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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

# SUMMARY OF PROGRESS THROUGH 1976

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

**SUMMARY OF PROGRESS  
THROUGH 1976**

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TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

1976

**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

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

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

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

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

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

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### MAILING ADDRESS:

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

### OFFICES AT:

2100 Pennsylvania Ave., N. W.  
Washington, D. C.  
Phone: 202-389-6734

## SUMMARY OF PROGRESS THROUGH 1976

### INTRODUCTION

The National Cooperative Highway Research Program (NCHRP) was established in 1962 to provide a continuing program of highway research. It is sponsored by member departments of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA), U. S. Department of Transportation, and carried out under a three-way agreement between these agencies and the National Academy of Sciences. AASHTO annually proposes specific research problems for inclusion in the NCHRP fiscal year activities. At least two-thirds of the member departments must approve the research problems and agree to their financial support before they can be brought into the Program. Following balloting by the member departments, the approved problems are referred to the Academy, where they are reviewed to determine their acceptability for administration by the Academy through the Transportation Research Board of its National Research Council. Each State annually contracts with the Academy to commit an amount equal to 4½% of its 1½% Federal-aid highway planning research (HPR) funds. From these contributions, a cooperative pool of about \$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 project panels or committees made up of persons knowledgeable in each particular problem area. They analyze the problems, outline particular projects and their objectives, and then prepare research project statements 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. There are presently some 531 members on these panels coming from 43 States, the District of Columbia, and Canada.

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the 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 regu-

larly visits his assigned projects throughout their contract periods. He discusses with each principal investigator the project's status to learn if the research is being pursued in line with the approved research plan. If necessary, frequent meetings involving the staff, panel and agency personnel are held to review project progress and provide guidance for continuing work. Finally, the projects engineer and the panel evaluate the completed research to determine the degree of technical compliance with the contract and the acceptability of the final report to the Board and the Academy.

The research findings are published in either of two regular NCHRP report series. Each highway administrator receives a copy immediately on publication, and some 3,500 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, 45 detailed progress reports have been submitted by the NCHRP to the sponsors to provide them with current information on the specifics of technical progress of the projects, as well as the specifics of administrative matters relating to Program operation. These reports are supplemented by publication of an annual summary of progress that is made available at the end of each year to both the sponsors and the public at large. The eleventh issue covers the Program from its inception through December 31, 1976, and illustrates in detail how the NCHRP functions.

Although research in the NCHRP is presently sponsored by AASHTO, the Program is designed to administer research for other agencies as well. However, the following description of how projects are formulated and research is administered applies specifically to research sponsored by the AASHTO.

### HOW NCHRP PROGRAMS ARE FORMULATED

Research problems from the American Association of State Highway and Transportation Officials are initiated on an annual basis, and there are many steps (refer to Fig-

ure 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 first screened to determine:

- If the proposed problem is of mutual interest to all or many of the States and whether it can be handled more

effectively under a cooperative program than by an individual member department.

- If the proposed problem represents an immediate research need in the transportation field.
- If similar efforts are already under way, or if satisfactory answers are already available. In these respects, a search is made of the relevant literature stored in the Board's automated Highway Research Information Service.
- The probability of success of completing the problem according to its scope, estimated cost, and time for completion.

The technical merits of the problems that survive this initial screening are then evaluated in depth by the Special AASHTO Select Committee on Research. Final priorities are placed on them during an annual meeting that is held specifically to formulate research programs for the NCHRP.

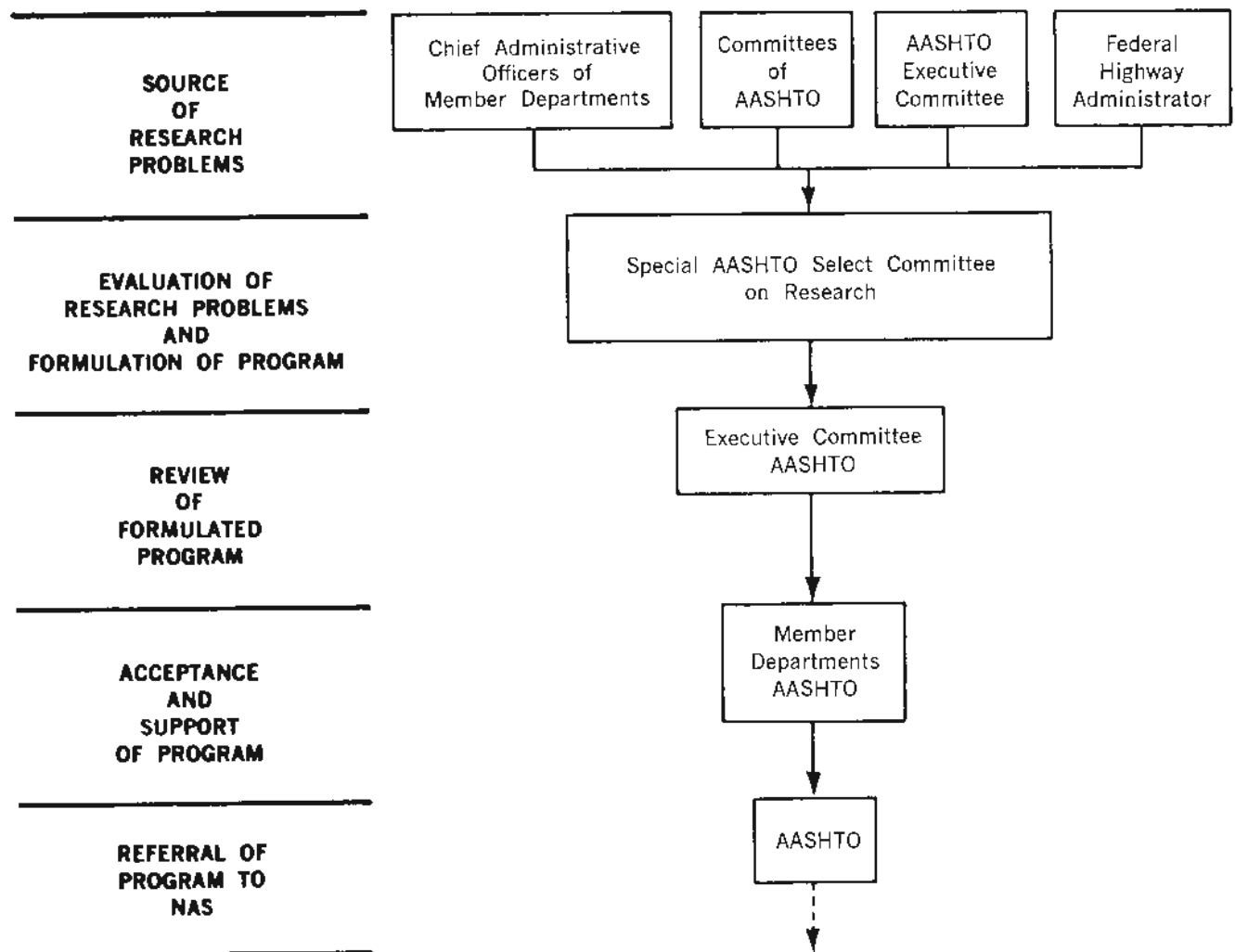


FIGURE 1

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



Based on the funding anticipated to be available from the Federal apportionment for the given fiscal year, the Committee carries out two major activities. First, a review is made to determine which completed or on-going projects should receive additional funding for further work. During this part of program development the committee receives NCHRP recommendations for continuations and has detailed status reports available on each project in the Program since FY '63. Also available are reports from the NCHRP, TRB, and Federal Highway Administration research staffs dealing with appropriateness of the proposed research in light of other research that is under way in this and other research programs.

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

The complete program, made up of continuations and new problems, is sent 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.

#### 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 but a fraction of the problems submitted.

In 1976 AASHTO referred the fifteenth program (FY '77) of research problems. From all programs through FY '77, 255 research projects have resulted, on which con-

tracts have been written with a total funding obligation of about \$37.2 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 sixteenth group of research problems (FY '78 program) was selected in September 1976 and will be received in 1977 following the States' ballot on the recommended problems.

#### FINANCING THE PROGRAM

Each year each State contracts with the National Academy of Sciences to support the Program. The agreement commits the State to 4½ percent of its 1½ percent Federal-aid planning and research (HPR) funds. A member department's contribution, if so elected and when authorized by the Federal Highway Administrator, may be financed directly from the Federal-aid monies without State matching funds. On the other hand, the member department's contribution may be financed from both Federal and State matching funds or entirely from State funds. From these contributions a cooperative pool of about \$3½ million is made available each year for NCHRP's contract research and for its administrative and technical operation.

#### HOW THE NCHRP IS ORGANIZED TO ADMINISTER RESEARCH PROGRAMS

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

In addition, the Board has established eight broad research fields under which project panels are organized to deal with research in specific problem areas falling within the broad fields (refer to Figure 3). For example, in the broad subject field of Transportation Planning each project falling within the more specific subject areas of Traffic Planning and Urban Transportation—areas 7 and 8, respectively—is assigned a project panel to provide technical guidance throughout the research and reporting phases. Those projects that do not conveniently fit under one of the first seven general fields are assigned to the eighth one, Special Projects.

