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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

**SUMMARY OF PROGRESS
THROUGH 1974**

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

1974

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and 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.

1 SUMMARY OF PROGRESS

Introduction

How NCHRP Programs are Formulated

Programs Received to Date

Financing the Program

How the NCHRP is Organized to Administer Research Programs

How the Projects are Placed Under Contract

Keeping Track of Research in Progress

Systematic Planning for Getting Research Results from NCHRP Projects into Practice

Promoting Useful Results

NCHRP Reporting of Research Results

Examples of Utilization of NCHRP Research Results

Award-Winning Research Under NCHRP

Summary

35 PROGRESS BY PROJECT

35	Area One: Pavements
45	Area Two: Economics
49	Area Three: Traffic Operations and Control
59	Area Four: General Materials
64	Area Five: Illumination and Visibility
68	Area Six: Snow and Ice Control
71	Area Seven: Traffic Planning
74	Area Eight: Urban Transportation
82	Area Nine: Bituminous Materials
84	Area Ten: Specifications, Procedures, and Practices
88	Area Eleven: Law
94	Area Twelve: Bridges
101	Area Thirteen: Equipment
101	Area Fourteen: Maintenance of Way and Structures
103	Area Fifteen: General Design
105	Area Sixteen: Roadside Development
106	Area Seventeen: Safety
107	Area Eighteen: Concrete Materials
108	Area Nineteen: Finance
110	Area Twenty: Special Projects
117	Area Twenty-One: Testing and Instrumentation
119	Area Twenty-Two: Vehicle Barrier Systems

122 SUMMARIES OF UNPUBLISHED REPORTS

FIGURES

- 2 Figure 1. Flow diagram for each program from initiation to referral by AASHTO to the National Academy of Sciences
- 4 Figure 2. Flow diagram for each program after referral to the National Academy of Sciences
- 5 Figure 3. Committee structure of NCHRP

TABLES

- 5 Table 1. Distribution of Panel and Special Project Advisory Committee Membership with Respect to Affiliation
- 6 Table 2. Number of Proposals Submitted
- 6 Table 3. Number of Agencies Submitting One or More Research Proposals
- 6 Table 4. Types of Agencies Submitting Proposals
- 8 Table 5. Projects for FY '63 Through FY '75, Summary of Status Through December 31, 1974
- 18 Table 6. Agency Distribution of FY '63 Through FY '75 Projects
- 29 Table 7. Published Reports of the National Cooperative Highway Research Program
- 32 Table 8. Unpublished Reports of the National Cooperative Highway Research Program
- 33 Table 9. NCHRP Research Results Digests

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1974

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 539 members on these panels coming from 45 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, 41 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 ninth issue covers the Program from its inception through December 31, 1974, 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-

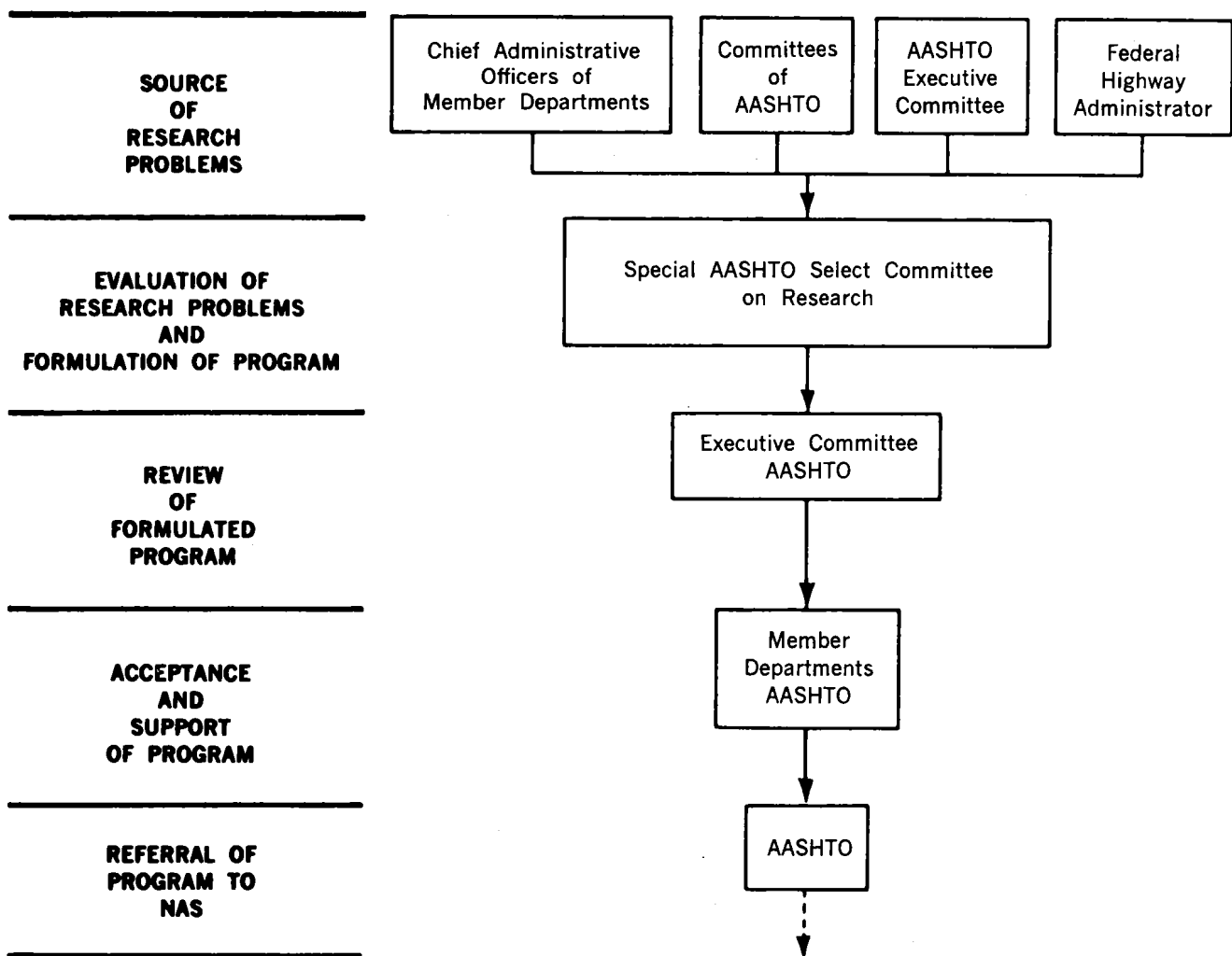


FIGURE 1

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 1974 AASHTO developed the thirteenth program (FY '75) of research problems. From the preceding programs to date, 232 research projects have resulted, on which contracts have been written with a total funding obligation of about \$31 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 fourteenth group of research problems (FY '76 program) will be received in 1975 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

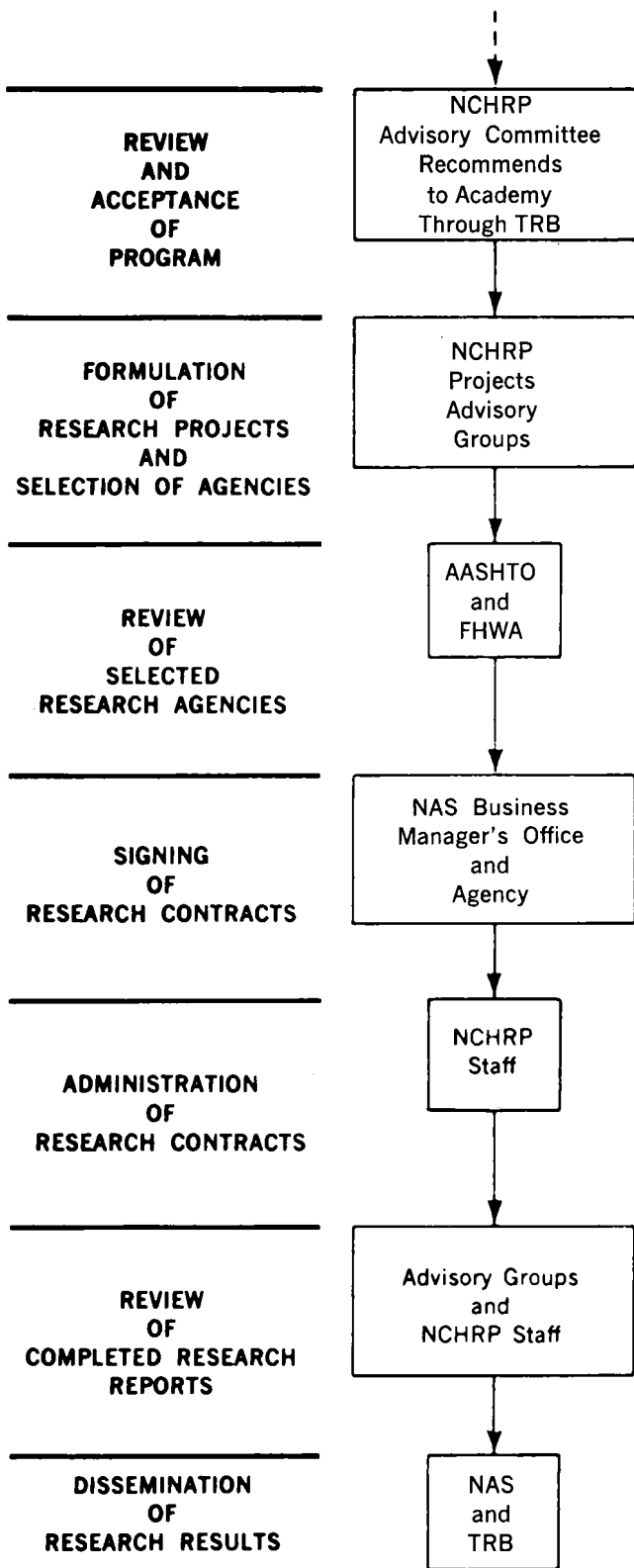


FIGURE 2

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, including FY 1975, within the fields of Figure 3 has been as follows:

NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
34	15.4	Socio-economic and environmental issues
28	17.7	Urban issues
4	2.0	Multimodal issues
40	22.2	Safety and accident prevention
18	1.0	Legal studies
10	9.0	Special projects (including in-house)
16	5.9	Improved materials quality and performance
12	4.4	Highway maintenance
22	5.9	Specifications, tests, and construction control
43	16.5	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 539 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 45 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.

TRANSPORTATION RESEARCH BOARD
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Committee Structure

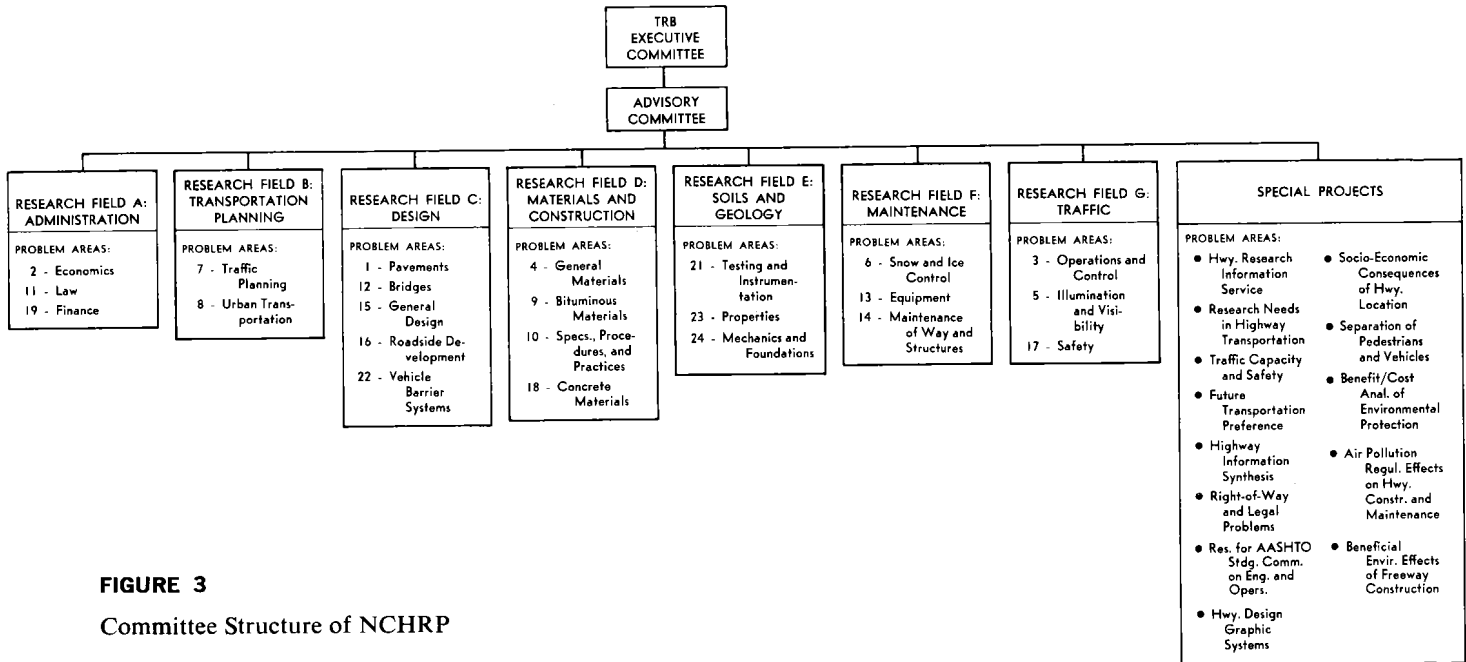


FIGURE 3

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 PANEL AND SPECIAL PROJECT ADVISORY COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	214	290
Federal Highway Administration	68	112
Special transportation and other governmental agencies	72	82
Educational institutions	77	115
Research institutes	4	6
Industry, consultants, and trade associations	90	120
Professional societies and service organizations	2	10
Transportation Research Board	12	86
All	539	821

TABLE 2
NUMBER OF PROPOSALS SUBMITTED

ITEM	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14	15	11
Proposals submitted	191	223	171	151	149	209	189	107	233	157	206	162	133
Proposals rec'd. per project (avg.)	6	8	12	9	12	13	10	12	17	11	15	11	11

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
1	26	32	56	59	70	90	69	55	103	63	96	88	65
2	18	22	29	18	20	18	22	8	22	24	20	17	19
3	7	14	11	8	4	11	8	5	8	8	13	5	6
4	5	8	2	5	4	0	2	4	8	3	4	3	1
5	4	4	1	1	1	5	0	1	2	2	3	0	0
6	4	1	0	0	1	3	1	0	1	0	0	1	0
7	1	4	0	1	0	1	0	0	0	0	0	1	0
8	1	1	0	0	0	0	2	0	1	0	0	0	1
9	1	0	0	0	0	0	0	0	1	0	0	0	0
10	2	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
All	69	87	100	92	100	128	106	73	146	100	136	115	92

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
Educational institutions	41	32	39	32	40	51	25	36	53	33	50	38	31
Research institutes	11	16	17	22	22	26	19	16	23	14	9	9	7
Industry, consultants, and trade associations	14	35	42	35	35	48	59	18	67	51	72	66	50
Professional societies and service organizations	2	0	1	2	0	0	0	0	0	0	0	0	0
State highway and transpor- tation departments	0	3	1	0	0	2	3	1	2	1	3	2	2
Special transportation and other governmental agencies	1	1	0	1	3	1	0	2	1	1	2	0	2
All	69	87	100	92	100	128	106	73	146	100	136	115	92
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14	15	11

