has been sufficient concern about the riding qualities of bridges that several new bridges have been instrumented and are under observation.

Effective Yield Point.—Because yielding is a time-dependent phenomenon, the effective yield point under a static or very slowly applied load is somewhat lower than that indicated by a standard tension test. In addition, there is considerable variation in the yield point of the material across the section of a beam, and the lower yield points usually occur in the flanges whereas mill test specimens are taken from the web. A combination of these factors may result in an effective flange yield point under static load being as much as 15 to 20 percent below the nominal specified yield point, particularly in beams with thick flanges. This in itself poses no particular problem so long as permitted overloads do not produce stresses greater than approximately 80 percent of the nominal yield point. Unfortunately, the highly nonlinear nature of the relationship between stress and permanent deflection causes this reduction in effective yield point to greatly magnify the deflections resulting from the Bauschinger effect.

Residual Stresses.—Residual stresses resulting from differential cooling after rolling are present in all rolled sections. Although some investigators have reported cooling residual stresses as high as 17 or 18 ksi for smaller beams, a maximum value of 10 ksi was found in the current study. It should probably be noted that measuring residual stresses in beams as received from the mill does not ensure that these residual stresses are due to cooling alone. The straightening processes used in the mill on large rolled sections induce cold-bending residual stresses, which are partially superimposed on cooling residual stresses. As a result there may be considerable variation in the residual stresses along the length of a beam. However, cold-bending residual stresses in the flanges of heavy wide-flange sections have a relatively small magnitude on the order of 5 or 6 ksi. Thus, even a combination of cooling and cold-bending residual stresses is not in itself sufficient to cause yielding at the normal design load. Even with permitted overloads the contribution to permanent deflection is relatively small.

Strain Softening.—The strain softening (Bauschinger effect) that accompanies cold bending in the mill or fabricating shop is a much more significant factor than the cold-bending residual stresses. Although the Bauschinger effect does not lower the yield point in structural steel as is sometimes implied, it does reduce the elastic limit well into the normal working-stress range. For the beam tested during Project 12-1, the permanent deflection due to a combination of cooling residual stresses, cold-bending residual stresses, and the Bauschinger effect was essentially zero at working load levels and 12 or 13 percent of the nominal elastic yield deflection following an application of permitted overload. However, the average static yield point of the flange in this beam was approximately 37.5 ksi. The permanent deflections were much higher for beams AC2 and BC2 in Project 12-6, wherein the average static flange yield points were approximately 31.5 ksi. Expressed as percentages of nominal elastic yield deflection, the permanent deflections in beams AC2 and BC2 were 15 and 12 percent, respectively, when subjected to design loads and 42 and 35 percent, respectively, when subjected to permitted overloads.

Slab Shrinkage.—All of the foregoing factors that contribute to permanent deflections in noncomposite beams also contribute to permanent deflections in composite beams. In addition, shrinkage of the concrete deck slab contributes to permanent deflections in composite beams. When known, the concrete shrinkage contribution to permanent deflection is relatively easy to calculate, but accurate predictions of shrinkage values in field-placed concrete are extremely difficult to make. Bridge deck shrinkage commonly varies from 0.0001 to 0.0003 in. per inch. Findings of this study indicate that in most cases permanent deflections resulting from deck slab shrinkage usually range from 30 to 60 percent of the elastic deflection caused by deadload of the deck.

Slip in the Shear Connection.—Slip in the shear connection contributes to the deflection of composite beams in two ways. Once the chemical bond has been broken, the shear connection is basically elastic in nature and the stiffness of the composite beam may be 10 to 15 percent less than that computed for the transformed section. Friction in the shear connection can then prevent complete recovery of the slip following removal of the load and can result in permanent deflection. However, when a shear connection includes sufficient connectors to fully develop the strength of the beam, permanent deflections resulting from slip in the shear connection are less than 5 percent of the nominal elastic yield deflection.

Cambering

Current Specifications and Practice.—The maximum and minimum cambers that can be produced at the mill are specified in the *Manual of Steel Construction* of the Ameri-

can Institute of Steel Construction. For cambers that exceed the maximum allowed by cold-cambering or where reverse or compound curves are required, cambering by heat in fabricating shops is suggested. Although the specifications make no specific mention of heating pattern, they do state:

> The mechanical properties of steels are largely unaffected by heating operations provided that the maximum temperature does not exceed 1100°F. for quenched and tempered alloy steels and 1,200°F. for other steels. The temperature should be carefully checked by temperature-indicating crayons or other suitable means during the heating process.