In terms of generalized subject areas, the distribution of all projects through FY 1977 within the fields of Figure 3 is as follows:

Members of the project panels do not act as consultants or advisors to project investigators. Members may, according to established policy, submit proposals for research. If they do, they are dropped from panel participation until the research agencies have been selected. If unsuccessful, they may return to full participation. Some

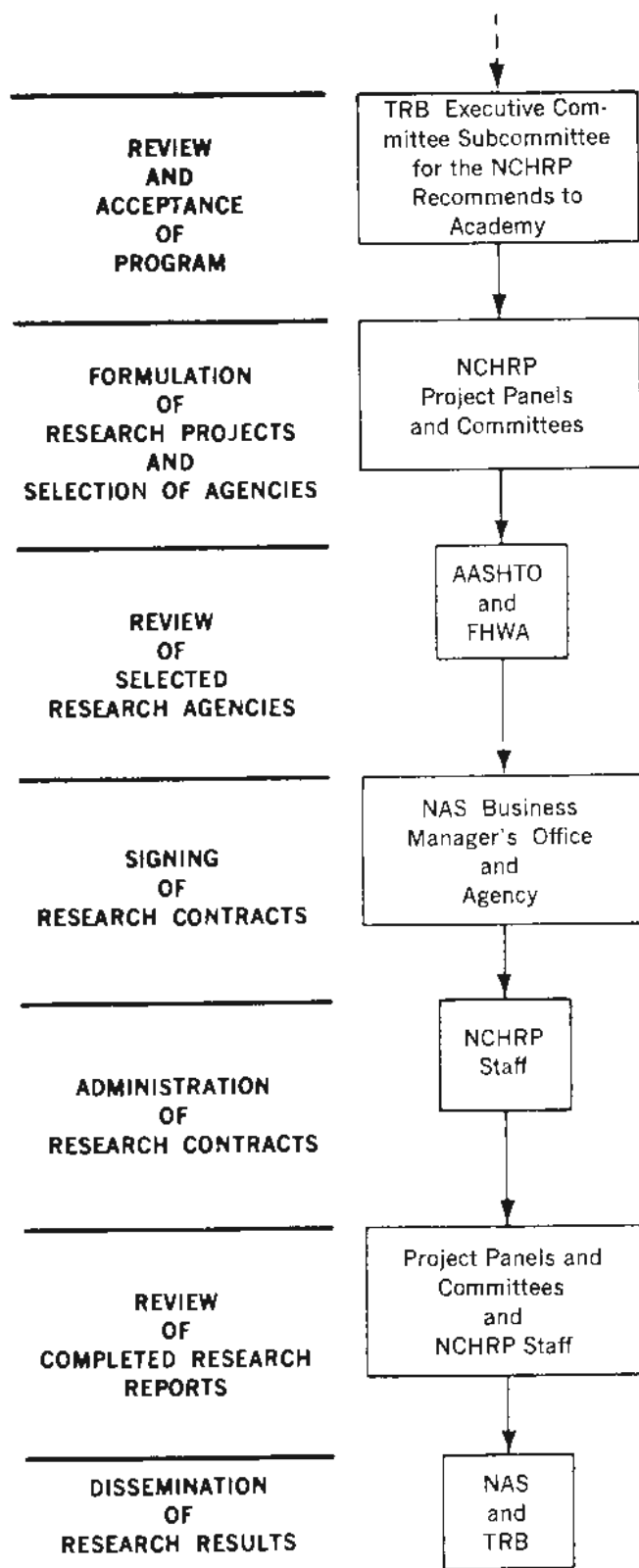


FIGURE 2

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

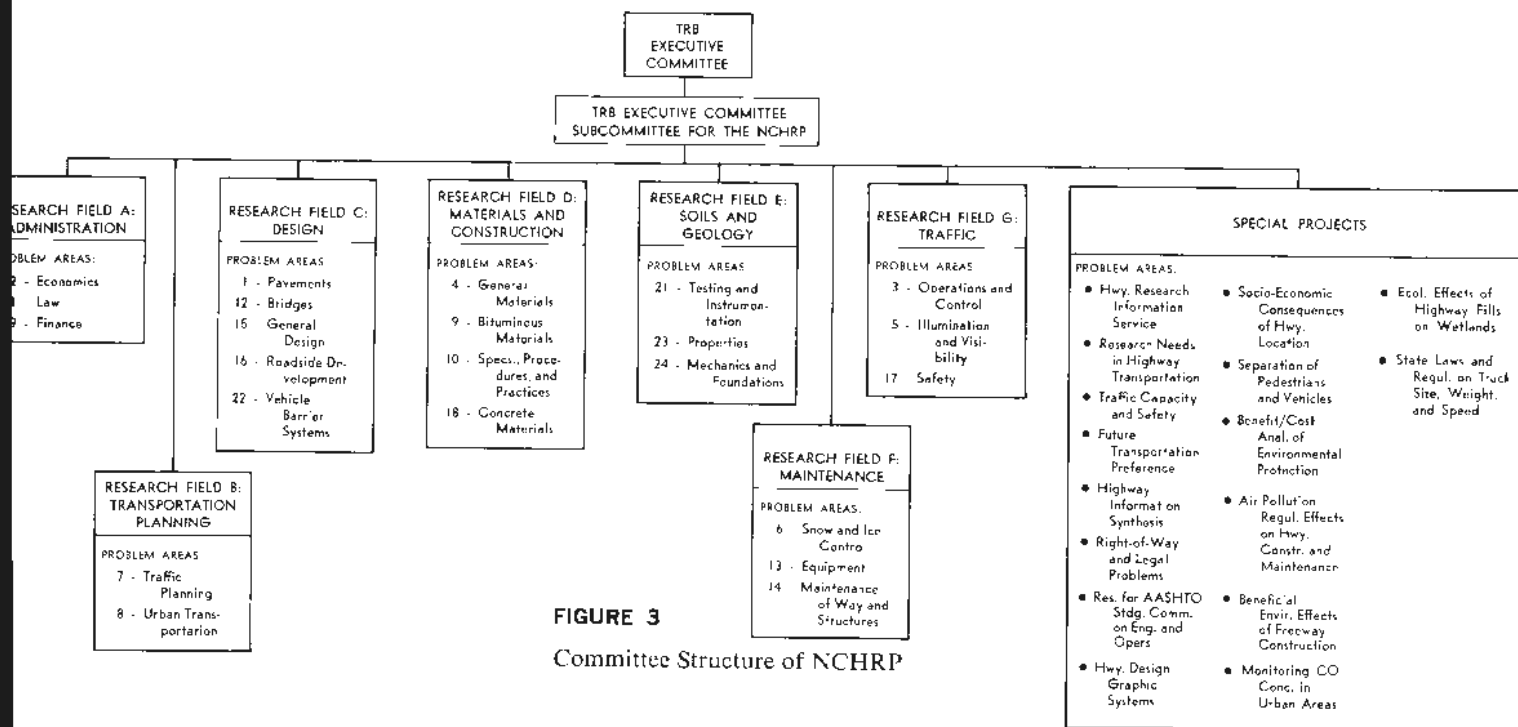
NO. OF PROJECTS	PERCENT OF FUNDS	GENERALIZED SUBJECT AREAS
38	12.8	Socio-economic and environmental issues
34	18.1	Urban issues
6	3.7	Multimodal issues
45	18.8	Safety and accident prevention
19	1.5	Legal studies
12	16.2	Special projects (including in-house)
19	6.0	Improved materials quality and performance
15	4.2	Highway maintenance
24	5.3	Specifications, tests, and construction control
44	13.4	Structural design and performance

530 individuals serve without compensation on these project panels, 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 43 States, the District of Columbia, and Canada. State highway and transportation department employees constitute a significant portion of panel membership. The duties and responsibilities of the membership include:

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

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

**TRANSPORTATION RESEARCH BOARD**  
**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**  
 Committee Structure



**FIGURE 3**  
 Committee Structure of NCHRP

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 project panels meet to write research "project statements" based on the research problems referred by AASHTO.

These statements are then sent automatically to a mailing list of some 3,000 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).

Contracts have been let to agencies headquartered in more than one-half of the States and the District of Columbia. Educational institutions have received about 37%;

research institutes, 21%; industry and consultants, 38%; professional societies and service organizations, 2%; state highway and transportation departments and special transportation and other governmental agencies, 2%. In cer-

**TABLE 1**  
 DISTRIBUTION OF PROJECT PANEL AND  
 COMMITTEE MEMBERSHIP WITH  
 RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway and transportation departments	222	276
Federal Highway Administration	68	99
Special transportation and other governmental agencies	73	86
Educational institutions	66	79
Research institutes	3	4
Industry, consultants, and trade associations	81	112
Professional societies and service organizations	5	5
Transportation Research Board	13	81
All	531	742

TABLE 2  
NUMBER OF PROPOSALS SUBMITTED

ITEM	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14	15	14	5	15
Proposals submitted	191	223	171	151	149	209	189	107	233	157	206	162	147	64	140
Proposals rec'd. per project (avg.)	6	8	12	9	12	13	10	12	17	11	15	11	11	13	9

TABLE 3  
NUMBER OF AGENCIES SUBMITTING ONE OR MORE RESEARCH PROPOSALS

NO. OF PROPOSALS SUBMITTED	NUMBER OF AGENCIES SUBMITTING PROPOSALS														
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76
1	26	32	56	59	70	90	70	55	103	63	96	88	73	44	80
2	18	22	29	18	20	18	22	8	22	24	20	17	19	4	14
3	7	14	11	8	4	11	8	5	8	8	13	5	8	4	4
4	5	8	2	5	4	0	2	4	8	3	4	3	1	0	1
5	4	4	1	1	1	5	0	1	2	2	3	0	0	0	2
6	4	1	0	0	1	3	1	0	1	0	0	1	0	0	1
7	1	4	0	1	0	1	0	0	0	0	0	1	0	0	0
8	1	1	0	0	0	0	2	0	1	0	0	0	1	0	0
9	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
All	69	87	100	92	100	128	106	73	146	100	136	115	102	52	102

TABLE 4  
TYPES OF AGENCIES SUBMITTING PROPOSALS

TYPE OF AGENCY	NO. OF AGENCIES SUBMITTING														
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76
Educational institutions	41	32	39	32	40	51	25	36	53	33	50	38	35	14	36
Research institutes	11	16	17	22	22	26	19	16	23	14	9	9	8	8	7
Industry, consultants, and trade associations	14	35	42	35	35	48	59	18	67	51	72	66	55	28	54
Professional societies and service organizations	2	0	1	2	0	0	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	1	3
Special transportation and other governmental agencies	1	1	0	1	3	1	0	2	1	1	2	0	2	1	2
All	69	87	100	92	100	128	106	73	146	100	136	115	102	52	102
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14	15	14	5	15

tain 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 15 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.