Contracts have been let to agencies headquartered in more than 27 States and the District of Columbia. Educational institutions have received about 38%; research institutes, 21%; industry and consultants, 37%; and state highway and transportation departments, 1%. 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 13 fiscal year programs conducted to date are listed in Table 5. There are 104 projects in traffic planning research, 113 in physical research, and 15 in the special projects area. The 232 projects are distributed among more than one-half of the States and the District of Columbia. To date, 187 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 '75, SUMMARY OF STATUS THROUGH DECEMBER 31, 1974

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
AREA ONE: DESIGN—PAVEMENTS			
1-1(1)	Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements	HRB	42,800*
1-1(2)	Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase	HRB	11,356*
1-2	Comparison of Different Methods for Evaluating Pavement Conditions	Purdue U	29,957*
1-3(1)	Factors Influencing Pavement Performance—Regional	Purdue U	45,982*
1-3(2)	Factors Influencing Pavement Performance—Local	Northwestern U	19,850*
1-3(3)	Factors Influencing Pavement Performance	U of California	19,800*
1-4(1)	Extension of Road Test Performance Concepts	Georgia Tech	10,000*
1-4(1)A	Extension of Road Test Performance Concepts	Duke U	19,924*
1-4(2)	Extension of Road Test Performance Concepts	Purdue U	12,243*
1-5	Detecting Variations in Load-Carrying Capacity of Flexible Pavements	Cornell Aero Lab	49,011*
1-5(2)	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements	Texas A & M	49,428*
1-6	Standard Measurements for Satellite Program—Measurement Team	Texas A & M	61,353*
1-7	Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces	Penn State U	24,815*
1-8	Factors Involved in the Design of Asphalt Pavement Surfaces	Materials R & D	23,255*
1-9	Evaluation of Studded Tires	Cornell Aero Lab	24,998*
1-10	Translating AASHO Road Test Findings—Basic Properties of Pavement Components	Materials R & D	99,803*
1-10A	Systems Approach to Pavement Design—Implementation Phase	Texas A & M	103,291*
1-10B	Development of Pavement Structural Subsystems	Materials R & D	100,000
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	250,000
			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	To Be Determined	
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	70,000
1-15	Design of Continuously Reinforced Concrete Pavements for Highways	U of Texas	149,985
1-16	Evaluation of Winter-Driving Traction Aids	Penn State U	150,000
AREA TWO: ADMINISTRATION—ECONOMICS			
2-1	Criteria for Highway Benefit Analysis	U of Washington	101,948*
2-2	Guidelines for the Determination of Community Consequences	U of Washington	48,873*
2-3	Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements	Cornell Aero Lab	155,972*
2-4	The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed	Texas A & M	77,100*
2-5	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Catholic U	49,998*
			51,265*
2-5A	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Paul J. Claffey	35,000*
			30,665*
2-6	Warranted Levels of Improvement for Local Rural Roads	Stanford U	40,000*
2-7	Road User Costs in Urban Areas	Catholic U	99,376*
2-8	Estimation and Evaluation of Diverted and Generated (Induced) Traffic	Northwestern U	40,000*
2-9	Effect of Highway Landscape Development on Nearby Property	Franklin Inst	149,103*
2-10	Future Needs for Oversize-Overweight Permit Operation on State Highways	Jorgensen & Assoc	99,655*
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	HRB	110,000
2-12	Highway User Economic Analysis	Stanford Res Inst	89,453
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)
2/15/63	2/28/65	Completed—Initial phase published as NCHRP Report 7; final report not to be published; summarized in Summary of Progress to June 30, 1967	1-2
2/15/63	9/30/67	Completed—Published as NCHRP Report 132	1-3(1)
9/1/63	9/30/64	Completed—Published as NCHRP Report 22	1-3(2)
4/1/64	10/31/65	Completed—Published as NCHRP Report 35	1-3(3)
10/1/63	9/30/64	Completed—Published as NCHRP Report 10	1-4(1)
2/1/65	9/30/66	Completed—Published as NCHRP Report 97	1-4(1)A
2/1/64	1/31/66	Completed—Published as NCHRP Report 30	1-4(2)
1/15/64	7/15/65	Completed—Published as NCHRP Report 21	1-5
9/1/66	6/30/68	Completed—Published as NCHRP Report 76	1-5(2)
3/31/64	1/31/67	Completed—Published as NCHRP Report 59	1-6
6/15/65	12/15/66	Completed—Published as NCHRP Report 37	1-7
1/1/65	2/28/66	Completed—Published as NCHRP Report 39	1-8
10/1/66	6/30/67	Completed—Published as NCHRP Report 61	1-9
9/12/66	3/11/68	Completed—Report included in NCHRP Reports 139,140	1-10
12/1/68	12/31/70	Completed—Published as NCHRP Reports 139,140	1-10
3/1/72	12/31/73	Report in editorial and publication process	1-10A
2/1/74	4/30/76	Research in progress	1-10B
10/23/67	6/30/70	Completed—Published as NCHRP Report 128	1-11
8/1/70	4/30/71	Completed—Published by AASHTO	1-11
8/25/69	6/8/73	Completed—Published as NCHRP Report 154	1-12
—	—	Project in developmental process	1-12A
9/16/70	5/15/73	Completed—Published as NCHRP Report 151	1-12(2)
11/1/71	6/30/75	Research in progress	1-12(3)
4/19/71	8/20/74	Report in editorial and publication process	1-13
2/15/72	5/31/73	Report in editorial and publication process	1-13(2)
10/15/72	1/14/74	Report in review stage	1-14
8/1/72	12/31/74	Report in review stage	1-15
6/3/74	6/2/76	Research in progress	1-16
6/1/63	11/30/67	Completed—Rep. not to be 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
8/11/69	8/10/70	Completed—Report included in NCHRP Report 111	2-5A
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6
2/1/64	5/31/66	Completed—Report included in NCHRP Report 111	2-7
5/1/64	8/31/66	Completed—Rep. not to be publ.; summarized in Summary of Progress to June 30, 1967	2-8
11/8/65	1/31/68	Completed—Published as NCHRP Report 75	2-9
11/1/66	4/30/68	Completed—Published as NCHRP Report 80	2-10
1/1/67	7/31/70	Completed—Published as NCHRP Report 122	2-11
4/1/74	6/30/75	Research in progress	2-12
2/15/63	2/29/64	Completed—Report not to be published; summarized in Summary of Progress to June 30, 1967	3-1
7/2/64	2/28/66	Completed—Published as NCHRP Reports 9, 28, 29	3-2
2/15/63	4/30/66	Completed—Published as NCHRP Report 51	3-3
2/15/63	11/30/65	Completed—Published as NCHRP Report 6	3-4
3/1/63	3/31/65	Completed—Published as NCHRP Report 40	3-4
7/1/65	12/15/66	Completed—Published as NCHRP Reports 3, 32	3-5
3/1/63	12/31/65	Completed—Published as NCHRP Report 73	3-5
7/1/66	7/31/67	Completed—Published as NCHRP Report 124	3-5
8/1/68	12/31/69	Completed—Published as NCHRP Reports 11, 41	3-6
4/1/63	8/15/66	Completed—Published as NCHRP Report 78	3-7
2/1/64	4/30/67	Completed—Published as NCHRP Report 117	3-7
10/14/68	1/15/70	Completed—Published as NCHRP Report 144	3-7
4/1/71	6/30/72	Report in review stage	3-7
9/1/72	11/30/74		

TABLE 5 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
NO.	TITLE		
AREA THREE (Continued)			
3-8	Factors Influencing Safety at Highway-Rail Grade Crossings	Voorhees & Assoc	17,171*
3-9	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control	Jorgensen & Assoc	74,250*
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	23,760*
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick	41,520*
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	258,331*
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways	Texas A & M	198,655*
3-14	Optimizing Flow on Existing Street Networks	Edwards & Kelcey	100,500*
3-15	Weaving Area Operations Study	Poly of New York	99,821*
3-16	Freeway Lane Drops	System Dev Corp	149,916
3-17	Improving Traffic Operations and Safety at Exit Gore Areas	Penn State U	990,000*
3-18(1)	Improved Control Logic for Use with Computer-Controlled Traffic	Stanford Res Inst	300,000*
3-18(2)	Traffic Control in Oversaturated Street Networks	Poly of New York	99,789*
3-18(3)	Cost Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems	To Be Determined	76,815*
3-19	Grade Effects on Traffic Flow Stability and Capacity	Midwest Res Inst	79,983*
3-20	Traffic Signal Warrants	KLD Associates	323,998
3-21	Motorist Response to Highway Guide Signing	BioTechnology Inc	200,000
3-22	Guidelines for Design and Operation of Ramp Control Systems	Stanford Res Inst	220,443
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	120,000*
3-24	Determine the Luminous Requirements for Retroreflective Highway Signing	U of Michigan	80,000
AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS			
4-1	Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents	U of Illinois	250,000
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	198,590
4-3(1)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	V P I	300,000
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	100,000
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	49,756*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	14,790*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	64,105*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	P C A	25,000*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	V P I	100,000
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	55,254*
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	99,981
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah St Dept Hy	200,000
4-9	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah St Dept Hy	93,494
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	125,000
4-10A	Waste Materials as Potential Replacements for Highway Aggregates	Valley Forge Lab	50,000*
4-11	Buried Plastic Pipe for Drainage of Transportation Facilities	Simpson Gumpertz	53,663
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	150,000*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	21,530*
5-2(3)	Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	81,187*
5-3	Visual Information Needed by the Driver at Night	Ohio State U	37,460*
5-4	Economic Study of Roadway Lighting	Franklin Inst	100,940*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	19,412*
5-5A	Development of Optimum Specifications for Glass Beads in Pavement Markings	Penn State U	50,000*
5-5B	Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing Is Prevalent	Texas A & M	99,350*
5-6	Highway Fog	Cornell Aero Lab	200,000
5-6A	Highway Fog	Sperry Rand	99,955*
5-7	Roadway Delineation Systems	Penn State U	93,540
5-8	Warrants for Highway Lighting	Texas A & M	469,526*
			199,627

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
12/1/63	12/31/64	Completed—Report included in NCHRP Report 50	3-8
4/1/65	1/6/67	Completed—Total project published as NCHRP Report 50	3-8
10/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10
9/1/66	9/30/68	Completed—Published as NCHRP Report 110	3-11
10/1/66	12/31/67	Completed—Report included in NCHRP Report 123	3-12
4/1/68	12/1/69	Completed—Report included in NCHRP Report 123	3-12
3/29/71	12/11/72	Completed—Rep. not to be publ.; summarized in Sum. of Prog. Through 1973	3-12
9/1/67	11/30/69	Completed—Published as NCHRP Report 93	3-13
10/1/67	1/10/70	Completed—Published as NCHRP Report 113	3-14
10/1/69	12/31/73	Report in editorial and publication process	3-15
11/1/69	4/30/71	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1971	3-16
5/1/72	10/31/73	Report in editorial and publication process	3-16
1/1/71	11/30/72	Completed—Published as NCHRP Report 145	3-17
7/15/71	5/15/74	Report in editorial and publication process	3-18(1)
9/1/71	3/31/75	Research in progress	3-18(2)
—	—	Project in developmental process	3-18(3)
9/1/71	8/31/74	Report in review stage	3-19
9/1/72	4/15/74	Completed—Report to be included in Phase II report	3-20
11/1/74	7/31/76	Research in progress	3-20
4/1/74	1/31/76	Research in progress	3-21
4/15/74	10/14/75	Research in progress	3-22
4/8/74	7/7/76	Research in progress	3-23
9/1/74	11/30/76	Research in progress	3-24
6/1/63	10/31/66	Completed—Report not to be published; summarized in Summary of Progress Through June 30, 1968	4-1
2/15/63	11/30/66	Completed—Published as NCHRP Report 98	4-2
3/1/63	9/30/64	Completed—Published as NCHRP Report 12	4-3(1)
7/1/65	3/31/67	Completed—Published as NCHRP Report 65	4-3(1)
3/25/63	1/31/65	Completed—Published as HRB Special Report 80 and NCHRP Report 15	4-3(2)
7/1/65	8/31/67	Completed—Published as NCHRP Report 66	4-3(2)
3/1/63	4/15/64	Completed—Published as NCHRP Report 8	4-4
2/15/63	8/31/65	Completed—Report not to be published; summarized in Summary of Progress Through June 30, 1968	4-5
3/1/65	11/30/66	Completed—Published as NCHRP Reports 74, 74A, 74B	4-6
10/1/67	2/28/70	Completed—Report to be included in Phase II Report	4-7
2/1/71	8/31/73	Report in review stage	4-7
1/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
4/1/71	6/30/73	Report in editorial and publication process	4-8(2)
9/1/71	3/31/74	Report in review stage	4-8(3)
10/1/68	6/30/71	Report in review stage	4-9
10/1/72	12/31/77	Research in progress	4-9
10/15/69	3/31/71	Completed—Published as NCHRP Report 135	4-10
9/1/72	11/30/73	Report in editorial and publication process	4-10A
9/16/74	3/15/77	Research in progress	4-11
2/15/63	5/31/66	Completed—Report included in NCHRP Report 60	5-2(1)
2/1/67	7/31/67	Completed—Report included in NCHRP Report 60	5-2(1)
2/15/63	8/31/65	Completed—Report included in NCHRP Report 60	5-2(2)
2/20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
9/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3
7/20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
3/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
7/15/67	9/15/69	Completed—Published as NCHRP Report 85	5-5
5/1/71	6/30/73	Report in editorial and publication process	5-5A
9/1/71	12/31/74	Report in review stage	5-5B
10/2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6
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