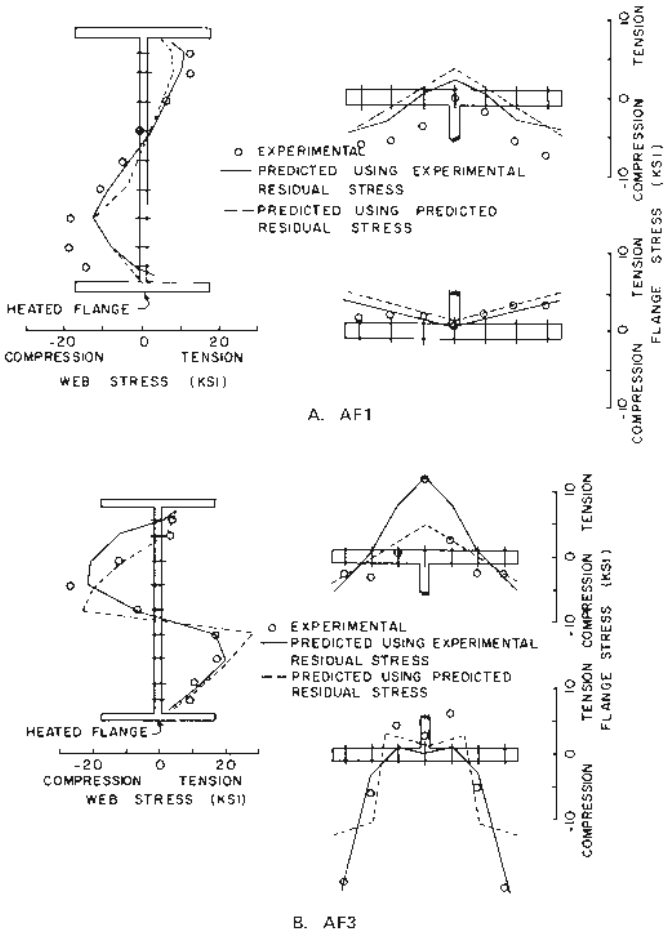


Figure 15. Residual stress after load test.

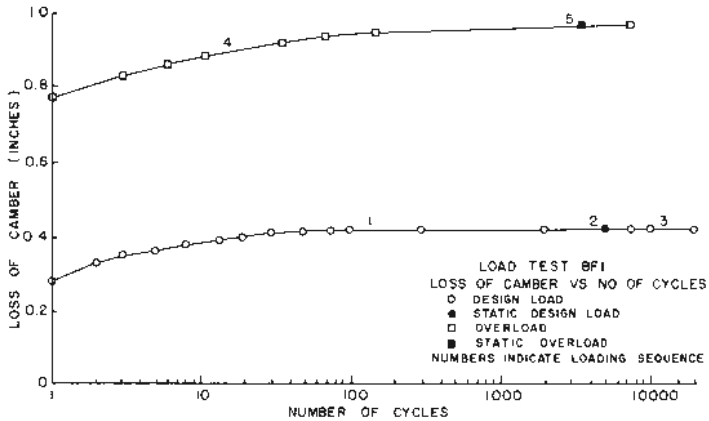


Figure 16. Loss of camber during cyclic load test for beam BF1.

Specifications used in both Wisconsin and New York limit the maximum temperature during heat cambering to 1,200 F. The Wisconsin specifications include:

> . . . The camber shall conform to a uniform, approximately circular curve. . . Camber may be prodnced either in the rolling mill, or in the fabricating shop by gaging, or it may be produced or corrected by local heating. . . The areas to be heated shall be so selected that distortion other than the required camber will not occur. A procedure shall be followed that precludes warpage of the beam flanges. When such procedure entails heating along the fillets as well as along the center portion of the outer face of the flange, the heat shall be applied to the fillets from each side simultaneously. Cambering by heating vertical sections of the web will not be permitted. Not less than three sections located approximately at the quarter points and at the centerline of the beam shall be heated. The length of each section shall he equal to approximately one and one-half times the depth of the beam. . . .

The primary objective was to duplicate field practice in the laboratory study rather than to satisfy specifications. As a result, only the cold-cambering and continuous-heating procedures satisfied the foregoing specifications. It is interesting to note, however, that those procedures that did not satisfy the specifications seemed to produce the best results.