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

Following the selection 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 panels. The factors constituting the basis for selection of the successful agency are identified, but the debriefing does not include a point-by-point comparison of all the elements considered in the evaluation criteria. Neither is there any revelation of confidential business information, trade secrets, techniques, or processes of the other proposers, nor is there any indication of the relative merits or technical standings of the unsuccessful proposers.

The projects included in the 15 fiscal year programs conducted to date are listed in Table 5. There are 114 projects in traffic planning research, 120 in physical research, and 21 in the special projects area. The 255 projects are distributed among more than one-half of the States and the District of Columbia. To date, 227 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 '77 SUMMARY OF STATUS THROUGH DECEMBER 31, 1976

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
<b>AREA ONE: DESIGN—PAVEMENTS</b>			
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	100,000*
1-10B	Development of Pavement Structural Subsystems	Materials R & D	250,000
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	63,720*
1-12	Determination of Pavement Friction Coefficients Required for Driving Tasks	Franklin Inst	309,244*
1-12A	Wet-Weather Skidding Accident Reduction at Intersections	Ohio DOT	199,955
1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques	Penn State U	319,000*
1-12(3)	Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces	Materials R & D	261,955
1-13	Effects of Studded Tires on Highway Safety	Calspan Corp	208,898
1-13(2)	Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions	U of Michigan	39,450*
1-14	Influence of Combined Highway Grade and Horizontal Alignment on Skidding	U of Michigan	69,968*
1-15	Design of Continuously Reinforced Concrete Pavements for Highways	U of Texas	151,870
1-16	Evaluation of Winter-Driving Traction Aids	Penn State U	300,000
1-17	Guidelines for Recycling Pavement Materials	Texas A&M	200,000
<b>AREA TWO: ADMINISTRATION—ECONOMICS</b>			
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*
2-5A	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Paul J. Claffey	35,000*
2-6	Warranted Levels of Improvement for Local Rural Roads	Stanford U	30,665*
2-7	Road User Costs in Urban Areas	Catholic U	40,000*
2-8	Estimation and Evaluation of Diverted and Generated (Induced) Traffic	Northwestern U	99,376*
2-9	Effect of Highway Landscape Development on Nearby Property	Franklin Inst	40,000*
2-10	Future Needs for Oversize-Overweight Permit Operation on State Highways	Franklin Inst	149,103*
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	Jorgensen & Assoc	99,655*
2-12	Highway User Economic Analysis	HRB	110,000*
		Stanford Res Inst	90,074
			9,995
<b>AREA THREE: TRAFFIC—OPERATIONS AND CONTROL</b>			
3-1	Development of Criteria for Evaluating Traffic Operations	Cornell Aero Lab	78,965*
3-2	Surveillance Methods and Ways and Means of Communicating with Drivers	Cornell Aero Lab	79,913*
3-3	Sensing and Communication Between Vehicles	Cornell Aero Lab	246,756*
3-4	Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location	Ohio State U	163,190*
3-5	Improved Criteria for Designing and Timing Traffic Signal Systems	Airborne Instr	78,517*
		Planning Res	49,474*
			123,030*
			48,155*
			93,717*
3-6	Effect of Regulatory Devices on Intersection Capacity and Operation	De Leuw, Cather	153,175*

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 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	Completed—Published as NCHRP Report 160	1-10A
2/1/74	9/30/76	Report in review stage	1-10B
10/23/67	6/30/70	Completed—Published as NCHRP Report 128	1-11
8/1/70	4/30/71	Completed—Published by AASHTO	1-11
8/25/69	6/8/73	Completed—Published as NCHRP Report 154	1-12
7/1/75	9/30/77	Research in progress	1-12A
9/16/70	5/15/73	Completed—Published as NCHRP Report 151	1-12(2)
11/1/71	9/30/75	Report in review stage	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 editorial and publication process	1-14
8/1/72	8/31/75	Completed—Rep. not to be publ.; agency report available for loan	1-15
6/3/74	6/2/77	Research in progress	1-16
11/1/76	1/31/79	Research in progress	1-17
6/1/63	11/30/67	Completed—Rep. not publ.; sum. in Summary of Progress Through June 30, 1968	2-1
7/1/63	8/31/64	Completed—Published as NCHRP Report 18	2-2
6/1/63	8/31/66	Completed—Published as NCHRP Report 47	2-3
6/1/63	8/31/66	Completed—Published as NCHRP Report 33	2-4
6/1/63	8/31/64	Completed—Published as NCHRP Report 13	2-5
6/1/65	12/31/66	Completed—Report included in NCHRP Report 111	2-5
7/1/67	12/31/68	Completed—Report included in NCHRP Report 111	2-5A
8/11/69	8/10/70	Completed—Report included in NCHRP Report 111	2-5A
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6
2/1/64	5/31/66	Completed—Report included in NCHRP Report 111	2-7
5/1/64	8/31/66	Completed—Rep. not publ.; 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	10/31/75	Completed—Report not published	2-12
10/11/76	1/5/77	Report in review stage	2-12
2/15/63	2/29/64	Completed—Report not published; summarized in Summary of Progress to June 30, 1967	3-1
7/2/64	2/28/66	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 Reports 11, 41	3-6

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	AMOUNT OR CONTRACT COST
<b>AREA THREE (Continued)</b>			
3-7	Establishment of Standards for Highway Noise Levels	Bolt Beranek	144,920* 69,930* 49,927* 316,011
3-8	Factors Influencing Safety at Highway-Rail Grade Crossings	Voorhees & Assoc	17,171* 74,250*
3-9	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control	Jorgensen & Assoc	23,760*
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	41,520*
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick	258,331*
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	198,655* 100,500* 99,821*
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways	Texas A & M	149,293*
3-14	Optimizing Flow on Existing Street Networks	Edwards & Kelcey	990,000*
3-15	Weaving Area Operations Study	Poly of New York	300,000*
3-16	Freeway Lane Drops	System Dev Corp	99,789* 76,815*
3-17	Improving Traffic Operations and Safety at Exit Gore Areas	Penn State U	79,983*
3-18(1)	Improved Control Logic for Use with Computer-Controlled Traffic	Stanford Res Inst	323,998* 52,912
3-18(2)	Traffic Control in Oversaturated Street Networks	Poly of New York	200,000
3-18(3)	Cost-Effectiveness Methodology for Evaluation of Signalized Street Network Surveillance and Control Systems	JHK & Assoc	100,000
3-19	Grade Effects on Traffic Flow Stability and Capacity	Midwest Res Inst	220,443
3-20	Traffic Signal Warrants	KLD Associates	120,000* 80,000
3-21	Motorist Response to Highway Guide Signing	BioTechnology	272,071
3-22	Guidelines for Design and Operation of Ramp Control Systems	Stanford Res Inst	199,030
3-22A	Guidelines for Design and Operation of Ramp Control Systems		
3-23	Guidelines for Uniformity in Traffic Control Signal Design Configurations	KLD Associates	300,000
3-24	Determine the Luminous Requirements for Retroreflective Highway Signing	U of Michigan	100,000
3-25	Cost and Safety Effectiveness of Highway Design Elements	Jorgensen Assoc	260,000
3-26	Investigation of Selected Noise Barrier Acoustical Parameters	Penn State U	74,795
3-27	Guidelines for Selecting Traffic Signal Control at Individual Intersections	Voorhees & Assoc	150,000
<b>AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS</b>			
4-1	Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents	U of Illinois	114,991*
4-2	A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines	Purdue U	63,990*
4-3(1)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	V P I	20,000* 23,337*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	56,457* 49,756*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	14,790*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	64,105*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	25,000*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	P C A	100,000* 50,000*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	V P I	55,254*
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	95,248*
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	190,177* 71,652
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah St Dept Hy	93,494*
4-9	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah St Dept Hy	125,000
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	50,000*
4-10A	Waste Materials as Potential Replacements for Highway Aggregates	Valley Forge Lab	53,663*
4-11	Buried Plastic Pipe for Drainage of Transportation Facilities	Simpson Gumpertz	200,000
4-12	Upgrading of Poor or Marginal Aggregates for PCC and Bituminous Pavements	Penn State U	150,000
4-13	Temporary Pavement Marking Systems	Sw Research Inst	49,500
<b>AREA FIVE: TRAFFIC—ILLUMINATION AND VISIBILITY</b>			
5-2(1)	Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents	Yale University	124,319* 21,530*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	81,187*



START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
2/1/64	4/30/67	Completed—Published as NCHRP Report 78	3-7
10/14/68	1/15/70	Completed—Published as NCHRP Report 117	3-7
4/1/71	6/30/72	Completed—Published as NCHRP Report 144	3-7
9/1/72	11/30/74	Completed—Published as NCHRP Reports 173, 174	3-7
12/1/63	12/31/64	Completed—Report included in NCHRP Report 50	3-8
4/1/65	1/6/67	Completed—Total project published as NCHRP Report 50	3-8
10/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10
9/1/66	9/30/68	Completed—Published as NCHRP Report 110	3-11
10/1/66	12/31/67	Completed—Report included in NCHRP Report 123	3-12
4/1/68	12/1/69	Completed—Report included in NCHRP Report 123	3-12
3/29/71	12/11/72	Completed—Rep. not publ.; summarized in Summary of Progress 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	Completed—Published as NCHRP Report 159	3-15
11/1/69	4/30/71	Completed—Rep. not publ.; summarized in Summary of Progress Through 1971	3-16
5/1/72	10/31/73	Completed—Published as NCHRP Report 175	3-16
1/1/71	11/30/72	Completed—Published as NCHRP Report 145	3-17
7/15/71	5/15/74	Completed—Report included in Phase II report	3-18(1)
4/15/75	8/31/76	Report in review stage	3-18(1)
9/1/71	6/30/75	Report in editorial and publication process	3-18(2)
5/1/75	7/31/76	Report in review stage	3-18(3)
9/1/71	8/31/74	Report in editorial and publication process	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	Report in review stage	3-20
4/1/74	1/31/76	Report in editorial and publication process	3-21
4/15/74	12/31/75	Completed—Report not publ.; agency report available for loan	3-22
4/8/74	2/28/77	Contract pending	3-22A
9/1/74	3/2/77	Research in progress	3-23
7/15/75	9/16/77	Research in progress	3-24
11/1/76	2/28/78	Research in progress	3-25
11/15/76	11/15/78	Research in progress	3-26
6/1/63	10/31/66	Completed—Report not 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 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 included in NCHRP Report 164	4-7
2/1/71	8/31/73	Completed—Report included in NCHRP Report 164	4-7
1/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
4/1/71	6/30/73	Completed—Published as NCHRP Report 172	4-8(2)
9/1/71	3/31/74	Report in editorial and publication process	4-8(3)
8/1/75	1/31/82	Research in progress	4-8(3)
10/1/68	6/30/71	Completed—Report to be included in Phase II report	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	Completed—Published as NCHRP Report 166	4-10A
9/16/74	3/15/78	Research in progress	4-11
12/1/76	2/28/79	Research in progress	4-12
11/1/76	2/28/78	Research in progress	4-13
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)