TABLE 5 (Continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
NO.	TITLE		
AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL			
6-1	Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles	IIT Research Inst	40,000*
6-2	Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures	Jorgensen & Assoc	25,000*
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Mem Inst	58,557*
6-4	Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Mem Inst	39,330*
6-5	Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents	U of Illinois	72,500*
6-6	To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete	Ohio State U	69,393*
6-7	Estimation of Disintegration in Concrete Structures	Geotechnics	8,547*
6-7A	Estimation of Disintegration in Concrete Structures	IIT Research Inst	44,614*
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Tallamy Assoc	25,000*
6-9	Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks	U of Illinois	200,000*
6-10	Develop Improved Snow Removal and Ice Control Techniques at Interchanges	Tallamy Assoc	95,000*
6-11	Economic Evaluation of the Effects of Ice and Frost on Bridge Decks	Midwest Res Inst	50,000*
			50,000
AREA SEVEN: TRANSPORTATION PLANNING—TRAFFIC PLANNING			
7-1	The Influence of Land Use on Urban Travel Patterns	Louis E. Keefer	62,674*
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	66,894*
7-3	Weighing Vehicles in Motion		24,652*
7-4	Factors and Trends in Trip Lengths	Franklin Inst	24,844*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Voorhees & Assoc	73,391*
7-6	Multiple Use of Lands Within Highway Rights-of-Way		89,250*
7-7	Motorists' Needs and Services on Interstate Highways	Yale University	61,730*
7-8	User Cost and Related Consequences of Alternative Levels of Highway Service	Barton-Aschman	99,675*
7-9	Development of Models for Predicting Weekend Recreational Traffic	Airborne Instr	24,220*
7-10	Peak-Period Traffic Congestion	Stanford Res Inst	99,267*
		Midwest Res Inst	99,070*
		Remak/Rosenbloom	74,983
			49,116
AREA EIGHT: TRANSPORTATION PLANNING—URBAN TRANSPORTATION			
8-1	Social and Economic Factors Affecting Travel	Vogt, Ivers	94,558*
8-2	Factors Influencing Modal Trip Assignment	IIT Research Inst	298,033*
8-3	Individual Preferences for Various Means of Transportation	U of Penn	63,282*
8-4	Criteria for Evaluating Alternative Transportation Plans	Northwestern U	89,900*
8-4A	Criteria for Evaluating Alternative Transportation Plans	U of Illinois	5,000*
8-5	Transportation Aspects of Land-Use Controls	Victor Gruen	25,967*
8-6	Individual Preferences for Alternative Dwelling Types and Environments		99,571*
8-7	Evaluation of Data Requirements and Collection Techniques for Transportation Planning	U of N Carolina	99,897*
8-7A	Data Requirements and Transportation Planning Procedures in Small Urban Areas	Creighton, Hamburg	190,000*
8-8(1)	The Impact of Highways upon Environmental Values (Study Design)	U of Tennessee	99,968
8-8(2)	The Impact of Highways upon Environmental Values (Study Design)	M I T	29,654*
8-8(3)	The Impact of Highways upon Environmental Values	Daniel, Mann et al	28,950*
8-9	Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems	M I T	470,000
8-10	Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities	Creighton, Hamburg	100,000*
8-11	Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility	Wilbur Smith	149,907
8-12	Travel Estimation Procedures for Quick Response to Urban Policy Issues	DACP, Inc	99,753
8-13	Disaggregate Travel Demand Models	Metro Wash COG	39,895
8-14	New Approaches to Understanding Travel Behavior	Chas River Assoc	100,000
8-15	State and Regional Transportation Impact Identification and Measurement	Social Policy Res	149,958
		Bigelow-Crain	80,000
AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS			
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion		50,000*
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Montana College	101,903*
9-4	Minimizing Premature Cracking of Asphaltic Concrete Pavements	Rensselaer	24,996*
		Materials R & D	99,560

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
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—Report not to be published; 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 to be 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 review stage	6-11
2/1/64	1/31/66	Completed—Published as NCHRP Report 24	7-1
4/1/66	9/30/67	Completed—Published as NCHRP Report 62	7-1
2/1/64	3/15/65	Completed—Report included in NCHRP Report 44	7-2
5/1/65	5/31/66	Completed—Total project published as NCHRP Report 44	7-2
2/1/64	8/31/67	Completed—Published as NCHRP Report 71	7-3
2/1/64	10/31/66	Completed—Published as NCHRP Report 48	7-4
10/23/67	1/10/69	Completed—Published as NCHRP Report 89	7-4
2/1/64	11/30/66	Completed—Published as NCHRP Report 58	7-5
2/1/66	2/28/67	Completed—Published as NCHRP Report 53	7-6
1/1/66	12/31/67	Completed—Published as NCHRP Report 64	7-7
9/1/70	4/15/72	Completed—Published as NCHRP Report 133	7-8
9/1/72	5/15/74	Contract to be extended	7-9
4/1/74	3/31/75	Research in progress	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 to be 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
10/14/68	1/10/69	Completed—Published as NCHRP Report 96	8-4A
4/1/65	5/31/66	Completed—Published as NCHRP Report 31	8-5
8/7/67	1/15/70	Completed—Published as NCHRP Report 121	8-5
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6
9/13/68	8/28/70	Completed—Published as NCHRP Report 120	8-7
6/1/73	12/31/74	Report in review 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	Report in editorial and publication process	8-8(3)
9/1/71	1/31/73	Completed—Published as NCHRP Report 146	8-9
9/1/71	7/31/73	Interim rep. publ. as NCHRP Report 143; final rep. in edit. and publ. process	8-10
9/16/74	9/15/75	Research in progress	8-11
9/3/74	5/2/75	Research in progress	8-12
9/15/74	12/14/75	Research in progress	8-13
12/1/74	5/31/76	Research in progress	8-14
9/1/74	8/31/75	Research in progress	8-15
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
11/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	9-1
1/1/65	10/31/67	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
11/1/71	6/30/73	Report in editorial and publication process	9-4

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
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*
10-4	Rapid Test Methods for Field Control of Construction	Clemson U	30,000*
10-5	Density and Moisture Content Measurements by Nuclear Methods	Res Triangle Inst	69,320*
10-5A	Optimization of Nuclear Density and Moisture Content Measurement Methods	N Carolina State U	28,801*
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	IIT Research Inst	59,835*
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	Ohio State U	51,214*
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	Pa Dept of Transp	108,821*
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	24,310*
10-10	Acceptance Criteria for Electroslag Weldments in Bridges	US Steel	151,982*
AREA ELEVEN: ADMINISTRATION—LAW			
11-1	Rules of Compensability and Valuation in Highway Land Acquisition	U of Wisconsin	84,840*
11-1(1)	Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation	Real Estate Res	5,000*
11-1(2)	Recognition of Benefits to Remainder Property in Highway Valuation	Montano & Assoc	5,000*
11-1(3)	Taxation Aspects of Right-of-Way Acquisition	U of Tulsa	2,250*
11-1(4)	Compensation in the Nature of Additives to Market Value	U of Oklahoma	2,500*
11-1(5)	Rules of Discovery and Disclosure in Highway Condemnation Proceedings	Long, Mikkelborg	2,500*
11-1(6)	Valuation and Condemnation Problems of Selected Special Purpose Properties	Edward E. Level	7,500*
11-1(7)	Valuation and Compensability of Noise, Pollution, and Other Environmental Factors	U of Oklahoma	2,500*
11-1(8)	Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides	Harrison Lewis	7,500*
11-1(9)	Valuation and Condemnation Problems Involving Trade Fixtures	Edward L. Snitzer	5,000*
11-1(10)	Compensability and Valuation Aspects of Residential Displacement in Highway Programs	Ross, Hardies et al.	5,000*
11-1(11)	Valuation Elements of Joint Development Projects, Including Air Rights	Real Estate Res	5,000*
11-2	Theory and Practice in Inverse Condemnation	Reg & Urban Plan	15,000*
11-3	Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements	Sutte, Jr. & Assoc	25,000*
11-3(1)	Public Control of Roadside Advertising Signs for Highway Beautification	Sutte, Jr. & Assoc	20,000*
11-3(2)	Public Control of Junkyards for Highway Beautification	Real Estate Res	13,300*
11-4	Elimination of Wide Divergence in Right-of-Way Valuation	Am Inst Rl Est App	24,959*
11-5	Valuation of Air Space	Daniel, Mann et al	49,800*
11-6	Valuation and Compensability of Noise Pollution	Jack Faucett Assoc	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	85,000
12-7	Effects of Weldments on Fatigue Strength of Steel Beams	Lehigh University	199,023*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	200,000*
12-9	Elastomeric Bearing Research		30,000
12-10	Analysis and Design of Bridge Bents	Battelle Mem Inst	70,000
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks	PCA	84,800*
12-12	Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings	Materials R & D	297,900
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks		206,034
12-14	Subcritical Crack Growth in Steel Bridge Members	US Steel	100,000
12-15	Detection and Repair of Fatigue Cracking in Highway Bridges	USS Eng & Consult	174,699
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	US Steel	99,923
		Lehigh U	100,000
		Battelle Columbus	186,915
AREA THIRTEEN: MAINTENANCE—EQUIPMENT			
13-1	Equipment Rental Rates	Ernst & Ernst	\$ 22,800*
AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES			
14-1	Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements	Tallamy Assoc	205,128*
14-2	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000*
14-3	Improved Pavement-Shoulder Joint Design	Georgia Tech	99,754
14-4	Reconditioning Heavy-Duty Freeways in Urban Areas	Texas A & M	99,665

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
1/15/63	11/14/64	Completed—Published as NCHRP Report 17	10-1
11/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
7/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
0/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
0/15/64	10/16/65	Completed—Published as NCHRP Report 46	10-3
2/1/64	2/28/65	Completed—Report included in NCHRP Report 103	10-4
5/1/65	2/28/67	Completed—Published as NCHRP Report 103	10-4
1/15/64	1/31/65	Completed—Published as NCHRP Report 14	10-5
4/1/65	10/7/66	Completed—Published as NCHRP Report 43	10-5
2/1/68	1/31/70	Completed—Published as NCHRP Report 125	10-5A
2/1/64	10/31/66	Completed—Published as NCHRP Report 52	10-6
2/1/64	3/31/65	Completed—Published as NCHRP Report 25	10-7
3/2/70	7/31/73	Report in editorial and publication process	10-8
11/1/69	2/28/74	Report in review stage	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)
10/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
9/16/68	4/30/69	No final report—Project terminated	11-1(3)
12/1/68	5/31/69	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	11-1(4)
9/15/68	4/14/69	Completed—Published as NCHRP Report 87	11-1(5)
9/2/68	11/28/69	Completed—Published as NCHRP Report 92	11-1(6)
10/1/68	3/31/69	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	11-1(7)
10/15/68	1/15/70	Completed—Published as NCHRP Report 134	11-1(8)
3/15/69	12/1/69	Completed—Published as NCHRP Report 94	11-1(9)
3/15/69	9/15/69	Completed—Published as NCHRP Report 107	11-1(10)
2/24/69	8/25/69	Completed—Rep. not to be 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
11/1/66	12/15/67	Completed—Published as NCHRP Report 56	11-3
10/1/68	12/31/69	Completed—Published as NCHRP Report 119	11-3(1)
9/2/68	2/28/70	Completed—Published as NCHRP Report 112	11-3(2)
7/1/69	2/28/71	Completed—Published as NCHRP Report 126	11-4
10/1/70	5/31/72	Completed—Published as NCHRP Report 142	11-5
4/1/74	6/30/75	Research in progress	11-6
2/1/65	6/30/67	Report included in Project 12-6 report	12-1
6/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
12/15/65	3/14/69	Completed—Report being made available only to sponsors	12-3
12/15/65	3/31/68	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1969	12-4
9/15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5
2/1/67	4/30/72	Report in editorial and publication process	12-6
10/1/66	1/31/70	Completed—Published as NCHRP Report 102	12-7
7/1/70	12/31/72	Completed—Published as NCHRP Report 147	12-7
3/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
1/2/70	6/30/71	Completed—Published as NCHRP Report 149	12-8
9/1/67	1/31/70	Completed—Published as NCHRP Report 109	12-9
1/1/70	12/31/73	Report in editorial and publication process	12-10
8/1/70	3/31/73	Report in editorial and publication process	12-11
7/15/73	4/15/77	Research in progress	12-11
10/1/70	8/31/75	Research in progress	12-12
10/1/72	7/31/74	Report in editorial and publication process	12-13
10/1/72	6/30/74	Report in editorial and publication process	12-14
10/1/72	3/31/75	Research in progress	12-15
9/1/74	2/28/77	Research in progress	12-16
2/1/65	1/31/66	Completed—Published as NCHRP Report 26	13-1
3/1/65	3/31/67	Completed—Published as NCHRP Report 42	14-1
10/1/70	3/31/73	Report in editorial and publication process	14-2
9/15/72	6/14/75	Research in progress	14-3
4/15/74	10/14/75	Research in progress	14-4

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
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*
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	100,000*
15-3	Rational Structural Analysis and Design of Pipe Culverts	Northwestern U	97,300
15-4	Estimating Runoff Rates from Small Rural Watersheds	Travelers Res Cen	49,937*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Gen Mot Corp	299,902*
15-6	Development of Criteria for Safer Luminaire Supports	Texas A & M	135,000*
15-6			150,000
AREA SIXTEEN: DESIGN—ROADSIDE DEVELOPMENT			
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	V P I	217,300*
16-2	Evaluation of Research on Roadside Development	Western States	100,000*
16-3	Erosion Control During Highway Construction	Utah State U	174,950
AREA SEVENTEEN: TRAFFIC—SAFETY			
17-1	Development of Improved Methods for Reduction of Traffic Accidents	Cornell Aero Lab	247,847*
17-2	Methods for Evaluating Highway Safety Improvements	ORI	29,973*
17-2A	Methods for Evaluating Highway Safety Improvements	Jorgensen & Assoc	98,403
AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS			
18-1	Re vibration of Retarded Concrete for Continuous 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 Budgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Ernst & Ernst	6,000*
19-2(3)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	6,000*
19-2(4)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	220,000*
19-3	Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways	Wilbur Smith	96,728*
AREA TWENTY: SPECIAL PROJECTS			
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy—Smith	98,760*
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	419,000
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	200,540†
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting	Patrick J. Athol	505,631*
20-4	Public Preference for Future Individual Transportation		20,000††
20-4		Chilton Research National Analysts	195,260*
20-5	Synthesis of Information Related to Highway Problems	TRB	83,911*
20-6	Right-of-Way and Legal Problems Arising out of Highway Programs	TRB	200,000§§
20-7	Research for AASHTO Standing Committee on Engineering and Operations	†††	65,000‡
20-7			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
20-12	Effects of Air Pollution Regulations on Highway Construction and Maintenance	Howard, Needles et al	89,000
20-13	Beneficial Environmental Effects Associated with Freeway Construction	Penn State U	49,965
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
22-2			80,000
22-3	Field Evaluation of Vehicle Barrier Systems	Calspan Corp	25,000
22-3A	Field Evaluation of Vehicle Barrier Systems	Arthur L. Elliott	10,000

* 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.

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	8/31/70	Completed—Published as NCHRP Reports 54, 115	15-1(2)
5/1/70	12/31/71	Completed—Published as NCHRP Reports 118, 129	15-1(2)
7/1/66	6/30/74	Initial phase published as NCHRP Report 108; Phase II report in review stage	15-2
10/1/67	12/31/68	Completed—Published as NCHRP Report 116	15-3
9/1/67	3/16/70	Completed—Published as NCHRP Report 136	15-4
8/15/67	1/10/69	Completed—Published as NCHRP Report 105	15-5
9/1/67	8/31/68	Completed—Published as NCHRP Report 77	15-6
3/1/66	4/30/72	Initial phase publ. as NCHRP Report 91; Phase II rep. in edit. and publ. process	16-1
10/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
11/1/73	10/31/75	Research in progress	16-3
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
1/10/72	6/20/72	Contract terminated—no report; research resumed under Project 17-2A	17-2
2/1/73	7/31/74	Report in editorial and publication process	17-2A
9/1/67	12/1/69	Completed—Published as NCHRP Report 106	18-1
10/1/72	9/30/75	Research in progress	18-2
9/5/67	9/4/68	Completed—Refer to Table 9 for publication	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)
9/15/70	6/14/72	Completed—Published as NCHRP Report 141	19-3
3/16/64	10/31/67	Completed—Informal publication only; Service is operational	20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55	20-2
12/15/66	1/31/69	Reports to be included in Project 20-3B report	20-3
1/1/67	12/31/68		20-3
11/20/68	5/31/71	Reports to be included in Project 20-3B 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
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
12/15/67	§§	Research in progress: Topic reports published as NCHRP Syntheses 1 through 26	20-5
11/1/68	‡	Research in progress: Refer to Table 9 for publications	20-6
12/2/68	§	Research in progress: Task 1 report published as NCHRP Report 148	20-7
		Task 5 report published as NCHRP Report 150	
		Task 6 report in editorial and publication process	
9/1/70	7/31/71	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	20-8
8/1/72	10/30/75	Research in progress	20-9
8/26/74	2/25/76	Research in progress	20-10
9/1/72	5/31/74	Report in review stage	20-11
4/1/74	3/31/75	Research in progress	20-12
9/3/74	6/2/75	Research in progress	20-13
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Report in review stage	21-2
4/1/72	9/30/73	Report in review stage	21-2(2)
9/3/74	12/2/76	Research in progress	21-2(3)
10/1/70	12/31/71	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	22-1
3/1/74	2/28/75	Research in progress	22-1A
1/1/72	9/30/73	Init. phase completed—rep. to be incl. in Phase II report	22-2
10/1/73	3/31/75	Research in progress—Task 2 report publ. as NCHRP Report 153	22-2
1/1/74	12/31/74	Report in review stage	22-3
7/1/74	12/31/74	Report in review stage	22-3A

§ Continuing activity supported at the annual amount shown.