Both the wedge- and spot-heating procedures greatly exceeded the 1,200 F maximum allowable temperature limit. However, specimens cut from these areas indicated that there was no appreciable grain growth in the steel or any apparent change in physical properties. Thus, there is serious doubt whether some of these restrictions are necessary or even desirable.

Evaluation of Cambering Procedures.—All of the cambering methods examined during this project induced unfavorable residual stress patterns that reduced the elastic limit of the beam and resulted in some (very small, in many specimens) loss of camber under permitted overloads. However, none of the cambering techniques proved to be detrimental to the strength of the beams tested in the laboratory. The residual stresses induced in the flanges by cold-bending were smaller in magnitude than those induced by any of the three flame-cambering procedures investigated. However, because of strain softening (Bauschinger effect), the reduction of the elastic limit and subsequent losses in camber were greater for the cold-cambering method than for two of the flame-cambering procedures. Figure 17 shows these phenomena by means of a plot of moment versus curvature for all of the test beams.

Load versus deflection graphs, shown in Figure 18, were prepared from the moment-curvature relationships. In general, deviations from the initial tangent line indicate permanent deflections or loss of camber. Loss of camber is influenced by the beam span and the lengths and locations of the zones affected by the cambering procedure in addition to the factors affecting curvature. This fact is illustrated by comparing Figures 17A and 18A. The moment-curvature relationships for beams AC2 (cambered) and AF3 are nearly the same, hut examination of the load-deflection plot

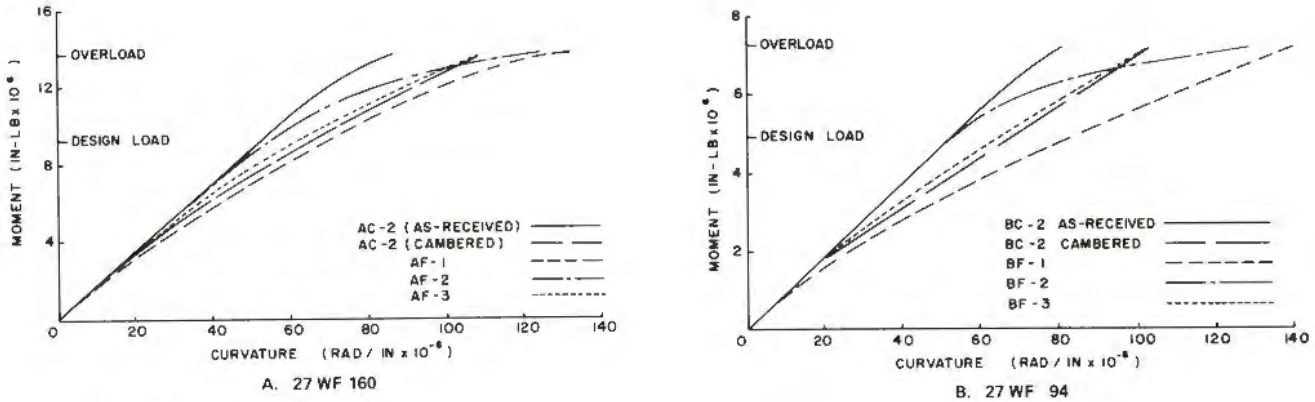


Figure 17. Moment vs curvature for test beams.