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
<b>AREA FIVE (Continued)</b>			
5-2(3)	Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	37,460*
5-3	Visual Information Needed by the Driver at Night	Ohio State U	100,940*
5-4	Economic Study of Roadway Lighting	Franklin Inst	19,412*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	50,000*
5-5A	Development of Optimum Specifications for Glass Beads in Pavement Markings	Penn State U	100,000*
5-5B	Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing Is Prevalent	Texas A & M	99,350*
5-6	Highway Fog		200,000*
5-6A	Highway Fog	Cornell Aero Lab	99,955*
5-7	Roadway Delineation Systems	Sperry Rand	93,540*
5-8	Warrants for Highway Lighting	Penn State U	469,526*
		Texas A & M	199,627
<b>AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL</b>			
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
<b>AREA SEVEN: TRANSPORTATION PLANNING—TRAFFIC PLANNING</b>			
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		66,894*
7-3	Weighing Vehicles in Motion	IIT Research Inst	24,652*
7-4	Factors and Trends in Trip Lengths		24,844*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Franklin Inst	73,391*
7-6	Multiple Use of Lands Within Highway Rights-of-Way	Voorhees & Assoc	89,250*
7-7	Motorists' Needs and Services on Interstate Highways		61,730*
7-8	User Cost and Related Consequences of Alternative Levels of Highway Service	Yale University	99,675*
7-9	Development of Models for Predicting Weekend Recreational Traffic	Barton-Aschman	24,220*
7-10	Peak-Period Traffic Congestion	Airborne Instr	99,267*
7-10(2)	The Institutional Aspects of Implementing Congestion-Reducing Techniques	Stanford Res Inst	99,070*
		Midwest Res Inst	74,983
		Remak/Rosenbloom	49,624
		Remak/Rosebloom	68,903
<b>AREA EIGHT: TRANSPORTATION PLANNING—URBAN TRANSPORTATION</b>			
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*
		Wilbur Smith	149,907*

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
2/20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
9/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3
7/20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
3/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
7/15/67	9/15/69	Completed—Published as NCHRP Report 85	5-5
5/1/71	6/30/73	Completed—Rep. not publ.; summarized in Summary of Progress Through 1976	5-5A
9/1/71	12/31/74	Report in editorial and publication process	5-5B
10/2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6
9/1/70	5/31/73	Completed—Published as NCHRP Report 171	5-6A
10/1/68	6/30/71	Completed—Published as NCHRP Report 130	5-7
3/16/70	2/15/73	Completed—Published as NCHRP Report 152	5-8
2/15/63	9/30/64	Completed—Published as NCHRP Report 19	6-1
2/15/63	2/29/64	Completed—Published as NCHRP Report 4	6-2
3/1/63	2/28/65	Completed—Published as NCHRP Report 16	6-3
3/1/63	4/30/65	Completed—Published as NCHRP Report 23	6-4
3/1/63	8/31/65	Completed—Published as NCHRP Report 27	6-5
3/1/63	2/28/66	Completed—Rep. not publ.; summarized in Summary of Progress to June 30, 1967	6-6
3/1/63	8/31/64	Contract terminated—no report; research resumed under Project 6-7A	6-7
2/1/65	7/31/66	Completed—Rep. not publ.; summarized in Summary of Progress to June 30, 1967	6-7A
2/15/63	2/29/64	Completed—Published as NCHRP Report 1	6-8
1/1/65	6/15/68	Completed—Published as NCHRP Report 101	6-9
9/1/67	9/30/70	Completed—Published as NCHRP Report 127	6-10
9/1/70	11/30/71	Init. phase completed—rep. to be incl. in Phase II rep.	6-11
9/12/72	9/11/74	Report in editorial and publication process	6-11
2/1/64	1/31/66	Completed—Published as NCHRP Report 24	7-1
4/1/66	9/30/67	Completed—Published as NCHRP Report 62	7-1
2/1/64	3/15/65	Completed—Report included in NCHRP Report 44	7-2
5/1/65	5/31/66	Completed—Total project published as NCHRP Report 44	7-2
2/1/64	8/31/67	Completed—Published as NCHRP Report 71	7-3
2/1/64	10/31/66	Completed—Published as NCHRP Report 48	7-4
10/23/67	1/10/69	Completed—Published as NCHRP Report 89	7-4
2/1/64	11/30/66	Completed—Published as NCHRP Report 58	7-5
2/1/66	2/28/67	Completed—Published as NCHRP Report 53	7-6
1/1/66	12/31/67	Completed—Published as NCHRP Report 64	7-7
9/1/70	4/15/72	Completed—Published as NCHRP Report 133	7-8
9/1/72	5/15/74	Completed—Rep. not publ.; summarized in Summary of Progress Through 1976	7-9
4/1/74	3/31/75	Completed—Published as NCHRP Report 169	7-10
4/1/75	9/15/77	Research in progress	7-10(2)
2/1/64	9/23/66	Completed—Published as NCHRP Report 70	8-1
2/1/64	8/31/66	Completed—Published as NCHRP Report 57	8-2
2/1/64	3/31/65	Completed—Rep. not publ.; summarized in Summary of Progress to June 30, 1967	8-3
2/1/65	8/1/67	Completed—Report included in NCHRP Report 96	8-4
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	6/14/75	Completed—Published as NCHRP Report 167	8-7A
9/16/68	3/14/69	Completed—Study design report not to be published	8-8(1)
9/9/68	3/7/69	Completed—Study design report not to be published	8-8(2)
9/15/69	7/31/74	Completed—Published as NCHRP Report 156	8-8(3)
9/1/71	1/31/73	Completed—Published as NCHRP Report 146	8-9
9/1/71	7/31/73	Completed—Published as NCHRP Reports 143 and 155	8-10

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
<b>AREA EIGHT (Continued)</b>			
8-11	Social, Economic, Environmental Consequences of Not Constructing a Transportation Facility	DACP, Inc	249,753
8-12	Travel Estimation Procedures for Quick Response to Urban Policy Issues	Metro Wash COG	39,895
8-12A	Travel Estimation Procedures for Quick Response to Urban Policy Issues	Cornsis Corp	160,000
8-13	Disaggregate Travel Demand Models	Chas River Assoc	100,000
8-14	New Approaches to Understanding Travel Behavior	Boston College	87,000
8-15	State and Regional Transportation Impact Identification and Measurement	Bigelow-Crain	149,860
8-16	Guidelines for Public Transportation Levels of Service and Evaluation	U of Tennessee	80,000
8-17	Freight Data Requirements for Statewide Transportation Systems Planning	R. Creighton Assoc	480,000
8-18	Techniques for Evaluating Options in Statewide Transportation Planning/Programming	Plng Envr Int/AMV	225,000
8-19	The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel	Cambridge Syst Inc	300,000
<b>AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS</b>			
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*
9-4A	Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress	Materials R & D Woodward-Clyde	99,560* 199,994
<b>AREA TEN: MATERIALS AND CONSTRUCTION—SPECIFICATIONS, PROCEDURES, AND PRACTICES</b>			
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		30,000*
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		28,801*
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	N Carolina State U	59,835*
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	IIT Research Inst	51,214*
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	Ohio State U	108,821*
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	Pa Dept of Transp	24,310* 151,982*
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	50,000*
10-10	Acceptance Criteria for Electroslag Weldments in Bridges	US Steel	300,000
10-11	Development of a Performance Specification for Bridge Deck Joint-Sealing Systems	Howard, Needles et al	29,996
<b>AREA ELEVEN: ADMINISTRATION—LAW</b>			
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, Mikkilborg	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
<b>AREA TWELVE: DESIGN—BRIDGES</b>			
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*