§§ Continuing activity supported at the annual amount shown beginning with FY '72.

‡ Continuing activity with average annual expenditures in the amount shown.

††† Texas A & M University Research Foundation to date.

TABLE 6
AGENCY DISTRIBUTION OF FY '63 THROUGH
FY '75 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS	
	NO.	%
Educational institutions	87	38
Research institutes	49	21
Industry, consultants, and trade associations	85	37
Professional societies and service organizations	5	2
State highway and transportation departments	3	1
Special transportation and other governmental agencies	1	1
All	230*	100

* Does not include Projects 1-12A (FY '74) and 3-18(3) (FY '75).

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. Empha-

sis is placed on the importance of a record of successful past performance in endeavors similar to those to be undertaken. Further, it is also stipulated that proposals are not acceptable if they do not contain specific statements as to how the contemplated results can be used to improve practice.

- Utilizing persons who are not only experts in the particular problem area but who also have a complete understanding of the needs of the practitioners to define the research problem and its objectives in the form of a precise project statement on which fully responsive research proposals can be based. Experts drawn from the highway and transportation departments play a major role in this task.

- Exercising extreme care in the process of selecting research agencies to ensure not only that the proposed research plan is the best possible in addressing the specifics of the objectives but that it also culminates in the best promise for providing the practitioner with a product that is both usable and readily implementable.

- Establishing—on the basis of staff and 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 publication in either of the two regular NCHRP series (Reports or Syntheses of Highway Practice) and are available, on a loan basis, to others having an interest in the research. Once published in their entirety, the drafts are destroyed.

After publication in the NCHRP series, each report or synthesis is sent immediately to the chief administrative officer of each highway or transportation department. Then, through the Transportation Research Board's selective distribution system, copies go automatically to about 100 libraries, Board representatives in the state highway and transportation departments, educational institutions, liaison representatives, appropriate panels and committees of the Board, and individual members who have selected publications in the particular subject area of the report. As a further means of disseminating the research reports, announcements of their availability are made to the trade press. Each of these reports contains a staff-prepared foreword that directs the attention of the busy reader to the persons who would be most interested in the results and, also, to how the results fit into present knowledge and practice. Also, during the conduct of the work, periodic progress reports are prepared by the staff and sent to each of the highway departments as a measure of providing a current awareness of on-going work. In addition, the Board's Technical Activities Staff personnel follow the progress of the work throughout its conduct and consequently are able to discuss application of the research results with the highway engineers during their various state highway and transportation department visits. Furthermore, AASHTO has provided the NCHRP with annual opportunities for staff and project researchers to go before the various committees of the Association to present the findings of their particular research and the usefulness of these findings to the practicing highway engineer. 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 AASHTO 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. Tallamy, Byrd, et al.	To develop a flexible pavement performance equation; in use as of June 1968. 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. 92nd Congress, 1st Sess.	In preparation of a <i>Highway Safety Program Manual</i> for issuance to the States. 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 <i>Interim Guide for Design of Pavement Structures, 1972</i>
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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
2-5	Reports 13, 111	One State (unknown)	To replace outdated material in AASHTO book, <i>Urban Freeway Design</i> .
2-5A	Report 111	AASHTO Woodrow W. Rankin, I.T.E.	In draft of proposed AASHTO publication, <i>A Policy on Arterial Highways in Urban Areas</i> . In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant and W. Grant Ireson	In textbook, <i>Principles of Engineering Economy</i> .
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 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 Minnesota Dept. of Hwys. California Div. of Hwys.	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. Steps taken toward implementation of the delay difference offset technique in an existing signal network. 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.
3-7	Agency final report Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Goodell, Grivas and Assoc. Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ. Georgia State Hwy. Dept. Minnesota Legislature Virginia Dept. of Hwys.	Obtained contract to use model described in report on a network in Detroit. 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. Noise design guide used in design of the urban freeway system. 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. 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

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			instance involved I-195, a six-lane depressed highway in a residential area of Richmond. Using the computer program from <i>Report 78</i> , 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 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 <i>Builders' Acoustical Manual</i> 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 <i>Expressways and Automobiles</i> (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.
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), in-

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			volving 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.
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.
3-18(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.
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."
5-4	Report 20	AASHTO Stdg. Comm. on Engrg. and Opers.	Input (with Report 77, Proj. 15-6) to the March 1969 publication, <i>Informational Guide to Roadway Lighting</i> .
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 (<i>Civil Eng.</i> , 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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		U.S. Park Serv.	Techniques used by consulting engineering firm for deck repair of Memorial Bridge, Washington, D.C., depended heavily on reported results.
6-10	Agency reports	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.
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.
8-8(3)	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.
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.
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. Illinois Div. of Hwys., Bur. of Rt.-of-Way	Rated as "excellent." Requested extra copies for use in development of new work in area of responsibility.
12-2	Report 83	California Div. of Hwys.	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. 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	AASHTO Naval Ship Res. and Devel. Lab. Illinois Dept. of Transp., Bur. of Design	Fatigue specification recommendations are being adopted as part of the latest interim specifications and will become standard practices as soon as released. Limited portions used in a technical report entitled "Some Observations on the Fatigue Behavior of Specimens and Structures." Findings have been found useful, and practice has been modified to conform with them.
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. Washington State Hwy. Comm. Ohio 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. In development of a unit maintenance expenditure index for the State. In a study to develop a forecast of maintenance needs for the 1970-80 decade and compare it with the trends in highway maintenance needs for the U.S. as a whole and for the Northeast region in particular.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
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 American Iron and Steel Inst. Illinois Div. of Hwys.	In planning, design, construction, maintenance, replacement of guardrails and median barriers. 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 <i>Report 54</i> . 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 <i>Design Manual</i> or <i>Highway Standards</i> 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.
	Report 115	Nevada Dept. of Hwys. Illinois Dept. of Transp., Bur. of Design	In evaluating acceptability of the Department's design criteria and standards. 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. Wisconsin Dept. of Transp. Kansas State Hwy. Commission Minnesota Dept. of Highways	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. 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. As basis for publication, "Design of Stable Roadside Channels." 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.
	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.
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, <i>Informational Guide to Roadway Lighting</i> .

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		California Div. of Hwys.	Instrumental in setting the standards for California and aiding in developing the most satisfactory break-away 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. U.S. Government	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. 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 Calspan	In development of a college textbook, <i>Economic Analysis for Highways</i> . As starting point for a Tri-Level Accident Research program for NHTSA and the Motor Vehicle Mfrs. Assn.
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.
19-4(2)	Report 131	Office of Research and Development, FHWA	As a primary reference in training courses on Managing Highway Maintenance.
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 <i>Highway Research in Progress</i> 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 <i>Instructional Memorandum 40-2-70</i> .
		New Mexico State Hwy. Dept.	In revising the Department's <i>Bridge Construction Manual</i> .
	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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	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.
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.
22-2	Res. Results Digests 43, 53	North Carolina Dept. of Transp. and Hwy. Safety	To specify breakaway cable terminals for both guardrails and median barriers on new installations.

* 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

TABLE 7

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

<i>Rep. No.</i>	<i>Title, Project, Pages, Price</i>	<i>Rep. No.</i>	<i>Title, Project, Pages, Price</i>
52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., \$3.80	77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., \$3.80
53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., \$3.20	78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., \$3.20
54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., \$2.60	79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., \$6.40
55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., \$2.80	80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., \$5.20
56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., \$6.40	81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., \$5.60
57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., \$3.20	82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., \$4.00
58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., \$3.60	83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., \$2.80
59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., \$3.20	84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., \$2.40
60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2), 148 p., \$6.00	85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., \$1.80
61	Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., \$3.00	86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., \$3.20
62	Urban Travel Patterns for Hospitals, Universities, Office Buildings and Capitols (Proj. 7-1), 144 p., \$5.60	87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., \$2.00
63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., \$4.00	88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., \$2.00
64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., \$3.60	89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., \$3.20
65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., \$1.40	90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., \$4.00
66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., \$2.80	91	Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., \$3.20
67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., \$2.20	92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., \$2.60
68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., \$2.00	93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., \$6.20
69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., \$2.80	94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., \$1.80
70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., \$3.00	95	Highway Fog (Proj. 5-6), 48 p., \$2.40
71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., \$2.80	96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., \$5.40
72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., \$2.20	97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., \$2.60
73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5), 55 p., \$2.80	98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p., \$5.00
74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., \$2.80	99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., \$2.60
74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., \$8.00	100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., \$3.40
74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., \$4.00	101	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., \$3.60
75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., \$3.60	102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., \$5.40
76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., \$2.00	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)

<i>Rep. No.</i>	<i>Title, Project, Pages, Price</i>	<i>Rep. No.</i>	<i>Title, Project, Pages, Price</i>
106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., \$3.40	134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 24 p., \$2.80
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., \$2.40	135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., \$3.60
108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., \$4.00	136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., \$4.60
109	Elastomeric Bearing Research (Proj. 12-9), 53 p., \$3.00	137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., \$4.20
110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., \$4.40	138	Instrumentation for Measurement of Moisture—Literature Review and Recommended Research (Proj. 21-1), 60 p., \$4.00
111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., \$5.20	139	Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., \$4.40
112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., \$2.60	140	Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., \$5.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., \$15.60	141	Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., \$8.40
114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., \$2.60	142	Valuation of Air Space (Proj. 11-5), 48 p., \$4.00
115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., \$3.60	143	Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., \$16.00
116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., \$6.40	144	Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., \$4.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., \$4.60	145	Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17), 120 p., \$6.00
118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., \$5.20	146	Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis (Proj. 8-9), 68 p., \$4.00
119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., \$3.60	147	Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., \$4.80
120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., \$4.80	148	Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., \$4.00
121	Protection of Highway Utility (Proj. 8-5), 115 p., \$5.60	149	Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., \$4.00
122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., \$13.60	150	Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., \$4.80
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., \$9.60	151	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques (Proj. 1-12(2)), 100 p., \$6.00
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., \$4.80	152	Warrants for Highway Lighting (Proj. 5-8), 117 p., \$6.40
125	Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., \$4.40	153	Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances (Proj. 22-2), 19 p., \$3.20
126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., \$3.00	154	Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites (Proj. 1-12). (in press)
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		

TABLE 7 (Continued)

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),	(in press)	

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.

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 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

^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	DIGEST NO.	PROJ. NO.	TITLE
3 ^b	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act	46	3-18(1)	Control Logic for Traffic Signal Networks
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	47 ^b	20-6	Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation
14	12-3	Waterproof Expansion Joints for Bridges	48	10-9	Surface Condition Rating System for Bituminous Pavements
19 ^b	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968	49	1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques
20 ^b	19-1	Budgeting for State Highway Departments	50	1-12	Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites
22 ^b	20-6	Valuation in Eminent Domain as Affected by Zoning	51	3-18(2)	Traffic Control in Oversaturated Street Networks
25 ^b	20-6	Federal Environmental Legislation and Regulations as Affecting Highways	53	22-2	Development of a Breakaway Cable Terminal for Median Barriers
30	4-7	Fatigue Strength of High-Yield Reinforcing Bars	54 ^b	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation
31 ^b	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way	55	20-7	Side-Friction Factors in the Design of Highway Curves
32 ^b	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970	56	12-11	Waterproof Membranes for Protection of Concrete Bridge Decks
35	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	57	4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases
39 ^b	20-6	Legal Effect of Representations as to Subsurface Conditions	58	9-4	Minimizing Premature Cracking in Asphaltic Concrete Pavement
40 ^b	20-6	Appeal Bodies for Highway Relocation Assistance	59	12-15	Classification of Welded Bridge Details for Fatigue Loading
41 ^b	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases	60	12-12	Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings
42 ^b	20-6	Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation	61	1-12(3)	Wear-Resistant and Skid-Resistant Highway Pavement Surfaces
43	22-2	Evaluation of Breakaway Cable Terminals for Guardrails	62	1-10A	Systems Approach to Flexible Pavement Design and Management
45 ^b	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned	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

^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 sub-grade 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 is 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 is in the NCHRP editorial and publication process.

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 rational 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. An interim report containing a preliminary draft of the structural subsystems is in the process of being prepared.

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

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. (Alternate detection systems may be proposed with evidence of successful performance and comparable cost).
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.

Project 1-12(2) FY '71**Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques***Research Agency:* The Pennsylvania State University*Principal Invest.:* 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 Invest.:* C. J. Van Til*Effective Date:* November 1, 1971*Completion Date:* June 30, 1975*Funds:* \$261,955

The highway accident problem is complex, involving relationships between the highway, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all the various aspects of this problem. NCHRP Project

1-12 pertains to one particular portion of the over-all highway accident problem of determining the pavement frictional coefficients required for any given set of conditions. Project 1-12(2) pertains to the concentrated effort to determine the causes of differences that currently exist in measuring the skid resistance of a pavement surface with a reasonable degree of reliability by using skid testers constructed in general compliance with ASTM Method E-274-69. With completion of Projects 1-12 and 1-12(2), highway departments will have better means for determining desirable skid resistance service levels and for reliably measuring the skid resistance of pavement surfaces.

Traffic density and the use of winter traction aids contribute to accelerated polishing and wear of highway pavement surfaces. The resulting loss of surface texture reduces tire-pavement friction. Channelized traffic can also produce wheelpath depressions or ruts that may be detrimental to vehicle control and permit ponding of water with adverse safety effects, such as splashing, ice formation, and increased potential for hydroplaning.

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

The 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, and the data are being analyzed.

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: \$70,000

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 non-specific 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.

This project deals with the particular portion of the over-all accident problem involving vehicle operation on highway sections containing the combination of horizontal alignment and vertical alignment—that is, cornering on a downgrade or an upgrade. In this situation, there is strong evidence from accident experience that highway, vehicle, and tire design, as well as operational factors—such as speed and surface condition—affect the onset of skidding. Furthermore, these several variables interact in such a way that a comprehensive parametric examination is required to define the relative importance of the separate variables.

The objective of the research is 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.

The specific objectives are to:

1. Examine analytically the roadway and vehicle factors that influence the safe operation of modern passenger automobiles on highway sections containing a combination of horizontal alignment and vertical alignment, with emphasis on the downgrade horizontal curvature condition. Specifically, the following parameters and variables are to be included in this analysis:
 - (a) Roadway:
 - (1) Grades.
 - (2) Superelevation rate and runoff.
 - (3) Radius and type of horizontal alignment.
 - (4) Pavement surface properties and conditions.
 - (5) Drainage.
 - (b) Vehicle and operation characteristics:
 - (1) Operating speeds and lateral acceleration.
 - (2) Braking and longitudinal acceleration.
 - (3) Weight, geometry, suspension, and related factors.
 - (4) Tire characteristics and conditions.

High-level mathematical simulation techniques for analyzing the operation of automobiles with varying vehicle parameters under roadway conditions have been developed through research in other programs and verified by full-scale tests. Due to this fact—coupled with the limited available funds for Project 1-14—the development of new models is not anticipated during this project.