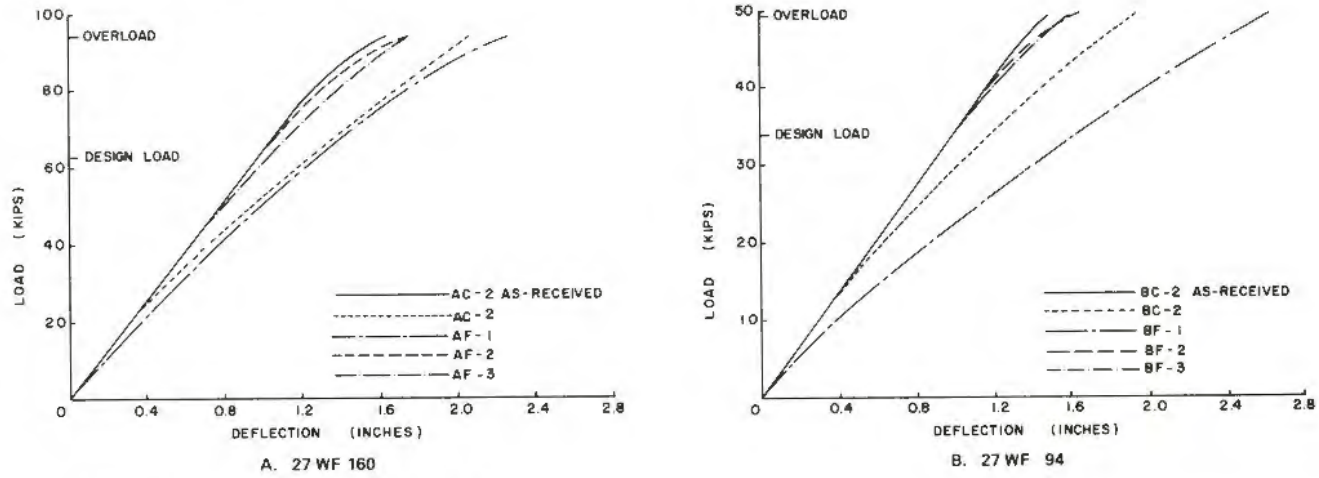


Figure 18. Load vs. deflection for test beams.

shows AC2 to have much greater deflection than AF3 because the spot-heating procedure (AF3) affected only short lengths of the beam while cold-cambering (AC2) affected the entire central section of the span. The point loading used in standard mill cold cambering would probably result in a loss of camber smaller than that of AC2 but larger than that of AF3. Tabular comparisons of camber losses are given in Table 5 as a percentage of the nominal elastic deflection at incipient yielding.

Suggested Cold-Cambering Procedure.—All of the load tests indicated that, regardless of the magnitude of camber or method of cambering, the camber essentially stabilized after the application of one slowly applied cycle of permitted overload. This observation and an understanding of

TABLE 5

PREDICTED VALUES OF PERMANENT CURVATURE OR DEFLECTION EXPRESSED AS PERCENTAGES OF THE NOMINAL ELASTIC YIELD CURVATURE OR DEFLECTION

	CURVATURE (PERCENTAGE)		DEFLECTION (PERCENTAGE)	
BEAM	DESIGN LOAD	OVERLOAD	DESIGN LOAD	OVERLOAD
AC2 as received	0	10	0	10
AC2 cambered	16	37	16	41
AF1	14	53	16	43
AF2	3	48	0	16
AF3	14	32	3	16
BC2 as received	0	4	0	5
BC2 cambered	16	40	14	38
BF1	36	72	32	65
BF2	0	55	0	11
BF3	13	30	2	9

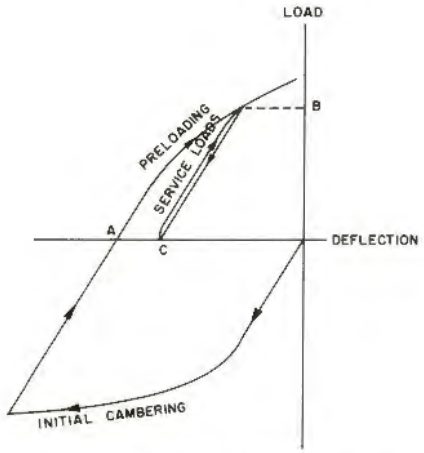


Figure 19. Cambering-overloading procedure.

the mechanism through which loss of camber occurs leads directly to the idea that a bridge could be constructed that would suffer essentially no loss of camber under service conditions if a cycle of overload were applied to beams in the mill or fabricating shop. An overload tends to erase both the undesirable residual stresses and the Bauschinger effect and tends to produce a favorable residual stress pattern, which effectively raises the elastic limit of a beam.

Although the principle of overloading applies to both flame-cambered and cold-cambered beams, the equipment required for overloading would also be suitable for cold bending so that it would probably be more economical to carry out the entire process in a single operation. The cambering process would then proceed as shown in Figure 19, in which point A is the initial camber, point B is the load that produces the allowable overload, and point C is the desired camber. Once the beam had been loaded to point B, the beam would have an elastic behavior at loads below the overload, B.

The application of overload in the mill or fabricating shop would require that the initial camber be greater than the desired camber by an amount equal to or greater than the expected loss of camber. Table 5 indicates that for cold cambering the expected loss of camber is approximately 40 percent of the nominal elastic yield deflection. Since any load equal to or greater than the permitted overload stabilizes the beam, an over-camber of 50 to 60 percent of the nominal elastic deflection at first yielding should be sufficient when cold cambering. To provide proper quality control, both the processes for cambering and overloading should be controlled on the basis of deflection.