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
9/16/74	2/28/77	Phase I completed—Report not to be publ.; Phase II research in progress	8-11
9/3/74	12/31/75	Completed—Report not publ.; agency report available for purchase	8-12
11/1/75	4/30/77	Research in progress	8-12A
9/15/74	1/31/76	Phase I completed—Report not publ.; agency report available for purchase	8-13
5/1/76	4/30/77	Phase II research in progress	8-13
1/1/75	12/31/76	Phase II completed—Rep. not publ.; agency report available for purchase	8-14
9/1/74	5/31/76	Phase I completed—Report not publ.; agency report available for purchase	8-15
1/1/76	3/31/78	Research in progress	8-16
7/15/75	2/15/77	Report in review stage	8-17
9/1/75	2/28/78	Research in progress	8-18
12/1/76	6/30/78	Research in progress	8-19
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
11/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	9-1
1/1/65	10/31/67	Completed—Rep. not publ.; 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
9/15/75	12/14/77	Research in progress	9-4A
11/15/63	11/14/64	Completed—Published as NCHRP Report 17	10-1
11/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
7/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
10/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
10/15/64	10/16/65	Completed—Published as NCHRP Report 46	10-3
2/1/64	2/28/65	Completed—Report included in NCHRP Report 103	10-4
5/1/65	2/28/67	Completed—Published as NCHRP Report 103	10-4
1/15/64	1/31/65	Completed—Published as NCHRP Report 14	10-5
4/1/65	10/7/66	Completed—Published as NCHRP Report 43	10-5
2/1/68	1/31/70	Completed—Published as NCHRP Report 125	10-5A
2/1/64	10/31/66	Completed—Published as NCHRP Report 52	10-6
2/1/64	3/31/65	Completed—Published as NCHRP Report 25	10-7
3/2/70	7/31/73	Completed—Published as NCHRP Report 168	10-8
11/1/69	2/28/74	Completed—Rep. not publ.; summarized in Summary of Progress Through 1976	10-9
5/1/74	3/31/77	Research in progress	10-10
12/1/76	11/30/77	Research in progress	10-11
1/1/65	4/30/67	Completed—Published as NCHRP Report 104	11-1
9/2/68	2/28/69	Completed—Published as NCHRP Report 114	11-1(1)
10/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
9/16/68	4/30/69	No final report—Project terminated	11-1(3)
12/1/68	5/31/69	Completed—Rep. not publ.; 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 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 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	7/31/75	Completed—Report not publ.; agency report available for loan	11-6
2/1/65	6/30/67	Report included in Project 12-6 report	12-1
6/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
12/15/65	3/14/69	Completed—Report available only to sponsors	12-3
12/15/65	3/31/68	Completed—Rep. not publ.; summarized in Summary of Progress Through 1969	12-4
9/15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
<b>AREA TWELVE (Continued)</b>			
12-6	Prediction of Permanent Camber of Bridges	U of Missouri	82,253*
12-7	Effects of Weldments on Fatigue Strength of Steel Beams	Lehigh University	199,023*
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	200,000* 28,793*
12-9	Elastomeric Bearing Research	Battelle Mem Inst	69,753* 84,800*
12-10	Analysis and Design of Bridge Bents	PCA	297,900*
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks	Materials R & D	206,025* 100,000
12-12	Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings	US Steel	310,000
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks	USS Eng & Consult	174,601*
12-13A	Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks	PCA	75,000
12-14	Subcritical Crack Growth in Steel Bridge Members	US Steel	99,923*
12-15	Detection and Repair of Fatigue Cracking in Highway Bridges	Lehigh U	100,000*
12-15(2)	Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams	Lehigh U	150,000
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbus	214,912
12-17	Evaluation of Repair Techniques for Damaged Steel Bridge Members	Battelle Columbus	50,000
<b>AREA THIRTEEN: MAINTENANCE—EQUIPMENT</b>			
13-1	Equipment Rental Rates	Ernst & Ernst	\$ 22,800*
<b>AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES</b>			
14-1	Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements	Tallamy Assoc	205,128*
14-2	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000*
14-3	Improved Pavement-Shoulder Joint Design	Georgia Tech	100,838*
14-4	Reconditioning Heavy-Duty Freeways in Urban Areas	Texas A & M	99,665
<b>AREA FIFTEEN: DESIGN—GENERAL DESIGN</b>			
15-1	Guardrail Design	Cornell Aero Lab	19,723*
15-1(2)	Guardrail Performance and Design	Sw Research Inst	280,000* 100,000*
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	97,300*
15-3	Rational Structural Analysis and Design of Pipe Culverts	Northwestern U	49,937*
15-4	Estimating Runoff Rates from Small Rural Watersheds	Travelers Res Cen	299,902*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Gen Mot Corp	135,000*
15-6	Development of Criteria for Safer Luminaire Supports	Texas A & M	147,254*
<b>AREA SIXTEEN: DESIGN—ROADSIDE DEVELOPMENT</b>			
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	V P I	217,300*
16-2	Evaluation of Research on Roadside Development	Western States	100,000*
16-3	Erosion Control During Highway Construction	Utah State U	179,224
<b>AREA SEVENTEEN: TRAFFIC—SAFETY</b>			
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*
<b>AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS</b>			
18-1	Reviibration of Retarded Concrete for Continuous Bridge Decks	U of Illinois	103,895*
18-2	Use of Polymers in Highway Concrete	Lehigh U	300,000
<b>AREA NINETEEN: ADMINISTRATION—FINANCE</b>			
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*
<b>AREA TWENTY: SPECIAL PROJECTS</b>			
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy-Smith	98,760*
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	394,016* 200,540†
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,631* 20,000†
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting	Patrick J. Athol	31,116*

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
2/1/67	4/30/72	Completed—Rep. not publ.; summarized in Summary of Progress Through 1975	12-6
10/1/66	1/31/70	Completed—Published as NCHRP Report 102	12-7
7/1/70	12/31/72	Completed—Published as NCHRP Report 147	12-7
3/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
1/2/70	6/30/71	Completed—Published as NCHRP Report 149	12-8
9/1/67	1/31/70	Completed—Published as NCHRP Report 109	12-9
1/1/70	12/31/73	Completed—Published as NCHRP Report 163	12-10
8/1/70	3/31/73	Completed—Published as NCHRP Report 165	12-11
7/15/73	6/30/78	Research in progress	12-11
10/1/70	10/31/75	Report in editorial and publication process	12-12
10/1/72	7/31/74	Report in editorial and publication process	12-13
8/1/75	7/31/78	Research in progress	12-13A
10/1/72	6/30/74	Report in editorial and publication process	12-14
10/1/72	4/30/75	Report in editorial and publication process	12-15
6/1/76	8/31/78	Research in progress	12-15(2)
9/1/74	11/30/77	Research in progress	12-16
11/15/76	11/14/77	Research in progress	12-17
2/1/65	1/31/66	Completed—Published as NCHRP Report 26	13-1
3/1/65	3/31/67	Completed—Published as NCHRP Report 42	14-1
10/1/70	3/31/73	Completed—Published as NCHRP Report 161	14-2
9/15/72	3/15/76	Report in editorial and publication process	14-3
4/15/74	3/24/76	Report in editorial and publication process	14-4
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	8/31/70	Completed—Published as NCHRP Reports 54, 115	15-1(2)
5/1/70	12/31/71	Completed—Published as NCHRP Reports 118, 129	15-1(2)
7/1/66	6/30/74	Completed—Publ. as NCHRP Rep. 108; Ph. II rep. sum. in Sum. of Prog. Through 1975	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	Completed—Published as NCHRP Reports 91 and 170	16-1
10/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
11/1/73	6/30/76	Report in review stage	16-3
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
1/10/72	6/20/72	Contract terminated—no report; research resumed under Project 17-2A	17-2
2/1/73	7/31/74	Completed—Published as NCHRP Report 162	17-2A
9/1/67	12/1/69	Completed—Published as NCHRP Report 106	18-1
10/1/72	9/30/75	Report in editorial and publication process	18-2
9/5/67	9/4/68	Completed—Report not publ.; summarized in NCHRP Research Results Digest 20	19-1
9/2/68	10/31/68	Completed—working plan, not published	19-2(1)
9/2/68	10/31/68	Completed—working plan, not published	19-2(2)
9/2/68	10/31/68	Completed—Research continued as Project 19-2(4)	19-2(3)
2/1/69	11/30/71	Completed—Published as NCHRP Report 131	19-2(4)
9/15/70	6/14/72	Completed—Published as NCHRP Report 141	19-3
3/16/64	10/31/67	Completed—Informal publication only; service is operational	20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55	20-2
12/15/66	1/31/69	Completed—Results to be summarized in Project 20-3C report	20-3
1/1/67	12/31/68		20-3
11/20/68	5/31/71	Completed—Results to be summarized in Project 20-3C report	20-3A
1/1/69	12/31/69		20-3A
7/1/72	9/27/74	Project terminated uncompleted; no reports prepared	20-3B

TABLE 5 (Continued)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
<b>AREA TWENTY (Continued)</b>			
20-3C	Summary of the Lodge Freeway Research	Asriel Taragin	10,375
20-3D	Summary of All Freeway Surveillance, Communication and Control Experience	To Be Determined	
20-4	Public Preference for Future Individual Transportation	Chilton Research	195,260*
		National Analysts	83,911*
20-5	Synthesis of Information Related to Highway Problems	TRB	300,000\$\$
20-6	Right-of-Way and Legal Problems Arising out of Highway Programs	TRB	75,000\$\$
20-7	Research for AASHTO Standing Committee on Engineering and Operations	†††	100,000\$
20-8	Interactive Graphic Systems for Highway Design	Control Data	49,672*
20-9	Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation	RMC Res Corp	214,279
20-10	The Benefits of Separating Pedestrians and Vehicles	Stanford Res Inst	100,000
20-11	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Poly of New York	100,000*
20-11A	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Cornell U	26,575
20-11B	Toward Environmental Benefit/Cost Analysis: Energy-Flow Analysis (Manual)	—	—
20-11C	Toward Environmental Benefit/Cost Methodology: Energy-Flow Analysis (Study Design)	—	—
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*
20-14	Monitoring Carbon Monoxide Concentrations in Urban Areas	Technol Serv Corp	99,973
20-15	Ecological Effects of Highway Fills on Wetlands	U of Mass	149,925
20-16	State Laws and Regulations on Truck Size, Weight, and Speed	R J Hansen Assoc	149,977
<b>AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION</b>			
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
<b>AREA TWENTY-TWO: DESIGN—VEHICLE BARRIER SYSTEMS</b>			
22-1	Concepts for Improved Traffic Barrier Systems	Walter W. White	25,000*
22-1A	Testing and Evaluation of Bridge Rail Concepts	Texas A & M	40,000*
22-2	Traffic Barrier Performance and Design	Sw Research Inst	125,000*
			80,000*
22-2(2)	Lower Service Level Highway Bridge Railings—Performance and Design Criteria	Sw Research Inst	195,000
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.
11/15/75	7/15/76	Completed—Rep. not to be publ.; agency report available for loan Project in developmental process	20-3C 20-3D
5/2/67	1/21/69 (CRS)	Completed—Published as NCHRP Reports 49, 82	20-4
5/2/67	1/2/68 (NA)	Completed—Published as NCHRP Reports 49, 82	20-4
12/15/67	§§	Research in progress: Topic reports published as NCHRP Syntheses 1 through 39	20-5
11/1/68	§§	Research in progress: Refer to Table 7 for publications	20-6
12/2/68	§	Research in progress: Completed task reports published as NCHRP Reports 148, 150, 157, 158; and as NCHRP Research Results Digests 55, 77	20-7
9/1/70	7/31/71	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	20-8
8/1/72	12/17/76	Report in review stage	20-9
8/26/74	4/30/76	Report in editorial and publication process	20-10
9/1/72	5/31/74	Completed—Rep. not publ.; agency report available for purchase	20-11
9/1/75	11/30/76	Completed—Rep. not publ.; agency report available for purchase	20-11A
—	—	Contract pending	20-11B
—	—	Contract pending	20-11C
4/1/74	7/31/75	Report in editorial and publication process	20-12
9/3/74	8/2/75	Report in editorial and publication process	20-13
10/1/76	1/31/78	Research in progress	20-14
12/1/76	11/30/78	Research in progress	20-15
10/11/76	1/11/78	Research in progress	20-16
8/25/69	2/24/71	Completed—Published as NCHRP Report 138	21-1
2/1/72	1/31/74	Completed—Report not to be publ.; to be included in Project 21-2(3) report	21-2
4/1/72	9/30/73	Completed—Report not to be publ.; to be included in Project 21-2(3) report	21-2(2)
9/3/74	3/1/77	Research in progress	21-2(3)
10/1/70	12/31/71	Completed—Rep. not publ.; summarized in Summary of Progress Through 1972	22-1
3/1/74	5/30/75	Report in editorial and publication process	22-1A
1/1/72	9/30/73	Init. phase completed—Findings incl. in report on Task 1, Phase II	22-2
10/1/73	3/31/75	Task 1 rep. sum. in NCHRP Res. Results Digest 84; Task 2 rep. publ. as NCHRP Report 153	22-2
8/1/76	7/31/78	Research in progress	22-2(2)
1/1/74	2/15/75	Completed—Rep. not publ.; summarized in NCHRP Research Results Digest 76	22-3
7/1/74	12/31/74	Completed—Rep. not publ.; summarized in NCHRP Research Results Digest 76	22-3A