2. Determine those combinations of speed, roadway geometrics, and pavement conditions that define the onset of skidding for modern passenger automobiles.

3. Evaluate the results of Objectives 1 and 2 by one or more of the following methods:

- (a) Comparison with accident experience and roadway characteristics.
- (b) Physical simulation.
- (c) Field studies.
- (d) Other.

4. Suggest measures for alleviating skidding accidents on highway sections containing a combination of horizontal and vertical alignment and prepare recommended additions or modifications to current AASHO design policy to accommodate anticipated vehicle maneuvers on this type of highway section.

The primary research tasks include (a) application of computer simulation techniques to study the influence of roadway, vehicle, tire, and pavement parameters on vehicle control; (b) interrogation of Ohio and Pennsylvania Turnpike accident data to determine relationships between horizontal and vertical alignment on accident experience; and (c) detailed analysis of two problem sites with combined horizontal and vertical alignment. The analytical studies have not predicted loss of control when parametric values are within reasonable limits. Combinations of excessive speed, severe maneuvers, poor drainage, inadequate tire tread, and low pavement skid resistance are necessary to indicate loss of vehicle control. Turnpike accident data analysis and the detailed field site investigations confirm the finding that accidents at downgrade-curve sites are due to conditions other than those considered during design rather than to a deficiency in the design policy. Procedures have been developed for detailed analysis of existing and planned sites involving combinations of grade and alignment and for recommending measures to reduce skidding accidents at this type of site.

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

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: December 31, 1974
Funds: \$149,985

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, now complete, included general condition surveys of CRCP performance in a large group of states and diagnostic studies in several; laboratory studies of the behavior of model CRCP slabs under repetitive loading; and theoretical analysis of CRCP behavior. The research has led to a proposed new CRCP design procedure and to suggestions for criteria that can improve the construction process. The final report has been received and is in the review process.

Project 1-16 FY '74

Evaluation of Winter-Driving Traction Aids

Research Agency: Pennsylvania State Univ.
Principal Invest.: W. E. Meyer
Effective Date: June 3, 1974
Completion Date: June 2, 1976
Funds: \$150,000

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.

This problem was originally included in the FY '74 program with an allocation of \$300,000, but was reduced to \$150,000 during the Special AASHTO Select Committee on Research meeting of September 11, 1973. The Project Statement and proposals were prepared on the basis of funding at \$300,000. The revised research plan, to be accomplished with a budget of \$150,000, anticipates partial completion of the objectives described above. Standardized procedures should be available for evaluating winter-driving traction aids with regard to performance on snow- and ice-covered pavement surfaces, the performance of a limited number of available traction aids should be evaluated, and the feasibility study of a cost-benefit-type analysis should be completed.

Continuation funding of \$150,000 is being considered during development of the FY '76 program. If approved, the continuation funding would become available July 1, 1975, and the objectives would be accomplished as originally planned.

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 im-

provements. 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. J. Andersen
Effective Date: April 1, 1974
Completion Date: June 30, 1975
Funds: \$89,453

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. A large amount of information now is available (new since 1960) that needs to be utilized to update the unit costs in the AASHO report or to initiate changes in the approach. Many of the new data are not in a form allowing convenient conversion for use in the 1960 report. Attempts to employ the new cost data may require revision of the report and changes in the methodology. The revised report should resolve criticisms of the 1960 report with regard to economic analysis concepts or analysis methods.

The objective of this research is 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 will provide for a means of evaluating public transit operating on public highways. This evaluation should allow comparison between transit operation and additional highway improvements. Further, procedures will be developed that will 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 is recognized that environmental and social factors are significant items of input to the deci-

sion-making process, this research is to be limited to road user benefits and costs only.

Current practice has been 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. A thorough study has been made of alternative methodologies, with the result that primary emphasis is expected to be given to the benefit/cost ratio method, with some sophistication in the computation of benefits to consider induced demand. Secondary emphasis will be given to the net present value method. New cost data are being collected and a format is being prepared to present these data in usable form. In the remaining six months, emphasis will be given to preparation of the manual and development of methodology to update costs.

AREA 3: OPERATIONS AND CONTROL

Project 3-1 FY '63 and FY '64

Development of Criteria for Evaluating Traffic Operations

<i>Research Agency:</i>	Cornell Aeronautical Laboratory	
<i>Principal Invest.:</i>	Jaime F. Torres	
<i>Effective Dates:</i>	Feb. 15, 1963	July 2, 1964
<i>Completion Dates:</i>	Feb. 29, 1964	Feb. 28, 1966
<i>Funds:</i>	\$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

<i>Research Agency:</i>	Cornell Aeronautical Laboratory
<i>Principal Invest.:</i>	Morton I. Weinberg
<i>Effective Date:</i>	February 15, 1963
<i>Completion Date:</i>	April 30, 1966
<i>Funds:</i>	\$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

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

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

Evaluation and comparative examinations of four intervehicular communication systems were completed. These involved both night and day study of car-following for no signal display, for the conventional brake light, for the tri-light system denoting brake and accelerator action and an acceleration information display of horizontal rows of green and red lights to indicate the magnitude of the vehicle's acceleration or deceleration. Studies of lane changing decisions were also made. Taxonomies of func-

tional 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 iso-

lated 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 Intersection 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

<i>Research Agency:</i>	Bolt Beranek and Newman			
<i>Principal Invest:</i>	Andrew Kugler			
<i>Effective Dates:</i>	2/1/64	10/14/68	4/1/71	9/1/72
<i>Completion Dates:</i>	4/30/67	1/15/70	6/30/72	11/30/74
<i>Funds:</i>	\$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 reports will be published; meanwhile, copies are available on a loan basis upon request to the Program Director. The film is also available on a loan basis.

Project 3-8 FY '64 and FY '65

Factors Influencing Safety at Highway-Rail Grade Crossings

<i>Research Agency:</i>	Alan M. Voorhees & Associates	
<i>Principal Invest.:</i>	David W. Schoppert Dan W. Hoyt	
<i>Effective Dates:</i>	Dec. 1, 1963	Apr. 1, 1965
<i>Completion Dates:</i>	Dec. 31, 1964	Jan. 6, 1967
<i>Funds:</i>	\$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. G. F. G. F.
 Warskow King 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 is in the NCHRP editorial and publication process. Copies of the report are available on a loan basis, meanwhile, upon request to the NCHRP Program Director.

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
Effective Date: July 15, 1971
Completion Date: May 15, 1974
Funds: \$323,998

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.

All initial phases of the research have been completed, and the final report on this phase of the project is in the

NCHRP editorial and publication process. Continued research is anticipated to refine certain elements of the ASCOT program system and to test the system on a computer-controlled signal network in another city. Loan copies of the project's final report and the program listing and specifications are available upon request to the NCHRP Program Director.

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: March 31, 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 of the project has been initiated, with the objectives of carrying out further studies in minimal-response signal policies, nonsignal effects and remedies, and highly responsive policies, as well as producing a set of recommendations and guidelines for applying solutions to the problems of oversaturation.

Project 3-18(3) FY '75**Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems***Research Agency:**Principal Invest.:**Effective Date:* Contract Pending*Completion Date:**Funds:* \$100,000

Many years have been devoted to the development, testing, and practical application of a variety of traffic surveillance and control systems for signalized street networks. Alternative systems range from very simple pre-timed control methods employing little or no traffic sensing to highly complex systems employing closed-loop traffic-responsive control with extensive sensing.

Accompanying the efforts to develop effective traffic control algorithms have been dramatic advances in digital computer technology and marked reductions in computer costs. These trends have led to more widespread use of digital control computers, even for functionally simple master control techniques.

Past methods for evaluating the merit of alternative traffic surveillance and control systems for signalized streets have relied to a substantial degree on subjective ratings based on engineering judgment. This is true even of the well-structured cost-utility evaluation method that has been used widely in signal system design studies in the past several years. Also, little attention has been given to the way that traffic flow characteristics of a given network might dictate the choice of the best control techniques. As traffic characteristics vary widely from one location to another, so may the most cost-effective control system vary accordingly.

Improved systematic procedures to evaluate alternative traffic control systems, presented in a readily understandable and implementable form, are therefore 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 non-responsive 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.

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, housetrailer, 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 review stage. 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 draft final report has been submitted, containing recommendations for warrants based on the work completed so far. This report is available for loan upon request to the Program Director of NCHRP. A continuation phase extending the proposed warrants to additional intersection configurations and developing a plan for warrant verification began in late 1974.

Project 3-21 FY '74

Motorist Response to Highway Guide Signing

Research Agency: BioTechnology, Inc.
Principal Invest.: Fred R. Hanscom
 Wallace G. Berger
Effective date: April 1, 1974
Completion Date: January 31, 1976
Funds: \$250,000

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.

By the end of 1974 the research team had prepared the Phase I report, collected all field data necessary, and begun the evaluation of the various measures of effectiveness that were tested. Copies of the Phase I report are available on a loan basis on 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: October 14, 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, are to analyze existing ramp control techniques and to develop design procedures for freeway ramp control systems. The research will consider 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 is considered to be outside the scope of this project. Additionally, this project is not to address

guidelines for extensive freeway surveillance features except where these features relate to the control systems.

More specifically, the following tasks are to be addressed:

1. Design guidelines for the configuration of traffic control devices for ramp control field installations shall be developed.
2. Recommendations and supporting rationale shall be 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 shall be thoroughly investigated. A control system hierarchy for integrated system management that would be applicable to most control system projects shall be structured. Implementable flow charts shall be prepared.
4. Recommendations and the supporting rationale regarding the selection of electronic hardware shall be prepared. The development of procedures for evaluating the cost-effectiveness of alternative techniques for data communication, data processing, and control is particularly important.
5. Guidelines for control system adjustment to accommodate changes in traffic patterns, capacity, or operating policy shall be developed.

Research to date has included: (a) visits to a number of ramp-metering installations; (b) study of control device configurations, selection criteria, and system hierarchies; (c) the outline development and drafting of parts of the user manual.

Project 3-23 FY '74

Guidelines for Uniformity in Traffic Control Signal Design Configurations

Research Agency: KLD Associates, Inc.
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.

Progress through December 1974 included completion of the surveys of both literature and current practice, completion of several analytical and accident studies, and collection of data at 40 intersection study sites.

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 will be 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 neces-

sary 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.

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

Work during the first four months has included a review of the research literature and currently marketed materials, a survey of current traffic engineering practice with respect to retroreflective sign materials, and initiation of the problem-definition activity leading up to the Phase II research plan.

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 Evaluating Degradation of Base Course Aggregates."

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

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

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. D. Walker
Effective 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 Univer-

sity (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

<i>Research Agency:</i>	The Pennsylvania State University	
<i>Principal Invest.:</i>	Dr. T. D. Larson	
<i>Effective Dates:</i>	Mar. 25, 1963	July 1, 1965
<i>Completion Dates:</i>	Jan. 31, 1965	Aug. 31, 1967
<i>Funds:</i>	\$56,457	\$49,756

This project involved the development of a rapid test(s) to distinguish deleterious particles in aggregates and thereby predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The study was similar to that conducted under Project 4-3(1) at Virginia Polytechnic Institute (the same objectives apply) but different in approach. A number of aggregates investigated were common to both studies.

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

HRB Special Report 80, "A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research," and

NCHRP Report 15, "Identification of Concrete Aggregates Exhibiting Frost Susceptibility."

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

NCHRP Report 66, "Identification of Frost-Susceptible Particles in Concrete Aggregates."

Project 4-4 FY '63

Synthetic Aggregates for Highway Uses

<i>Research Agency:</i>	Battelle Memorial Institute	
<i>Principal Invest.:</i>	M. J. Snyder F. F. Fondriest	
<i>Effective Date:</i>	March 1, 1963	
<i>Completion Date:</i>	April 15, 1964	
<i>Funds:</i>	\$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

<i>Research Agency:</i>	Michigan Technological University
<i>Principal Invest.:</i>	Dr. W. M. Haas
<i>Effective Date:</i>	February 15, 1963
<i>Completion Date:</i>	August 31, 1965
<i>Funds:</i>	\$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

<i>Research Agency:</i>	Steel Structures Painting Council
<i>Principal Invest.:</i>	John D. Keane
<i>Effective Date:</i>	March 1, 1965
<i>Completion Date:</i>	November 30, 1966
<i>Funds:</i>	\$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 AASHTO 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 (60-ksi yield strength) to support realistic design criteria. This was approached through the design and execution of a statistically valid experiment with major emphasis on the evaluation of the effect of stress range; minimum stress, including reversal of stress; bar diameter (a minimum range of No. 5 to No. 9 bars); type of specimen; and grade of steel.

Phase I experimental work consisted of repeated-load tests on 236 rectangular or 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. NCHRP Research Results Digest 30 summarizes the results of Phase I.

Phase II had the objectives of (1) determining the effect of surface geometry (deformation pattern and details), and (2) incorporating the results of Phases I and II into a single final report.

The study has been completed and has achieved its objective of providing the evidence necessary to support a design criterion for the fatigue behavior of ASTM A 432 steel reinforcement bars (60,000-psi yield strength). The project report has been received and is in the review stage.

Project 4-8 FY '68

Research Needs Relating to Performance of Aggregates in Highway Construction

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. D. Walker
Effective Date: January 1, 1968
Completion Date: April 30, 1969
Funds: \$55,254

There is concern over the shortage of high-grade aggregates available at reasonable cost in many areas of the country. Efficient use of aggregates is handicapped by lack of quantitative information on the interaction between properties of the aggregate and its performance in a particular environment. The total problem involves (1) identification of the uses for which available aggregates are suitable with normal processing, (2) methods of upgrading available aggregates where necessary to make them acceptable for a particular use, and (3) adapting construction practices to permit use of available aggregates.

The objective of this research was to formulate a comprehensive series of statements of research problems and recommended studies (including estimates of time, cost, and priority) which have as their objective the development of procedures by the use of which a highway materials engineer may evaluate quantitatively the relevant properties of aggregates to be selected for a given class of use, in a given environment of service, for a given level of performance.

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

NCHRP Report 100, "Research Needs Relating to Performance of Aggregates in Highway Construction."

Project 4-8(2) FY '71

Density Standards for Field Compaction of Granular Bases and Subbases

Research Agency: Clemson University
Principal Invest.: J. P. Rostron
Effective Date: April 1, 1971
Completion Date: June 30, 1973
Funds: \$99,981

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% AASHTO 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 acceptance plans to control compaction during construction and/or design procedures is not anticipated.

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

Predicting Moisture-Induced Damage to Asphaltic Concrete

Research Agency: University of Idaho
Principal Invest.: Dr. Robert P. Lottman
Effective Date: September 1, 1971
Completion Date: March 31, 1974
Funds: \$200,000

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 was to meet an interim need for a laboratory testing system that would quantitatively predict the ability of asphaltic concrete to resist the detrimental effects of moisture under field conditions. Research 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 test 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.

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

Project 4-9 FY '69

Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices

<i>Research Agency:</i>	Utah State Highway Department	
<i>Principal Invest.:</i>	Dale E. Peterson	
<i>Effective Date:</i>	Oct. 1, 1968	Oct. 1, 1972
<i>Completion Date:</i>	June 30, 1971	Dec. 31, 1977
<i>Funds:</i>	\$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-month and 12-month samplings and observations following construction have been completed. An interim report containing findings after two years of exposure of the experimental sections is due in the fall of 1975.