Conclusions

1. Because the apparent yield point of a material is sensitive to the rate of loading, yielding may occur in a beam under slowly applied overloads at stresses substantially less than the nominal yield point, which must be satisfied by a standard mill test. This phenomenon is a potential source of permanent deflection in all beams, both cambered and uncambered, and regardless of the cambering method.

2. Residual stresses in as-received beams may be of sufficient magnitude to cause small permanent deflections in beams following permitted overloads.

3. Residual stresses of only 5 or 6 ksi are developed in the flanges during cold cambering. However, a strain softening phenomenon known as the Bauschinger effect combines with the residual stresses to produce losses of camber equal to or greater than those caused by all but one of the flame-cambering methods.

4. Individual beams in a single lot may exhibit wide variations in loss of camber under service conditions if during cold cambering part of the beams are overcambered and subsequently reverse loaded to correct the camber. These variations can result in differential deflections between adjacent beams, which may very well contribute to deck deterioration.

5. Results of this study indicate that very stable beams, which should suffer virtually no loss of camber under service conditions, can be produced if all beams are intentionally overcambered and subsequently reverse loaded to reduce camber to the desired value.

6. Even though there was considerable error in predicting the actual residual stress distributions resulting from flame cambering, both theory and experiment indicate that residual stresses near the yield point are likely to result from all of the flame-cambering processes. These residual stresses in the tension flange of the beam result in some losses of camber under service load conditions.

7. Although the induced residual stresses are rather high, beams cambered by the spot- and wedge-heating methods suffer relatively small camber losses because residual stresses are induced in only small percentages of their lengths.

8. Effective use of the wedge-heating and spot-heating methods seems to require heating of the material above the critical temperature (1,500 F to 1,700 F). However, the A36 steel used in this study underwent apparently no significant metallurgical change and no significant change in mechanical properties.

9. Flame cambering by continuous heating produces high residual stresses throughout the length of the beam that result in large losses of camber.

10. Loss of camber under cyclic loading increases during the first several hundred cycles of load but tends to stabilize at a value approximately equal to the loss following one slowly applied application of load.

11. In composite beams, shrinkage of the deck slab results in permanent deflections that, in most cases, vary between 30 to 60 percent of the elastic deflection caused by dead load of the slab. However, this deflection can be computed and compensated for by increasing camber.

12. Slip in the shear connection of composite beams may reduce the stiffness of the beam 10 to 15 percent, but the contribution to permanent deflection is relatively small.

13. Cold cambering and continuous heating are the most uniform and the easiest processes to model. Consequently, their results are predicted with the greatest accuracy. Because they involve human judgment factors, the spot-heating and wedge-heating processes vary considerably from beam to beam and are extremely difficult to model. As a result, predictions of residual stresses and camber loss are considerably less accurate than for continuous heating and cold cambering.

Project 15-2 FY '66

Design to Control Erosion in Roadside Drainage Channels

By: Dr. Alvin G. Anderson
Research Agency: University of Minnesota

Introduction

The objective of NCHRP Project 15-2 has been to develop criteria and design procedures for the use of aggregate or riprap linings for drainage channels suitable for conditions intermediate between those for which turf cover performs satisfactorily and those for which paved channels or pipe flumes are more economical. The tentative design procedures, developed from analysis of previous research on sediment transport and verified by limited experimental testing in the hydraulics laboratory, were published in *NCHRP Report 108,* "Tentative Design Procedures for Riprap-Lined Channels." During the field evaluation phase of the study, riprap linings for five channels were designed in accordance with the procedures described in Report 108. Four of the channels have been constructed and are performing satisfactorily. Two have been subjected to discharges approaching the design discharges without signs of erosion.

Findings

The drainage channels designed and constructed in accordance with the procedures described in Report 108 and subjected to field evaluation are listed in Table 1. Data used in the design of the riprap lining for each channel, and photographs of performance, are included in the field evaluation report, which has been distributed to all state highway agencies.

The Hop Brook site in Manchester, Conn., is a stream relocation with a design discharge much greater than that initially intended to be included within the scope of the project. The study procedures were extrapolated to determine the desired riprap size and the cost estimate for the 4,400-ft-long relocation compared with the cost of a paved lining. The riprap lining was constructed at an estimated saving of $94,000. The only evidence of stress after several years of use has been localized at the side inlets where excess energy from the inlet flow was not appropriately dissipated. This situation was easily corrected during maintenance operations.