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, Inc.
Principal Invest: Frank J. Heger
Effective Date: September 16, 1974
Completion Date: March 15, 1977
Funds \$150,000

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 environmen-

tal 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.

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 driv-

ing through the test area of the Connecticut Turnpike. Driver-questionnaire information was used to determine apprehension based on a numerical score and also to locate those events related to illumination which appeared to be most vexing to drivers.

The analysis included nonparametric tests of the effects of illumination, weather, moon brightness (as a function of elevation and phase), traffic volume, driver experience, driver familiarity, and day vs. night upon DDS scores and NTD scores.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-3 FY '64

Visual Information Needed by the Driver at Night

Research Agency: The Ohio State University
Principal Invest.: Dr. Thomas H. Rockwell
 Dr. Ronald L. Ernst
Effective Date: September 1, 1964
Completion Date: March 31, 1967
Funds: \$100,940

This research was designed to determine minimum information necessary to maintain control stability and identify the information which is normally used. Visual degradation studies were conducted to determine limits of performance stability based on driver performance criteria previously established. Mapping of the visual field through selective degradation was conducted to identify classes of information used by nighttime drivers. Research was conducted to determine times and distances to satisfy information needs for optimal control. Visual cues were scaled by photometric calibration of viewed object contrasts and edge markings. An eye marking unit was employed to assess relative cue importance in maintaining performance. An attempt was made to formulate the effect of freeway informational features on driving performance based on perceptual and highway design factors.

The project report has been published as:

NCHRP Report 99, "Visual Information Needed by the Driver at Night."

Project 5-4 FY '64

Economic Study of Roadway Lighting

Research Agency: The Franklin Institute
Principal Invest.: Arno Cassel
Effective Date: July 20, 1964
Completion Date: August 31, 1965
Funds: \$19,412

The purpose of this project was to determine capital cost ranges and operating costs for prevailing light sources in relation to type of luminaire distribution system and light intensity on the pavement.

The researchers collected data for economic comparisons, including costs for hardware, installation, useful operating life, power, maintenance, depreciation, taxes, insurance, and financing for various lighting systems. Sample type and quantity of equipment were analyzed to provide standard illumination levels on typical two-lane, four-lane, and six-lane divided highways. A literature search was made of available lighting cost studies, specifications, design criteria for highway lighting installations, maintenance, and replacement factors. Methods for evaluating capital improvement proposals were reviewed, and the annual cost method appeared to be most suitable for evaluating costs of different roadway lighting configurations. Questionnaires were received from public utility companies, municipalities, and State highway departments to acquire cost information.

The project report has been published as:

NCHRP Report 20, "Economic Study of Roadway Lighting."

Project 5-5 FY '65

Nighttime Use of Highway Pavement Delineation Materials

Research Agency: Southwest Research Institute
Principal Invest.: John M. Dale
Effective 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 utilizing existing materials or developing new materials and techniques were investigated.

This program was initiated by a field study of the performance characteristics of conventional marking materials. Following this, the researchers conducted studies of the physical nature of reflective materials with particular emphasis on their performance characteristics under various types of water films. Attention was directed to the development of a systematic approach to marking pavements wherein one qualifies the surface to be marked, determines the water film thicknesses to be encountered, and then selects one of several marking systems that will perform under the imposed conditions.

The project report on the laboratory phase of the research has been published as:

NCHRP Report 45, "Development of Improved Pavement Marking Materials—Laboratory Phase."

The purpose of the continuation phase was to further develop, optimize, and field test the new marking system that emerged from the initial research effort.

The project report on the field phase of the research has been published as:

NCHRP Report 85, "Development of Formed-in-Place Wet Reflective Markers."

In addition to the final report, a motion picture film 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 review stage. 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 and 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 has been accepted as a safety hazard in many states. 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 compu-

tation 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 review stage.

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.: Edward L. Perkins
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

Peak-Period Traffic Congestion

Research Agency: Remak-Rosenbloom
Principal Invest.: Sandra Rosenbloom
Effective Date: April 1, 1974
Completion Date: March 31, 1975
Funds: \$49,116

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 are (1) to conduct a state-of-the-art survey to identify methods currently used or envisioned to alleviate the problem, and (2) to develop a plan for research to achieve implementable solutions for short- and long-range aspects of the problem. The state-of-the-art should be appraised in terms of transportation and non-transportation considerations, including social, economic,

and environmental impacts, and technical, financial, and political feasibility. It is expected that the survey will highlight (1) methods capable of immediate implementation, (2) applicability of methods to various urban situations, and (3) deficiencies in knowledge.

Approaches to ameliorate peak-period traffic congestion have been classified as social, socio-economic, socio-technical, and technical. These have been summarized in an interim state-of-the-art report. Experience with each approach is described under the following categories: Concepts, costs, time framework, funding source, political feasibility, and impacts. Work is being completed on the evaluation of approaches, both singularly and as packages. In the remaining period for this project, emphasis will be given to preparation of the final report, which is expected to include research programs in two categories—those ready to be demonstrated and those requiring further conceptual development. In addition, the final report is expected to include recommended approaches for immediate implementation and recommended approaches that should not be used.

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 metropolitan areas having rail rapid transit, a study of factors influencing choice in travel mode, and prediction models for modal choice based on discriminant functions with a comparison of reported trips and computed paths.

A survey of travel choice of IIT Research Institute personnel was conducted. The reported trip time was compared with computed times using the updated 1965 CATS network. The Chicago 1960 census data were analyzed to improve predictive techniques for mode choice. A composite Chicago travel network was developed, with an analysis of variance of reported and computed transit travel time.

The project report has been published as:

NCHRP Report 57, "Factors Influencing Modal Trip Assignment."

Project 8-3 FY '64

Individual Preferences for Various Means of Transportation

Research Agency: University of Pennsylvania
Principal Invest.: Dr. Russell L. Ackoff
Effective Date: February 1, 1964
Completion Date: March 31, 1965
Funds: \$63,282

This project was designed to probe individuals' transportation preferences as contrasted to the more objective studies that Project 8-2 is concerned with. It was expected that the research would develop additional knowledge as to why and under what conditions persons will use or shift from one form of transportation to another. Better infor-

mation 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 transportation planning in areas of rapid growth and intensive development. The effects of zoning and general plans were studied, as were highway geometry and access control, in regard to protecting the investment of the highway systems.

A first technical report has been published as:

NCHRP Report 31, "A Review of Transportation Aspects of Land-Use Control."

This project was continued to establish principles or guidelines for developing land-use controls and other techniques that will be stable and effective in the protection of highway utility. The research effort was conceptual in nature and presented a variety of ideas and proposals by which the highway investment can be protected. Some of the guidelines were developed in considerable detail. These can be incorporated into the procedures and practices of land-use and highway administrators. Other principles were developed as a base from which more detailed analyses can be undertaken.

The project report discusses basic interrelationships between transportation facilities and land use and how such relationships can cause transportation facility breakdowns. The effects of changing land-use controls on the utility of highways are discussed, with special attention being given to large traffic generators located near freeway interchanges.

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

NCHRP Report 121, "Protection of Highway Utility."

Project 8-6 FY '66

Individual Preferences for Alternative Dwelling Types and Environments

Research Agency: University of North Carolina
Principal Invest.: F. Stuart Chapin, Jr.
Effective Date: February 14, 1966
Completion Date: March 13, 1968
Funds: \$99,897

In predicting the future demand for transportation, it is imperative that future densities of residential areas be projected. In order that this may be done with confidence, a better understanding must be acquired for the preferences of various housing types and environments.

To measure and report on a representative cross section of the population, the researchers interviewed a sample of 1,476 households in various metropolitan areas. Logical relationships were developed between desired home type, price range, travel access mix, and living qualities. An attempt was made at estimating the number of people expected to move in a specified time period and where they will probably locate.

A national survey in 43 Standard Metropolitan Statistical Areas was conducted in October and November 1966. The information provides a detailed, factual profile on the mobility and residential choice behavior of households in metropolitan areas.

The project report deals with a summary of findings on housing choice of the households interviewed; an analysis of the residential mobility process; an analysis of the housing-choice process; and, drawing on these analyses, a discussion of the elements needed for a model of moving behavior which will have the capability of dealing with both the mobility and choice processes as components of residential changes.

The project report has been published as:

NCHRP Report 81, "Moving Behavior and Residential Choice—A National Survey."

Project 8-7 FY '69

Evaluation of Data Requirements and Collection Techniques for Transportation Planning

Research Agency: Creighton, Hamburg
Principal Invest.: Roger L. Creighton
Effective Date: September 13, 1968
Completion Date: August 28, 1970
Funds: \$190,000

Urban transportation planning studies require travel, transportation facility, land-use, and various socioeconomic data. Techniques for obtaining these data are slow and costly. The accuracy, utility, and adequacy of the data and the methods employed for their collection and assem-

bly 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: December 31, 1974
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 objective of this research was to develop a simplified transportation planning process for a small urban area 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 on simulation. The investigation considered both planning process requirements and data requirements to take full advantage of recent advances in the understanding of travel behavior, dwelling unit analysis, and new census procedures with increased data availability.

The final report is in the review process. It is expected to give emphasis to the required organizational framework

and to simplified land-use and travel-demand forecasting techniques. The transportation planning process developed is not to be applied uniformly to all small, self-standing urban areas, but customized to fit the identified issues and needs of an urban area.

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 in-

tegration of the highway with the community. To achieve desirable levels of integration, research was programmed by AASHTO to (1) develop a practicable method for evaluating the immediate and long-term effects of highways on the social and environmental considerations of communities, and (2) test, evaluate, and refine the method through application to specific cases covering a range of situations. Because the method must maximize the probability that significant community values will in fact be considered, even if the state of the art does not allow all of these values to be measured quantitatively or predicted precisely, the research emphasized development of a method in the context of the location process. Although the scope covers all types of highways, the study findings hold for all types of transportation facilities and many other public works projects.

Under Project 8-8(1) MIT prepared a study design that served as the working plan for the first phase of the study that addressed the need for a pragmatic approach to the problem—in spite of the present lack of knowledge about how to measure and predict impacts of highways on the community—and resulted in 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 method and adapt it to specific situations; (2) extending the method for use in metropolitan area, statewide multimodal, and systems-level planning; (3) extending, testing, and refining the techniques set forth in the Procedural Guide; and (4) revising the Procedural Guide to reflect the additional knowledge.

The agency report presents an integrated approach for systematically incorporating social, economic, and environmental factors into transportation planning and decision-making that stresses:

- Timely identification of the nature, magnitude, and incidence of potential social, economic, and environmental effects so that, in all phases of transportation planning, alternatives may be developed that avoid or minimize adverse effects and that take full advantage of opportunities to increase benefits.
- Early, effective, knowledgeable involvement of the public to clarify issues and to aid in the development and evaluation of proposals.
- Effective use of expertise and resources, both of the transportation agency and of other institutions and agencies, with a maximum of flexibility and openness.
- Consideration of a range of transportation improvements involving various types of highway facilities; other modes; transportation regulations, controls, and constraints; and the no-build option.

Because transportation planning is conducted in a variety of institutional and environmental settings and serves a range of needs, the discussions emphasize over-all procedures—strategies, work styles, ways of viewing problems—that should be generally applicable to transportation agencies at the national, state, regional, and local levels of government, and in rural as well as urban settings. To assist in

making these procedures operational, specific techniques that might be used in implementing the approach also are described.

The procedures 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 procedures 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 stem from direct observation of the problems transportation agencies are facing.

A major objective has been to present recommendations that can be put into immediate operation. Thus, most of the methods and techniques can be adopted individually without difficulty. Taken together, however, the proposals reflect a philosophy of transportation planning and decision-making that is significantly different from what has been traditional. The over-all approach, then, has far-reaching implications for the transportation professional.

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

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.

Preferential bus facilities for improving bus commuting include preferential (including exclusive) bus lanes and ramps; traffic controls for smooth, uncongested flow; loading points and shelters; and park-ride lots. Although transportation planners and traffic engineers are interested in advanced bus utilization applications, their ability to implement these concepts is hindered by the lack of planning experience and design guidelines for these various elements.

The goal of this project was to develop a single reference source of information on bus utilization applications that increase the person-carrying capacity of existing highway facilities. This goal was met and the final report constitutes a reference source documenting existing and proposed preferential bus facilities for expediting movement of buses on highways; contains guidelines for planning and designing preferential bus facilities; and recommends needed research.

An interim report, "Bus Utilization of Highway Facilities—State of the Art," has been published as NCHRP Report 143. The final report is in the NCHRP editorial and publication process and will be issued in early 1975 as NCHRP Report 155, "Bus Use of Highways—Planning and Design Guidelines."

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: September 15, 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 is to strengthen techniques for the evaluation of the NCTF alternative. The research will recognize that the primary application of the resulting techniques is for transportation planning and project decision-making purposes, including major highways and transit facilities, and will explore their application in concert with comprehensive planning. It will specify 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.

A two-phase project is anticipated. Specific objectives for Phase I are as follows:

1. Conceptualize a practical approach (analysis, evaluation techniques, procedures) to determine the social, economic, and environmental consequences resulting from either a decision not to construct a transportation facility or a decision to delay the facility.
2. Within this framework, evaluate the experience to date in analyzing and portraying the social and economic consequences of the NCTF alternative. This evaluation should include a review of completed and on-going transportation, social, economic, and environmental impact analyses from both a methodological and decision-making viewpoint. Selected examples, covering situations where build and NCTF decisions have been made, should be examined in depth to define the sufficiency of the no-build evaluation and the influence that it had on the decision, as well as the consequences of that decision. This evaluation could also include a review of state action plans, on-going research activities, and any other appropriate literature and experience.
3. Identify deficiencies in current analyses of the NCTF alternative.
4. Provide interim guidelines for the analysis of the NCTF alternative.

5. Prepare a research plan for Phase II to develop techniques to overcome deficiencies identified in Objective 3. This plan will specify both technical approach and estimated costs.

Through December 1974, an analytical framework for defining and evaluating the NCTF alternative has been developed.

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: May 2, 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 specific objectives of Phase I are as follows, under which major emphasis is being given to Objective B, Tasks 3 and 4:

A. To identify and categorize the urban policy issues for which travel estimates are required. 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. Develop criteria and rationale for classifying policy issues that require travel estimation input.

Task 2. Compile and catalog policy issues according to the developed classification and identify the requirements each places on the travel estimation procedures.

B. To evaluate travel estimating procedures, available and soon to be available, as to their ability to satisfy the requirements of policy issues. The evaluation criteria should be based on the policy issue analysis and may include timeliness, needed accuracy, cost, utility, etc. The conceptual evaluation not only should provide the basis for selecting the most appropriate areas for detailed testing and expansion of capabilities, but also should be designed to provide a ready reference for the planner.

Task 1. List travel estimation procedures (in use and soon to be available) for quick response to urban policy issues.

Task 2. Develop a classification of travel estimation procedures as they relate to Objective A and establish criteria to evaluate the procedures.

Task 3. Describe and catalog the procedures according to the developed classification.

Task 4. Evaluate travel estimation procedures in terms of the criteria developed in Task 2 of this objective. This task will be based on a review of documentation and experience in previous applications and no field testing is anticipated.

C. To prepare on the basis of Objective B a fully supported set of recommendations for the subsequent phases of the project. It is expected that the recommendations will include detailed testing of available techniques, preparation of manuals, modification of techniques, and development of new procedures. The scope, products, level of effort, and staging of the recommended research should be addressed. The recommendations should emphasize the provision of field-tested, operational tools with quick response times.

Through December 1974, policy issues requiring travel estimation input have been catalogued. Travel estimating procedures have been inventoried and a start has been made on criteria to evaluate the procedures.

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 forecast-

ing 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.

Progress through December 1974 includes the identification of strengths and weaknesses of existing disaggregate modeling approaches. A start has been made to extend the present state of disaggregate modeling.

Project 8-14 FY '75

New Approaches to Understanding Travel Behavior

Research Agency: Social Policy Research Group
Principal Invest: Marc A. Fried
Effective Date: December 1, 1974
Completion Date: May 31, 1976
Funds: \$149,958

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.

Research to meet the described need is planned to be conducted in two separately funded phases. The specific tasks of Phase I are:

1. Review and categorize alternative behavioral approaches to travel theory, particularly in terms of those kinds of stimuli and their interrelationships assumed to influence travel in each of these approaches. An interim report will be submitted on completion of this task.
2. Detail criteria for evaluating the significance of these factors and interrelationships as determinants of travel. These criteria should include responsiveness to policy questions. (Relevant policy issues should be identified in the proposal.)
3. Using these criteria, evaluate alternate approaches.
4. From the evaluation, conceptualize a general theory of travel demand for detailed analysis in Phase II. The theory can consist of:
 - (a) One of those evaluated, judged to be most viable.

- (b) A synthesis of those approaches.
- (c) An entirely new approach.

5. The basis for the theory shall be thoroughly and effectively evaluated, using the criteria developed in Task 2. An interim report on Tasks 2 through 5 will be submitted on completion of Task 5.

6. Identify those variables and their interrelationships assumed in the conceptualized approach developed above.

7. Assess candidate procedures for measuring these variables. This step could include several small pilot studies or group studies.

8. Based on Tasks 4 through 7, devise a plan for research under Phase II.

In the one month that the project has been under way, a start has been made on the review and categorization of alternative behavioral approaches to travel theory.

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: August 31, 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.

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 will emphasize 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. This project is intended to describe technical meth-

odologies to assist the states in their decision-making processes. As such, the project is to examine specific identification and measurement techniques, in contrast to issues of impact evaluation and design of the over-all planning and policy-making process.

The investigation will consider, but is not limited to, 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 will be given in each of the described methodologies to identifying distributional effects.

To achieve the stated objective, the proposed research will be conducted in two phases. Phase I Tasks are as follows:

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.

Three overlapping mechanisms for identifying and measuring state and regional transportation impacts are being used. A start has been made on the literature search and personal interviews. This will be followed by a study of cases.

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 project report is in the NCHRP editorial and publication process.

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. To provide further knowledge for a possible solution to these difficulties, the over-all objectives of this research were to (1) find the effects of stockpiling and handling on the properties of an aggregate, including segregation and degradation, and (2) establish suggested procedures for better practices in stockpiling and handling.

Initial research was directed principally to the aspects of stockpiling, and the results have been published as:

NCHRP Report 5, "Effects of Different Methods of Stockpiling Aggregates."

Continuation of the initial research was authorized to expand the scope to include, in addition to further stockpiling investigations, the effects on aggregate properties of several routine methods for handling, spreading, and compacting bases. This work has been completed, and the project report has been published as:

NCHRP Report 46, "Effects of Different Methods of Stockpiling and Handling Aggregates."

Project 10-4 FY '64 and FY '65

Rapid Test Methods for Field Control of Construction

Research Agency: Clemson University
Principal Invest.: Dr. A. E. Schwartz
Effective 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, subbases, and base com-

ponents. Some of the researchers have indicated such devices are applicable for field control, while others are still evaluating the technique. If these nuclear devices are capable of accurate and reliable determinations, there is a possibility that considerable economy may result in construction and control procedures. The objectives of the initial research were (1) to review the literature and other available data to determine what has been done by others in the evaluation and correlation of nuclear equipment, (2) to evaluate and analyze assembled data considering such factors as accuracy and precision, and (3) to make recommendations for the development of needed equipment.

Research on the initial phase has been completed and the project report for this phase has been published as:

NCHRP Report 14, "Density and Moisture Content Measurements by Nuclear Methods—Interim Report."

The objective of the continuation phase was to investigate in depth the promising findings from the initial research. Theoretical investigations were supplemented by field experiments to establish a technique for calibrating nuclear gauges to provide improved accuracy in the measurement of soil moisture content and density. In the pursuit of these objectives, calibration standards were developed which are applicable to nuclear gauges currently in use.

Research on the continuation phase has been completed, and the project report for this phase has been published as:

NCHRP Report 43, "Density and Moisture Content Measurements by Nuclear Methods."

Project 10-5A FY '68

Optimization of Nuclear Density and Moisture Content Measurement Methods

Research Agency: North Carolina State University
Principal Invest.: Dr. R. P. Gardner
Effective Date: February 1, 1968
Completion Date: January 31, 1970
Funds: \$51,214

In recent years there have been numerous investigations of nuclear methods for determining the moisture content and density of subgrade, subbase, and base components of highway pavements. Nuclear devices have been evaluated and found to be potentially more accurate and faster than conventional measurement methods. During the conduct of Project 10-5 the primary problems associated with these devices were identified as sensitivity elemental composition, nonuniform response to the sample due to the nonhomogeneous nature of soil and aggregate materials, surface roughness of the measurement area, and gauge calibration. Several nuclear gauge calibration methods were developed utilizing calibration model, energy discrimination, and dual-gauge principles.

The essential objective of this study was to optimize nuclear gauge calibration methods and thus improve operational performance of the gauges for control of moisture and density during construction of highway subgrade, subbase, and base components. 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 non-destructive 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 seal-coat applications should be made are needed.

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

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 review stage.

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 is expected to include at least 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, fatigue, 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.

Phase II is to 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 31, 1974, the agency has completed tasks 1 and 2, and most of the weldments required for task 3 have been made. Testing is well under way and will continue through most of 1975. The report prepared under task 2 has been reviewed by the advisory panel, revised by the agency, and is now available for loan on request to the NCHRP Program Director.

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 condemning 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 relocation assistance and for decisions between alternatives in specific situations.

The research report contains discussions of the constitutional requirements and limitations and how the basic standards for the payment of compensation to persons whose property is taken for public use are derived from such sources. The need for new compensation techniques is discussed and analyzed. Traditionally, "consequential damages" resulting from the taking of a man's property have been considered part of the burden of citizenship. The rapid increase of residential takings has caused great pressure on government to compensate more of these consequential damages. The various monetary and nonmonetary effects are outlined to indicate the wide range of losses that may result when residences are taken.

The project report has been published as:

NCHRP Report 107, "New Approaches to Compensation for Residential Takings."

Project 11-1(11) FY '68

Valuation Elements of Joint Development Projects, Including Air Rights

Research Agency: Real Estate Research Corp.

Principal Invest.: John M. Bohling

Effective Date: February 24, 1969

Completion Date: August 25, 1969

Funds: \$5,000

Interest is increasing with respect to joint development projects involving highways and other kinds of public and

private facilities. There is actually little information available, however, about the application of known appraisal concepts to such joint development projects. Additionally, a whole new valuation dimension has come into focus, involving the valuation of vertical planes of value (air rights). All of these aspects need to be explored.

The study briefly reviewed the legal factors covering the valuation of air rights and of joint development projects. An exploration was made of known appraisal concepts and valuation principles and their application to the valuation of multiple-use projects. The findings of this study will provide guidance for appraisal practitioners and public officials concerned with the valuation of joint development projects.

The study found that the current appraisal technique, as presented by the Keuhnle and White formulas, appears to present the best potential for the valuation of multiple-use projects, particularly as they apply to rights-of-way. These formulas present the value of the property interest to be disposed of (the air rights or tunnel easement) in order to approximate the difference between the value of the fee property before and after the specific property interest is conveyed. These formulas take into consideration other costs or benefits, such as (a) economic value loss because of reduction in functional utility due to construction, (b) added costs of constructing improvements in a different fashion than if erected on surface fee, (c) additional interest expense which would be incurred, (d) savings in excavation costs, (e) tenant relocation, (f) demolition.

The final report 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 includes an inventory and review of before-and-after case study material where air space has been bought, sold, or leased. An analysis has been 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 evaluates the adequacy of existing legislation and analyzes and reports 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 has been developed.

The variables and factors that influence air space acquisition and the valuation processes have been identified and analyzed. Matrices have been 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: June 30, 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 is 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 will include at least 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.

Through December 31, 1974, the agency has completed tasks 1 and 2, and most of task 3. Tasks 4 and 5 are about 50 percent complete.

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 AASHO 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. It was proposed to include in the work 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 proposed for consideration. The planned level of subsequent effort related to (1) an analysis, for the overloads now permitted by AASHO specifications, of typical steel-stringer highway bridges of the specified type and modern design to determine the residual stress levels necessary to result in permanent deformations and (2) an extension of this analysis to determine the redistribution of residual stresses due to overloads causing permanent deformation and to determine the effect of repeated cycles of overloading.

The final report has been included in the report for Project 12-6 and is in the NCHRP editorial and publication process.

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 summary 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: September 15, 1966
Completion Date: November 15, 1968
Funds: \$173,255

This project sought to determine environmental conditions under which special protection is required and to develop effective protective systems under both pre- and post-tensioning configurations. Specifically, the objectives were (1) to conduct a thorough survey of available domestic and foreign data on corrosion and prevention of

corrosion of prestressing steel in bridges, buildings, pavements, and other structures; (2) to review present practice to evaluate the effectiveness of prevention of corrosion and mechanical damage during manufacturing, shipping, and placing; (3) to identify the mechanisms of corrosion which attack prestressing tendons under various conditions, possibly including, but not limited to, the influence of concrete and grout composition, the presence of free water, electrolysis, and the presence or absence of cracking; (4) to devise an appropriate accelerated corrosion test or tests simulating the various service conditions surrounding prestressing tendons; (5) to evaluate various possible protective systems for prestressing tendons, including, but not limited to, metallic, plastic, or inhibitive coatings, grout substitutes or admixtures, cathodic protection, etc.; (6) to perform field and laboratory experiments to determine the effectiveness of present grouting methods for post-tensioned work and to suggest improvements in methods and/or materials; and (7) to evaluate the effectiveness of concrete cover over tendons.

The final report has been published as:

NCHRP Report 90, "Protection of Steel in Prestressed Concrete Bridges."

Project 12-6 FY '67

Prediction of Permanent Camber of Bridges

Research Agency: University of Missouri
Principal Invest.: Dr. James W. Baldwin, Jr.
 Dr. Adrian Pauw
Effective Date: February 1, 1967
Completion Date: April 30, 1972
Funds: \$85,000

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 should 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 includes the findings of Project 12-1 and is in the NCHRP editorial and publication process.

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. To date, 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 includes a continuing review of existing data and mathematical relationships defining the fatigue behavior of various details under constant-amplitude loading. It also includes 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: \$30,000 \$70,000

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 has as its objective the quantification of the service requirements to produce design criteria for bridge rail systems. This objective is 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 has 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 129, "Bridge Rail Design—Factors, Trends and Guidelines."

Project 12-9 FY '67**Elastomeric Bearing Research**

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

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

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

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

NCHRP Report 109, "Elastomeric Bearing Research."

Project 12-10 FY '70**Analysis and Design of Bridge Bents**

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

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

Although the ultimate need is to establish valid design procedures that are applicable to many configurations of bridge bents, this project was limited to investigation of bent

caps concealed in straight, continuous, reinforced concrete bridges.

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

Research was based on prototypes representative of popular box-girder designs. The accomplishment of the research included: (1) reviewing the technical literature; (2) determining a design procedure for single- and multiple-column bents; (3) determining the cap design width by defining the extent of superstructure participating in supporting the cap loads; and (4) specifying changes required in the AASHTO specifications to permit use of the recommended design procedures.

To achieve the objectives of this research, a plan was developed that includes testing of 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 2/5-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 accompany 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**

<i>Research Agency:</i>	Materials Research & Development	
<i>Principal Invest.:</i>	C. J. Van Til	C. J. Van Til
	B. J. Carr	
<i>Effective Dates:</i>	Aug. 1, 1970	July 15, 1973
<i>Completion Dates:</i>	Mar. 31, 1973	Apr. 15, 1977
<i>Funds:</i>	\$206,034	\$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.

Under Phase II, several state highway agencies have agreed to incorporate the five systems selected as most promising in new deck construction. It is anticipated that the installations will be completed in 1975.

The report for Phase I is in the NCHRP editorial and publication process.

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: July 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. A program of field tests is currently under way to develop this information.

This project is 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 plans to achieve 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 will be tested later; 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.

Through December 31, 1970, the agency concentrated on the collection and evaluation of field stress measurements of bridges under traffic available from the Federal Highway Administration and various state highway departments. In addition, a large effort went into planning a statistically valid experimental design for the pilot test program of small specimens and also the large beam specimens. Planning for the test setups, instrumentation, and methods for observation and recording was essentially completed.

Through December 31, 1971, the agency completed the review of field stresses in highway bridges, selected Rayleigh distributions for variable-amplitude stress spectra to be used in the experimentation, fabricated almost all the test specimens, initiated testing small specimens for crack-growth studies and beam coverplate simulation studies, initiated testing large welded beam specimens, and conducted analyses of the limited test data.

Through December 31, 1972, the agency concentrated primarily on testing beam and crack growth specimens. In October 1972 an interim report was submitted by the agency and reviewed by the project advisory panel. Section I of the report describes the material properties and fabrication methods for the beams and specimens. Section II describes the test setup procedures for the plate-specimen

and the beam tests. Section III summarizes available field measurements of stresses in short-span bridges under traffic and describes the stress spectra that were developed from these measurements for use in the testing program. Section IV describes the fatigue-crack-growth behavior of 514 steel under the variable-amplitude random-sequence stress spectra developed in Section III. This report will not be published, but loan copies are available on request to the NCHRP Program Director.

Through December 31, 1973, the agency continued testing of large beam specimens and analysis of data. Some 153 cover-plate beams and 54 small crack-growth specimens were tested through October 1, 1973. After that time, effort was concentrated on testing of the 66 plain-welded beams called for in the research plan.

Through December 31, 1974, all testing was completed with the exception of a few long-life specimens to be subjected to very low stress ranges. The remaining months of this project will be devoted to data analysis and the writing of a final report.

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 Engrs 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. The objective was approached by two phases of research.

Under Phase I, on which research has been completed, the two primary approaches to cathodic protection—the impressed current system and the sacrificial anode system—were both 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 Phase I study was developed. The Phase II field evaluation is pending.

The final report for Phase I is in the NCHRP editorial and publication process. Meanwhile, loan copies of the agency draft are available from the NCHRP Program Director.

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: March 31, 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 this research project are to: (1) compile a state-of-the-art review of existing methods of non-destructive 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 are to be confirmed by tests of "as welded" and of fatigue-damaged coverplate beam specimens of A36 steel. These tests are to be comparable to and correlated with those conducted in NCHRP Project 12-7 and reported in

NCHRP Report 102. The experimental variables are to include crack size at the time of repair or improvement, 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 completed during 1974. The latter was published in March 1974 as NCHRP Research Results Digest 59, "Classification of Welded Bridge Details for Fatigue Loading."

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: \$186,915

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 aggravate the condition because it prevents processes such as flushing and drying that might help to remove chlorides and also because it prevents visual examination of the deck.