The channel at Moose Lake, Minn., was also a stream relocation between a railroad embankment and a highway. During the first year after construction the channel was subjected to a flow near the design discharge as a result of unusually heavy rainstorms in the area. Inspection indicated that the channel effectively withstood the attack of the flood flow.

The field evaluation sections in Wisconsin and Montana were typical roadway channels with relatively small design discharges. The roadside ditch along a two-lane highway in a sandy soil area of Chippewa County, Wis., was unstable and in need of some type of erosion control. A locally available gravel was selected as the riprap lining

TABLE 1

DRAINAGE CHANNELS DESIGNED ACCORDING TO PROPOSED TENTATIVE DESIGN PROCEDURES

Location	Present State	Design Q (cfs)	Design Slope	Riprap d_{50} (ft) Design	Riprap d_{50} (ft) Used	Bottom Width (ft)	Side Slopes	Design Depth (ft)	Max. Q to date (cfs)[a]	Present Condition
Manchester, Conn.	Const. 1969	3900	0.007	1.06	1.5	20	2:1	9.15	1500	Very good, vegetation on sides and top. Mean size of riprap appears to vary somewhat along channel.
Moose Lake, Minn.	Const. 1971	275	0.003	0.21	0.25	12	3:1	4.0	250	Channel very good. All riprap in place. Erosion at outlet of culvert at upstream end.
Klamath Falls, Ore.	Design	1100	0.0054	0.43		15	2.5:1	5.3	-	Chandler Wayside Park
Chippewa County, Wis.	Const. 1969	6	0.017	0.08	0.08	10	4:1	0.5	-	Roadside drainage. Good condition. Some damage from truck wheels.
Montana I-90-8(66)	Const. 1971	18	0.05	0.6	0.33	0	6:1	-	-	Median strip. Appears to be in good condition. Riprap gravel uniformly graded 2-in. minimum to 8-in. maximum.

[a] Approximate.

in accordance with the Project 15-2 design procedures and placed as the ditch lining. Inspection after four years of service indicated that vegetation has been established in the channel and it is in good condition.

The Montana site is the median ditch of a divided Interstate highway near Billings. Because of the noncritical nature of the site and the concern that the design procedure may be unnecessarily conservative, the median size of the riprap actually used was 4 in., even though the design procedure indicated that a median size of more than 7 in. would be desirable. The channel has successfully withstood one hydrologic event approximating the design discharge. This same event caused failure of the blanket-type lining of a nearby channel. The blanket lining has since been replaced by riprap.

Inspection of the study drainage channels indicated that special care should be taken with regard to culverts and other transition structures leading into riprap-lined drainage channels. Such structures cause localized increases in velocity and scouring forces that are not accounted for in the design procedures. These increased scouring forces must be counteracted by the placement of appropriately larger sizes of riprap based on a study of culvert hydraulics or local experience.

Applications

Based on the previous laboratory studies and the observations made during the field evaluation phase, the design procedures contained in NCHRP Report 108 are unquestionably useful for the design of riprap-lined channels. The channels for which they have been used were effective in transporting surface runoff without erosion. In all cases in which the riprap lining was in place a year or more, vegetation has grown through the interstices of the rock. In some cases the rock is no longer visible and the channel appearance is greatly improved.

In the development of the design procedures, conservative values of constants were chosen. Additional factors of safety are introduced by (1) the selection of riprap gradations equal to or larger than the design size and (2) the eventual establishment of vegetation in the lining. Performance of the median ditch at the Montana site indicates that the design procedure may be unduly conservative, particularly in noncritical situations. Continued observations should be made by user agencies to further evaluate the conservative nature of the procedures.

The results of the project are particularly noteworthy from an implementation standpoint in that (1) practical design procedures have been prepared in easy-to-use table and chart form and published in NCHRP Report 108, (2) channels built in accordance with the design procedures have successfully undergone considerable laboratory and field evaluation, and (3) the design procedures are already being incorporated into manuals and publications on erosion control by highway agencies.

The Kansas Highway Department has used the procedure to prepare specifications for a series of predesigned channels all having side slopes of 4:1 and varying bottom widths to accommodate a range of discharges and longitudinal slopes. The Minnesota Highway Department has combined the riprap lining with topsoil to support the growth of grass. As the vegetation develops, the root structure penetrating the riprap provides a significant increase in resistance to erosion.

The FHWA is using NCHRP Report 108 as the source document for the section on riprap linings in a new publication on stable channel designs and is also including the procedure in the curriculum of FHWA-sponsored workshops for hydraulic engineers.