Numerous techniques are currently used to arrest and repair the damage caused by corroding reinforcing steel in otherwise structurally sound concrete bridge decks. Repair techniques include removal of the concrete to or below the level of the top mat of reinforcing steel, a variety of treatments of the steel, and use of various materials to replace the concrete removed. In addition to replacement of the damaged concrete, the repair often includes application of an overlay with or without a waterproofing membrane. The effect of these methods on subsequent corrosion has not been determined.

The over-all objective of this research 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 meth-

ods currently used throughout the United States. The major emphasis of the project shall be on commonly used methods but some methods that have been used experimentally in the field may also be investigated.

The preliminary field survey will determine how well repair methods appear to be working and identify or "screen" methods for further study. It will include development of a study sample using bridges that (a) have been subjected to deicing salts, (b) have deteriorated due to corrosion of reinforcing steel, and (c) have been repaired. These bridges will be ones for which significant information is available with regard to repair methods and subsequent performance of the repair. This information will be supplemented by limited on-site inspections. The study sample will also represent bridges with different severities of environmental exposure and different repair techniques.

The laboratory evaluation will be 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 will include 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 will probably include electrical measurements, chloride analyses, and any other corrosion detecting procedures the researcher may choose.

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, 1974, the preliminary field survey has almost been completed and specimen preparation is under way for the laboratory evaluation.

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 is in the NCHRP editorial and publication process.

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: June 14, 1975
Funds: \$99,754

Many miles of highways have been constructed and are being designed and constructed with portland cement concrete roadway pavements and bituminous-surfaced shoulders. The resulting longitudinal joint between the pavement and the shoulder contributes to costly maintenance and inconvenience to motorists. Keeping this joint sealed to prevent the intrusion of water and other objectionable material is very difficult, but of prime importance to pavement performance. If the joint is not completely sealed, surface water will eventually get beneath the pavement and paved shoulder and contribute to pumping, faulting of transverse pavement joints, and shoulder settlement. Additionally, the presence of water in the subgrade and base course can cause swelling of some soils and frost damage in cold climates that, when combined with the physical forces of expansion and contraction and compaction under heavy wheel loads, results in deterioration of both pavement and shoulder surfaces.

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 are 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 is being conducted jointly with the University of Michigan.

The study has been 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. All field surveys and measurements of joint movement have been completed. The field data were used in designing laboratory test equipment and procedures to assess the capabilities of sealers in accommodating the movements. Laboratory tests of sealer response to movement have been completed. The laboratory study of the permeability and intrusion-resistance characteristics of some underdrain materials has also been completed. A small field study was made of the entry of water at pavement-shoulder joints and its rate of egress from drainage layers. The final report for the project is in preparation.

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: October 14, 1975
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 at this time. This phase is 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 to date has included a state-of-the-art study, visits to several sites of expressway rehabilitation activity, and the gathering of information on potential rehabilitation materials, including polymer concretes, epoxy admixture concretes, fiber concrete, fiber-sulfur concrete, rapid-setting cements, and foamed polymers. A laboratory study to complement existing data on materials with information germane to the project was started. 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. A report covering the field evaluation work is in the review stage.

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 unengaged, 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 unengaged 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 pro-

vide 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 Israelson
 Paul E. Packer
Effective Date: November 1, 1973
Completion Date: October 31, 1975
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 has been 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 undervalued, 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 is the development of recom-

mendations for an interim set of specific guidelines for erosion control based on existing information.

The objectives of this project are 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 is being conducted jointly with the U.S. Forest Service.

Work on the project has included a search and cataloging 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 has been established as the project base for estimating soil loss. Existing maps that divide the country into areas of varying soil erosion potential are being used in application of the universal equation.

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 method-

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

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. The public experiences considerable inconvenience and expense as a result of obstruction to traffic caused by reconstruction and making repairs as necessary. 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 is to develop the technology for the economical use of polymers to improve the serviceability of concrete in highways. The immediate goal of this project concerns economically feasible methods for impregnation of both old and new concrete bridge decks in place.

To avoid unnecessary duplication of effort, the work will be structured to consider all known related work completed or in progress at such institutions as the U.S. Bureau of Reclamation, Brookhaven National Laboratory, and the University of Texas.

More specifically, the work will include the following:

1. Selection of a chemical system such as methyl methacrylate or polyester-styrene and appropriate catalysts, accelerators, etc.
2. Development of field techniques and apparatus for surface impregnation of concrete using the selected chemical system. The apparatus will be scaled for field use on bridge decks, although not necessarily developed to the stage of a production item.
3. Evaluation of the effectiveness of the technique as related to (a) properties and condition of the concrete to be impregnated, (b) preparation of concrete for impregnation, and (c) properties of impregnated concrete (especially durability, skid resistance, abrasion resistance, strength, impermeability, etc.)
4. Demonstration of the techniques in the field on one or more existing bridge decks, and tests thereon as in Task 3(c). At least one of the decks will be chloride-contaminated but otherwise sound except for areas of steel corrosion. Impregnation to the bottom of the top layer of reinforcement, or to a depth of 4 in., will be sought.
5. Preparation of a manual describing procedures that may be used to routinely impregnate concrete bridge decks.

The program is being conducted jointly by Lehigh University and The Pennsylvania State University.

Progress to date has included a state-of-the-art survey, laboratory development of engineering data on the penetration capabilities of candidate materials, testing of drying techniques and prototype impregnation equipment, and durability studies. Impregnation of a small area of a bridge deck using laboratory-size equipment and a subsequent impregnation using equipment of a more nearly practical size were successful in that the intended 4-in. depth of penetration was achieved.

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 ab-

stracts 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: \$419,000 \$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 in-

* 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.

creasing the effectiveness of the freeway and surface street system, and equipment configurations were recommended to improve the system based on a cost-effectiveness study.

A technical report, "An Evaluation of Two Types of Freeway Control Systems," covering the 1967 research work was submitted and accepted. The report includes an evaluation of the initial NPG television and advisory speed and lane-control signs and a description and evaluation of the ramp-metering system. Six additional reports were prepared covering the 1967 research work.

The major work items proposed for completion in 1968 were a pilot study of a freeway-frontage road driver information system, further freeway operations studies using improved detection and refined control techniques, environmental effects studies, pilot equipment studies for traffic-responsive signal control throughout the corridor, and a preliminary design for a more extensive driver-communication system to include the surface streets within the corridor. The project report for the 1968 work, "A Freeway Corridor Surveillance, Information, and Control System," 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.

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 equip-

† 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.

ment 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.

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: \$50,000

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 com-

mittee 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 over-run 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 and other measures will be considered for obtaining the desired summary reports.

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 sub-groups.

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-'74

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 26 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: "Pavement Widening;" "PCC Pavements for Low-Volume Roads and City Streets."

The following topic report is in the review stage: "Treatment of Soft Foundations for Embankments."

The following topics are in the research stage: "Intersection Design and Control of Off-Ramp Terminals;" "Sub-surface Explorations;" "Pile Foundations;" "Adverse-Weather Construction Methods;" "Tunnel Operations;" "Durability Criteria for Selection of Pipe Culverts;" "Ef-

fects of Studded Tires;" "New Application of Instrumentation and Equipment for Testing Highway Materials;" "Statistically Oriented End Result Specifications;" "State Utility Accommodation Policies and Practices;" "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;" "Use of Asphalt Emulsions by the Paving Industry."

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

A major and continuing need of state highway departments involves the assembly, analysis, and evaluation of operating practices and the legal elements of special problems involving right-of-way acquisition and control and highway law in general. Individual State experiences need to be compared and made available for possible application nationally. Need exists with respect to both immediate and longer-range right-of-way and legal problems.

In spite of this critical need today, there is really no present mechanism that is capable of responding in time to be of practical assistance to state highway departments. The Right-of-Way and Legal Affairs Committee of the American Association of State Highway Officials has tried all of the known channels in an effort to initiate such research, but the response has been negative for one reason or another.

Accordingly, state highway officials have agreed that an appropriate mechanism be initiated under which needed research of the type suggested can be undertaken and with dispatch. Prototypes of such a device may be found in the various AASHO and HRB road-test projects that have been undertaken and, perhaps more closely related, in the 1956-60 special HRB Highway Laws Project.

NCHRP Project 20-6 has been established to meet the aforementioned need and is a continuing effort involving research on a priority listing of topics selected by the cognizant NCHRP project 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 (Final report being revised)
 Study No. 11—Personal Liability of Highway Department Employees (Final report postponed)
 Study No. 12—Tort Liability of Highway Departments Arising Out of Skidding Accidents (Final report being revised)
 Study No. 13—Appeal Bodies for Relocation Assistance (Research Results Digest No. 40)
 Study No. 14—Admissibility and Use of Severance Studies in Condemnation Litigation (Terminated due to insufficient data on which to base the study)
 Study No. 15—Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases (Research Results Digest No. 41)
 Study No. 16—Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation (Research Results Digest No. 42)
 Study No. 17—Liability for Design Defect (In progress)
 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 Changing Concept of “Highway Purpose”
- 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

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 will be included in the text, which is now in the editorial and publication process and is expected to be completed early in 1975.

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 high-

way access, and the legal interrelationships of the Federal and state governments. Contracts for the writing of papers on study topics 36 through 44 have been awarded to persons of known competence in these particular fields. These papers are scheduled for completion by the end of 1974, and the third volume is expected to be published by the end of 1975.

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

Project 20-7 FY '69 and continuing

Research for AASHTO Standing Committee on Engineering and Operations

Research Agency: Open *

Principal Invest.: December 2, 1968

Effective Date: Continuing

Completion Date: \$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 AASHTO activities. In earlier years, objectives of the Committee were attained through the establishment at the Texas Transportation Institute (TTI) of a continuing research capability; however, 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 and, to date, conducted by TTI 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.” 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.” Research has been completed and the final report is in the review stage. 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.” The final report has been completed and transmitted to the AASHTO Committee.

* Texas A&M University and Stanford Research Institute (Project 2-12) to date.

Task 4, "Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures." 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." 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." 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. The final report is in the NCHRP editorial and publication process.

Task 7, "Safety at Narrow Bridge Sites." A study has been made of available information on the problem of safety at narrow bridges and on safety measures that have proved successful. Field studies of motorist reaction to currently used treatments and to new treatments designed to improve safety are in progress.

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: October 30, 1975
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 have been identified and a start has been made on the analysis procedure that will be used in assessing equity. Data have been collected from home interviews prior to displacement at six sites geographically distributed throughout the United States. As of December 31, 1974, displacees are still in the process of being moved at four of the six sites. This has delayed the collection of some "after" data to the Spring of 1975. Emphasis in 1975 is expected to be in the development of techniques to predict and display the consequences of highway-induced residential dislocation. Furthermore, such techniques are to be incorporated into a procedural manual.

Project 20-10 FY '73**The Benefits of Separating Pedestrians and Vehicles**

Research Agency: Stanford Research Institute
Principal Invest.: Ronald L. Braun
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.

Through December 1974 the researchers have completed their literature review. They have identified promising methodologies and data requirements to be applied to two case studies.

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 research has been completed. The final report will

not be published but will be summarized in the Research Results Digest series. Meanwhile, loan copies are available on request to the NCHRP Program Director.

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: March 31, 1975

Funds: \$89,000

Existing and proposed air pollution regulations, coupled with highway agency commitments to environmental protection, require changes in construction and maintenance procedures and activities. Information is needed to define the activities that produce pollutant emissions in such magnitudes that the violation of air quality regulations or national ambient air quality standards is probable. Practical solutions to these problems have not been adequately defined.

The basic goal of this project is to identify, evaluate, and recommend procedures for highway construction and maintenance that will enable compliance with ambient air quality standards and regulations. Specifically, the research objectives are to:

1. Survey air quality regulations and the affected construction and maintenance practices.
2. Formulate alternate procedures to mitigate adverse effects from fugitive dust emissions.
3. Outline other necessary research.

The survey of air quality regulations and presumed affected construction and maintenance practices has been completed. Questionnaires, telephone contact, and in-person visits were used in the survey. Data are being summarized and evaluated for the final report. Early in the project the types and quantities of atmospheric pollution released from construction and maintenance activities were documented and measured. In the remaining contract period emphasis will be on preparation of the final report, which is to include recommended criteria that can be used as standards in evaluating alternative dust mitigation procedures. Furthermore, the report is expected to include alternative mitigating procedures for hydrocarbons.

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: June 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 been documented to any degree. The proposed study is needed to provide an evaluation of environmental improvements attributable to freeways in order to place present and future freeways in proper perspective.

The objective of this project is to determine the long- and short-range positive aspects of freeway construction. These will be differentiated, where necessary, for urban and rural freeways. A literature search, analysis, and evaluation is expected. As an example, the investigators should be 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 is being used to catalogue and classify beneficial environmental effects. Literature reviews and surveys conducted by a multi-disciplinary team are expected to develop the required information for the matrix. Progress through December 1974 includes completion of the literature search and review.

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 project report is in the review stage.

Project 21-2(2) FY '72

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

Research Agency: State U. of New York at Buffalo
Principal Invest.: Dr. E. T. Selig
Effective Date: April 1, 1972
Completion Date: September 30, 1973
Funds: \$29,953

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

It is recognized that the moisture sensor is the critical

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

The objectives of this project were to design, build a prototype model, and conduct a laboratory verification program for a sensor capable of measuring moisture in granular and soil materials that would be suitable for highway needs.

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

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.

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-millisecond 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: February 28, 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 this project is to evaluate the prototype of the proposed barrier by full-scale impact tests.

The accomplishment of this objective will include 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°. The approach railing used is to conform to one of the systems included in *NCHRP Report 118*.
 - (d) A fourth test under impact conditions to be determined by results of prior tests.

Through December 31, 1974, research has been completed, and the draft final report is in the review stage.

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. The systems 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 must be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

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 is structured to emphasize the systematic experimental development of terminal treatment that will fulfill this need. Terminal treatments for a number of selected guardrail systems are being investigated. The new work builds on earlier preliminary NCHRP efforts that are described in NCHRP Reports 118 (1971) and 129 (1972).

The initial work 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 now 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, concentrated on the development of a crash-cushioning terminal for use with median barriers. The results of this effort are reported in NCHRP Research Re-

sults Digest No. 53 (December 1973). Publication of an NCHRP report covering the findings of this first phase of research will be postponed pending completion of additional work on the BCT in Phase II. A copy of the uncorrected draft of the agency's final report may be obtained on a loan basis by request to the NCHRP Program Director.

The Phase II research started on October 1, 1973. It is expected to lead to the refinement of BCT designs to provide more safety for smaller cars. It is also anticipated that additional development of the BCT will improve its economy relative to first cost, maintenance, and repair. A total of \$60,000 has been allotted for this effort.

Through December 31, 1974, crash testing and an analytical investigation have been completed. The preliminary draft of the final report is in preparation.

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: December 31, 1974
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.

The findings of this research establish the feasibility and efficacy of a full-blown field evaluation study. The design of such a study was one of the tasks in this project. It is expected that the findings will be valuable in identifying weaknesses in existing barriers and determining the need for improvements. The information also could be used to de-

velop warrants for retrofitting inadequate installations. In addition, the right kind of accident data would be helpful in selecting barrier test conditions.

Accomplishment of the objectives of this project included the following tasks:

1. Identify 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 presently available from each of these sources as to its suitability to the needs identified in Task 1.
4. Recommend several alternative processes for using presently available data and for collecting new types of data that would be more appropriate than those now available. This task should also deal with potential sources of funding.
5. Outline subsequent phases of the project 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 may be discovered during this study.

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

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 final report is in the acceptance review stage.

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 final reports are 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. No such summary has been prepared during 1974.

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