§ Continuing activity supported at the annual amount shown.

§§ Continuing activity supported in FY '77 at amount shown.

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

TABLE 6  
AGENCY DISTRIBUTION OF FY '63 THROUGH  
FY '77 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS	
	NO.	%
Educational institutions	95	38
Research institutes	54	21
Industry, consultants, and trade associations	94	37
Professional societies and service organizations	5	2
State highway and transportation departments	3	>1
Special transportation and other governmental agencies	1	<1
All	252	100

#### KEEPING TRACK OF RESEARCH IN PROGRESS

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the broad areas of physical research, traffic planning, and special projects research are responsible for administrative and technical surveillance of the contracts. In addition to reviewing quarterly progress reports and monthly progress schedules, and maintaining telephone contacts, each projects engineer visits his assigned research agencies throughout their contract periods. He discusses with each principal investigator his project's status to learn if the research is being pursued in line with the approved research plan. Finally, the projects engineer and appropriate project panel evaluate the completed research to determine the degree of technical compliance with the contract.

#### SYSTEMATIC PLANNING FOR GETTING RESEARCH RESULTS FROM NCHRP PROJECTS INTO PRACTICE

##### Promoting Useful Results

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

- Establishing the agency and personnel qualifications that are mandatory if the goals are to be achieved. Emphasis is placed on the importance of a record of successful past performance in endeavors similar to those to be under-

taken. Further, it is also stipulated that proposals are not acceptable if they do not contain specific statements as to how the contemplated results can be used to improve practice.

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

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

- Establishing—on the basis of staff and project panel review of and suggested modifications to the research plan—a clear meeting of the minds as to what specifically is expected from the research and the personnel carrying it out in order to meet the needs of the practicing engineer.

- Acquiring an amplified research plan that is intended to detail comprehensively the approved research plan and to include a specific schedule of events for the major tasks. This document is used by the staff in the day-to-day surveillance of the project's progress and by the project panel as required.

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

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

##### NCHRP Reporting of Research Results

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

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

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

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

#### IMPLEMENTING RESEARCH RESULTS

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, Ill. Particular use made of recommendations for experimental designs, measurement programs, and data processing analysis.
		Connecticut Dept. of Transportation	To design experimental pavement projects.
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.
1-3(2)	Report 22	Connecticut Dept. of Transportation	In study of highway maintenance quality levels for Ohio Dept. of Hwys.
1-3(3)	Report 35	Connecticut Dept. of Transportation	In evaluating flexible experimental pavements.
1-4	Report 10	Connecticut Dept. of Transportation	In analyses of data from experimental pavements.
1-4(2)	Report 30	Connecticut Dept. of Transportation	In evaluating flexible experimental pavements.
1-5	Report 21	Connecticut Dept. of Transportation	In evaluating flexible experimental pavements.
1-5(2)	Report 76	North Dakota State Highway Dept. Connecticut Dept. of Transportation	Major equipment purchase was based on successful use of similar equipment in conduct of project. In evaluating flexible experimental pavements.
1-7	Report 37	Nat'l. Hwy. Safety Bur. 92nd Congress, 1st Sess. Connecticut Dept. of Transportation	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. As justification to establish skid test program in Connecticut.
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. Connecticut Dept. of Transportation	In evaluation of proposed State legislation regarding use of studded tires. In providing documentation for studded tire legislation.
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

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			design of pavement systems for Forest Service roads.
1-12	— Report 154	AASHTO 92nd Congress, 1st Sess. Connecticut Dept. of Transportation	Partly published as <i>Interim Guide for Design of Pavement Structures, 1972</i> House of Representatives subcommittee hearings on highway safety and skidding. As background information on skid-testing program.
1-12(2)	— Report 151	92nd Congress, 1st Sess. Connecticut Dept. of Transportation	See Project 1-12. As background information on skid-testing program.
1-12(3)	— Agency report	92nd Congress, 1st Sess. New York Dept. of Transportation	See Project 1-12. Will lean heavily on the suggestions presented when purchasing or altering skid trailers and when modifying operational procedures.
1-14	Agency final report	Va. Dept. of Highways	Safety Committee reviewed agency recommendations for improvements at high accident site with resulting request for FHWA approval as an Interstate Safety Project.
2-5	Reports 13, 111	One State (unknown)	To replace outdated material in AASHTO book, <i>Urban Freeway Design</i> .
2-5A	Report 111	AASHTO Woodrow W. Rankin, J.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> .
2-12	Agency final report and Report 111	Federal Supply Service, Genl. Serv. Admin.	Vehicle operating cost data applied in review of Govt. employee automobile costs.
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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
3-7	Agency final report Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Goodell, Grivas and Assoc.	Obtained contract to use model described in report on a network in Detroit.
		Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ.	Demand for the tape has been large, and loan copies have been circulated widely. Although the principal use of the tape has been educational in nature, one County Board of Education was so impressed with the noise differential between the open and closed window situation that consideration was given to installation of air conditioning and storm windows for school buildings adjacent to freeways.
		Georgia State Hwy. Dept.	Noise design guide used in design of the urban freeway system.
		Minnesota Legislature	For demonstration purposes in hearings by House Transportation Committee, and Senate Highways and Natural Resources and Environment Committees. Both Senate committees took favorable action on a Truck Noise Control bill patterned after the California law.
		Virginia Dept. of Hwys.	To evaluate noise for several proposed highways and to make subsequent explanations to the public on the impact of the noise on the community. One instance involved I-195, a six-lane depressed highway in a residential area of Richmond. Using the computer program from <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 AASHTO	As primary texts in a "noise school" for parish (county) engineers. As source documents for new (1974) publication, "Guide on Evaluation and Attenuation of Traffic Noise."

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	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.
	Agency final report	National Bureau of Standards	Published a form of the Noise Prediction Nomogram adapted to an "L-equivalent" measure.
		Maryland-Natl. Capital Park and Plan. Comm.	Found to be useful and quite accurate as a tool in preparation of land-use plans.
	Reports 78, 117, 144	Connecticut Dept. of Transportation	As a basis for noise analyses.
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.
		Connecticut Dept. of Transportation	Source reference for Railroad-Highway Safety Grade Crossing Program.
3-9	Report 84	California Div. of Hwys.	Recommendations being used on the Freeway Surveillance and Control Project (Los Angeles), involving expenditure of about \$8 million in three years.
3-12	Report 123	Transp. Systems Center	Information on fixed highway signing principles was particularly helpful in providing control signals to pilots at Kennedy International Airport (New York).
	Agency report	Street Name Signing Comm., ITE	As background information in review of street name signing applications to meet motorists' needs.
3-13	Report 93	City of Waco, Tex.	Plans to incorporate in subdivision and zoning regulations many of the controls recommended as a means of attempting to protect facility capacity and safety.
3-14	Film, "Relief for Tired Streets"	New York Dept. of Transportation	To encourage municipalities in the State to apply traffic engineering solutions to their congestion problems.
3-15	Agency report	Consultant	Using nomographs and incorporating the research findings into some current projects.
3-16	Agency final report	FHWA	As support material in resolving an operations problem.
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.

## EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		New York State Dept. of Transp.	As background and design evaluation for a centralized computer traffic surveillance and control system in the Northern Long Island Corridor.
3-20	Agency report	FHWA	To develop interest in warrant improvement within Signals Subcommittee of National Advisory Committee on Uniform Traffic Control Devices.
4-3	Reports 12, 15, 65, and 66	ASTM	Basis for development of C671, "Tentative Method of Test for Critical Dilation of Concrete Specimens Subject to Freezing," and C682, "Resistance of Aggregates to Freezing."
4-6	Reports 74, 74A, 74B	Connecticut Dept. of Transportation	As backup in developing paint systems for highway bridges.
4-11	Agency interim report	Federal Aviation Admin.	Tentative guidelines for selection and installation of plastic pipe were used to reduce time and funds required for a research project on plastic pipe for airport drainage.
		State Highway and Transportation Materials Engineers	On basis of advisory panel member comments that information in report would be useful to practicing engineers, report was distributed to members of AASHTO Operating Sub-Committee on Materials.
		U.S. Forest Service	Distributed to each regional office on basis of headquarters office determination that it will prove of use to engineers involved in design of road and sanitary sewer projects.
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.
		Connecticut Dept. of Transportation	In developing deicing chemical policy.
6-2	Report 4	California Div. of Hwys.	See Project 6-1.
		Connecticut Dept. of Transportation	In developing snow and ice policies.
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."
		Connecticut Dept. of Transportation	In developing treatments to prevent deterioration of portland cement concrete bridge decks.
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.



EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
6-8	Report 1	California Div. of Hwys. U.S. Park Serv.	See Project 6-1.  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.
	Report 127	Connecticut Dept. of Transportation	As source reference for snow and ice policy.
	Report 127 and 35 mm slides	New York State Dept. of Transp.	Region 5 duplicated a loan set of 35-mm slides illustrating Appendix J for showing at Region meetings. They have proven helpful for both design and maintenance activities.
7-4	Report 89	Illinois Dept. of Transp., Bur. of Planning	Findings have been found useful, and practice has been modified to conform with them.
7-7	Report 64	Ohio Dept. of Hwys.	Implemented several recommendations pertaining to rest areas with maps and other information of interest to motorists, signing conformity, service patrols, patrol aircraft, and medicopter service.
7-8	Report 133	Connecticut Dept. of Transportation	As a basis for noise analyses.
7-10	Agency interim report	Oregon County Transit Dist.	In preparation of an energy contingency plan.
	Agency final report	U.S. Environmental Protection Agency	To brief members of Senate Public Works Committee on the state of the art of transportation controls.
8-3	Agency final report	Arizona Hwy. Dept.	Source material for decisions based on consumer sensitivity to the various factors considered in trip making.
8-4	Report 96	Univ. of Wisconsin, Dept. of Engineering	As a text in short course on Urban Transportation Planning.
8-5	Report 121	Univ. of Wisconsin, Dept. of Engineering	As a text in Traffic Engineering Seminar.
8-8(3)	Agency interim report	Iowa State Hwy. Comm.	In development of an action plan in conformance with FHWA PPM 90-4.
		Delaware Dept. of Hwys. and Transp.	In development of an action plan in conformance with FHWA PPM 90-4.
	Agency final report	New York DOT, Transp. Planning Div.	In preparation of a synthesis report giving background to regional personnel responsible for citizen participation. Also useful in development of NY State Action Plan.
		FHWA	Assisted in development of PPM 90-4.
	Report 156	Michigan DOT Nat'l. Inst. for Road Research, South Africa	Assisted in preparation of the state's Action Plan. In developing similar procedures in South Africa.
		Connecticut Dept. of Transportation	In preparing environmental impact statements.
8-11	Agency final report	Illinois Department of Transportation	Portions incorporated into a manual on assessment of ecological impacts from highways for distribution to

## EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			district engineers and others doing work for the department.
8-12	Agency final report, Phase I	FHWA	By regional transportation planners to provide technical support to the states.
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.
		Connecticut Dept. of Transportation	As reference by Specifications Division.
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.
10-2A	Report 69	Connecticut Dept. of Transportation	In developing statistical specifications.
10-5	Reports 14, 13	Connecticut Dept. of Transportation	In establishing nuclear density and moisture tests in soils.
10-6	Report 52	Illinois Div. of Hwys., Bur. of Res. and Devel.	Considering a trial of recommendation for use of nuclear pellet technique for measuring pavement thickness.
10-8	Agency final report	Pennsylvania Dept. of Transportation	The Ohio State ultrasonic gauge, several eddy current proximity gauges, and additional pachometers will be used with the new statistically based acceptance specifications to reduce over-all construction costs.
10-9	Res. Results Digest 48	U. of Minnesota and Minnesota Dept. of Hwys.	In seminars conducted throughout Minnesota to train city and county personnel in use of the pavement surface condition rating system.
11-1(6)	Report 92	New Mexico State Hwy. Comm.	In settling negotiations for purchase of an airport.
11-3	Report 56	Indiana State Hwy. Comm., Land Ac. Div.	Rated as "excellent." Requested extra copies for use in development of new work in area of responsibility.
		Illinois Div. of Hwys., Bur. of Rt.-of-Way	Most of the principles set forth have been in practice. Land Economic Study unit will conduct a study according to the report recommendation for one method of analysis of the value of scenic easements.
12-2	Report 83	California Div. of Hwys.	Own research project on "Analysis, Design and Behavior of Highway Bridges" used both basic knowledge and example of a well-devised rational approach to further simplify the proposed formulas and criteria recommended as revisions to the AASHTO Specifications, and to consolidate and authenticate the proposed criteria by further model

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			and prototype verification of analytically obtained values.
12-5	Report 90	California Div. of Hwys.	Confirmed the Division's present practices, gave reassurance that its long-term investment in prestressed concrete structures is sound, and answered the question as to practicability of protective coatings.
12-7	Report 102	Naval Ship Res. and Devel. Lab.	Limited portions used in a technical report entitled "Some Observations on the Fatigue Behavior of Specimens and Structures."
		Illinois Dept. of Transp., Bur. of Design	Findings have been found useful, and practice has been modified to conform with them.
	Report 147	Connecticut Dept. of Transportation AASHTO	To change bridge design parameters in order to reduce fatigue cracking. Fatigue specification recommendations were adopted in total in the 1974 Interim AASHTO "Standard Specifications for Highway Bridges."
		Connecticut Dept. of Transportation	To accomplish design modifications in bridges intended to reduce fatigue cracking.
		American Railway Engineering Assn.	To develop modifications to fatigue provisions in AREA Specifications (1975).
12-8	Report 86	Canadian Stds. Assn.	Committee on Design of Highway Bridges used results in updating standards for bridge railing loads.
		Connecticut Dept. of Transportation	To provide backup information for current bridge-rail design.
13-1	Report 26	Delaware State Hwy. Dept.	In a study of highway maintenance management, Advanced Management Planning, Inc., recommended use as a guide in establishing equipment rental rates.
14-1	Report 42	Minnesota Dept. of Hwys.	Of considerable assistance to the investigators in the Maintenance Program Budget Pilot Study, which includes a determination of the sets of road characteristics to which quality and quantity standards codes should be assigned.
		Washington State Hwy. Comm.	In development of a unit maintenance expenditure index for the State.
		Ohio Dept. of Hwys.	In a study to develop a forecast of maintenance needs 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.
		Connecticut Dept. of Transportation	In establishing Maintenance Management System.
15-1	Report 36	Commercial firm	In formulating a design for a new fiberglass guardrail system.
15-1(2)	Report 54	Federal and State agencies	In planning, design, construction, maintenance, replacement of guardrails and median barriers.
		American Iron and Steel Inst.	Recommendations on standardization of guardrail hardware by the Highway Task Force of the Institute's Sheet Committee to include use of the flat washer illustrated on page 29 of <i>Report 54</i> .
		Illinois Div. of Hwys.	Included in highway design policies and standards by Bur. of Design. New Bur. of Maintenance standards for guardrail and median barriers adapted from report. Bur. of Traffic comments highlight <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 bar-

## EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
			riers, 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	Connecticut Dept. of Transportation New York State Dept. of Transp.	As a basis of guide rail systems currently used in Connecticut. As a vital supplement to a recently prepared design manual covering policies, procedures, and standards. Design guide refers to report for further information.
15-2	Report 108	Connecticut Dept. of Transp.	On trial basis, used the design technique developed for channels lined with riprap. Major relocation of a stream and tributaries having a design flood discharge of 3,900 cfs from a drainage area of 7.3 square miles was involved. Saving from use of riprap instead of paving was estimated to be more than \$90,000. Evaluation of the effectiveness of the treatment is continuing, especially observation of behavior during and after any significant storms.
		Wisconsin Dept. of Transp.	Channel design procedure applied to ditches along the Lake Wissota-Cadott Road in Chippewa County. These were previously subject to erosion, but none has occurred since use of riprap according to the procedure.
		Kansas State Hwy. Commission Minnesota Dept. of Highways	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.
		Colorado State Dept. of Hwys. Soil Conserv. Serv., U.S. Dept. of Agr.	Method to size riprap protection included in Ch. 8 of Design Manual. Recommendations used in preparation of <i>SCS Tech. Release No. 59 "Hydraulic Design of Riprap Gradient Control Structures."</i>
	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.
	Report 108 and agency final report	Consultant, Madrid, Spain	Riprap design procedure applied to channels along motorways in Spain.
15-4	Report 136	Indiana State Highway Comm.	Used National Small Streams Data Inventory compiled during project as an additional check on flood flow estimates.
15-6	Report 77	AASHTO Stdg. Comm. on Engrg. and Oper.	Input (with Report 20, Proj. 5-4) to the March 1969 publication, <i>Informational Guide to Roadway Lighting</i> .
		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.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
16-1	Report 91	Connecticut Dept. of Transportation California Div. of Hwys. U.S. Government	As a basis for breakaway luminaries for highway lighting. 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	Connecticut Dept. of Transportation Robley Winfrey Calspan	In preparation of environmental impact statements. 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.
17-2A	Agency final report Report 162	South Dakota Dept. of Transportation, Div. of Hwys. Northwestern Univ.	To assist in evaluating safety improvements accomplished under on ongoing safety program. As a reference and teaching aid in a graduate course in highway safety programming.
19-2(4)	Report 131	Office of Highway Safety, FHWA Office of Research and Development, FHWA	By staff serving as instructors for a series of regional seminars on evaluation of safety improvements. As a primary reference in training courses on Managing Highway Maintenance.
19-3	Report 141	Natl. Inst. for Road Research, South Africa	As source document in investigating certain aspects of vehicle sizes and weights on South African highways.
20-1	(HRIS)	Many diverse agencies	The Highway Research Information Service is known to be used widely by a number of organizations in addition to state highway departments. Recognition has been given to the periodic issues of <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 1 Synthesis 4	Connecticut Dept. of Transportation California Div. of Hwys. U.S. Dept. of Transp. New Mexico State Hwy. Dept.	As a basis for current signing patterns from Maintenance. 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. In preparation of <i>Instructional Memorandum 40-2-70</i> . In revising the Department's <i>Bridge Construction Manual</i> .

## EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	Synthesis 5	Center for Public Works Studies and Experimentation (Spain) Louisiana Dept. of Hwys.	Translated into Spanish as an "Information Bulletin" of the Transport and Soil Mechanics Laboratory. As procedural guide to emergency measures to contain and/or control scour at bridge sites.
	Synthesis 6	Connecticut Dept. of Transportation	In project scheduling.
	Synthesis 7	92nd Congress, 1st Sess. Connecticut Dept. of Transportation	See Project 1-12. Provided justification for motorist aid call-box system.
	Synthesis 10	Connecticut Dept. of Transportation	By Maintenance in training personnel for equipment responsibilities.
	Synthesis 11	AASHTO	As a text in Highway Management Course (conducted by the Highway Management Institute at the Univ. of Mississippi).
	Synthesis 12	Connecticut Dept. of Transportation	As a basis for Maintenance Telecommunication System.
	Synthesis 14	Texas Hwy. Dept.  Connecticut Dept. of Transportation	Recommended to District offices as a reference to answer skid-resistance questions from both Departmental and non-Departmental personnel. To provide guidelines for skid-resistance program in Connecticut.
	Synthesis 16	Connecticut Dept. of Transportation	Reference source for design of CRC pavements.
	Synthesis 18	Texas Hwy. Dept. and Texas Div., FHWA	As background information in plan preparation, plan review, construction supervision, construction inspection, and maintenance activity.
	Synthesis 24	Connecticut Dept. of Transportation	As input into snow and ice policy.
	Synthesis 32	Connecticut Dept. of Transportation	As backup for studded-tire legislation.
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.

## EXAMPLES OF UTILIZATION OF NCHRP RESULTS (Continued)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
	Report 157	Connecticut Dept. of Transportation	In developing the scrap tire attenuation system.
20-12	Agency final report	FHWA	In preparation of a handbook on "Air Pollution Control for Construction and Maintenance."
22-2	Res. Results Digests 43, 53	California, Michigan, and states in FHWA Region 4 Federal Aviation Administration	To specify breakaway cable terminals for both guardrails and median barriers on new installations.  To install breakaway cable terminals as part of a demonstration project on the Dulles Airport Access Highway.
	Report 153	AASHTO	Referenced in Section 1.1.9A(2), Loadings and Geometrics, of the 1975 "Interim Bridge Specifications."

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

## AWARD-WINNING RESEARCH UNDER NCHRP

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

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

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

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

Other projects prominent in various other classes of awards are:

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

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

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

## PERSONNEL

In May 1976 John E. Burke retired after some 40 years in the engineering profession. He joined the NCHRP as a

Projects Engineer on May 8, 1972, following his earlier retirement from the Illinois Department of Transportation.

## SUMMARY

The National Cooperative Highway Research Program is a unique contract research effort designed to respond quickly and efficiently to the needs of state highway and transportation departments through the solution of the pressing transportation problems. Although the Transportation Research Board administers the Program, the research content is solely the prerogative of the American Association of State Highway and Transportation Officials and its

member departments. The Program is one of applied (rather than basic) research, and every possible effort is made to help administrators and engineers put the findings to early use. Program policy ensures maximum exposure of the research while in progress in the hope that research results will, in fact, more quickly find their way into practice in the form of policies, procedures, specifications, and standards of state highway and transportation departments.

TABLE 7

## PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

<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), 64 p., \$4.40
127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., \$5.20	155	Bus Use of Highways—Planning and Design Guidelines (Proj. 8-10), 161 p., \$7.60
128	Evaluation of AASHTO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., \$5.60	156	Transportation Decision-Making—A Guide to Social and Environmental Considerations (Proj. 8-8(3)), 135 p., \$7.20
129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., \$4.80	157	Crash Cushions of Waste Materials (Proj. 20-7), 73 p., \$4.80
130	Roadway Delineation Systems (Proj. 5-7), 349 p., \$14.00	158	Selection of Safe Roadside Cross Sections (Proj. 20-7), 57 p., \$4.40
131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., \$8.40	159	Weaving Areas—Design and Analysis (Proj. 3-15), 119 p., \$6.40
132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., \$7.20	160	Flexible Pavement Design and Management—Systems Approach Implementation (Proj. 1-10A), 53 p., \$4.00
133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., \$5.60		

TABLE 7 (Continued)

<i>Rep. No.</i>	<i>Title, Project, Pages, Price</i>	<i>No.</i>	<i>Title, Pages, Price</i>
161	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities (Proj. 14-2), 55 p., \$4.40		
162	Methods for Evaluating Highway Safety Improvements (Proj. 17-2A), 150 p., \$7.40		
163	Design of Bent Caps for Concrete Box-Girder Bridges (Proj. 12-10), 124 p., \$6.80		
164	Fatigue Strength of High-Yield Reinforcing Bars (Proj. 4-7), 90 p., \$5.60		
165	Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase (Proj. 12-11), 70 pp., \$4.80		
166	Waste Materials as Potential Replacements for Highway Aggregates (Proj. 4-10A), 94 p., \$5.60		
167	Transportation Planning for Small Urban Areas (Proj. 8-7A), 71 p., \$4.80		
168	Rapid Measurement of Concrete Pavement Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems (Proj. 10-8), 63 p., \$4.80		
169	Peak-Period Traffic Congestion—Options for Current Programs (Proj. 7-10), 65 p., \$4.80		
170	Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase (Proj. 16-1), 88 p., \$5.60		
171	Highway Fog—Visibility Measures and Guidance Systems (Proj. 5-6A), 40 p., \$4.00		
172	Density Standards for Field Compaction of Granular Bases and Subbases (Proj. 4-8(2)), 73 p., \$4.80		
173	Highway Noise—Generation and Control (Proj. 3-7), (in press)		
174	Highway Noise—A Design Guide for Prediction and Control (Proj. 3-7), (in press)		
175	Freeway Lane Drops (Proj. 3-16), (in press)		
			istration and Operations (Proj. 20-5, Topic 3-03), 29 p., \$2.80
		13	Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., \$2.80
		14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., \$4.00
		15	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., \$3.60
		16	Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., \$2.80
		17	Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., \$3.60
		18	Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., \$4.00
		19	Design, Construction, and Maintenance of PCC Pavement Joints (Proj. 20-5, Topic 3-04), 40 p., \$3.60
		20	Rest Areas (Proj. 20-5, Topic 4-04), 38 p., \$3.60
		21	Highway Location Reference Methods (Proj. 20-5, Topic 4-06), 30 p., \$3.20
		22	Maintenance Management of Traffic Signal Equipment and Systems (Proj. 20-5, Topic 4-03), 41 p., \$4.00
		23	Getting Research Findings into Practice (Proj. 20-5, Topic 11), 24 p., \$3.20
		24	Minimizing Deicing Chemical Use (Proj. 20-5, Topic 4-02), 58 p., \$4.00
		25	Reconditioning High-Volume Freeways in Urban Areas (Proj. 20-5, Topic 5-01), 56 p., \$4.00
		26	Roadway Design in Seasonal Frost Areas (Proj. 20-5, Topic 3-07), 104 p., \$6.00
		27	PCC Pavements for Low-Volume Roads and City Streets (Proj. 20-5, Topic 5-06), 31 p., \$3.60
		28	Partial-Lane Pavement Widening (Proj. 20-5, Topic 5-05), 30 p., \$3.20
		29	Treatment of Soft Foundations for Highway Embankments (Proj. 20-5, Topic 4-09), 25 p., \$3.20
		30	Bituminous Emulsions for Highway Pavements (Proj. 20-5, Topic 6-10), 76 p., \$4.80
		31	Highway Tunnel Operations (Proj. 20-5, Topic 5-08), 29 p., \$3.20
		32	Effects of Studded Tires (Proj. 20-5, Topic 5-13), 46 p., \$4.00
		33	Acquisition and Use of Geotechnical Information (Proj. 20-5, Topic 5-03), 40 p., \$4.00
		34	Policies for Accommodation of Utilities on Highway Rights-of-Way (Proj. 20-5, Topic 6-03), 22 p., \$3.20
		35	Design and Control of Freeway Off-Ramp Terminals (Proj. 20-5, Topic 5-02), 61 p., \$4.40
		36	Instrumentation and Equipment for Testing Highway Materials, Products, and Performance (Proj. 20-5, Topic 6-01), 70 p., \$4.80
		37	Lime-Fly Ash-Stabilized Bases and Subbases (Proj. 20-5, Topic 6-06), 66 p., \$4.80
		38	Statistically Oriented End-Result Specifications (Proj. 20-5, Topic 6-02), 40 p., \$4.00
		39	Transportation Requirements for the Handicapped, Elderly, and Economically Disadvantaged (Proj. 20-5, Topic 6-07), 54 p., \$4.40
<b>Synthesis of Highway Practice</b>			
<i>No.</i>	<i>Title, Pages, Price</i>		
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 Admin-		

TABLE 8  
 UNPUBLISHED REPORTS OF THE NATIONAL  
 COOPERATIVE HIGHWAY RESEARCH PROGRAM <sup>a</sup>

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PROJECT SUMMARIES IN *SUMMARY OF  
 PROGRESS REPORT* FOR PERIOD ENDING

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June 30, 1967	1-2, 2-8, 3-1, 6-6, 6-7A, 8-3
June 30, 1968	2-1, 4-1, 4-5
Dec. 31, 1969	12-4
Dec. 31, 1971	3-16
Dec. 31, 1972	9-2, 11-1(4), 11-1(7), 11-1(11), 20-8, 22-1
Dec. 31, 1973	3-12
Dec. 31, 1975	12-1/12-6, 15-2
Dec. 31, 1976	3-7, 5-5A, 7-9, 10-9

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<sup>a</sup> See Table 5 for project titles. For information on obtaining copies of research agency reports write to Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48106.

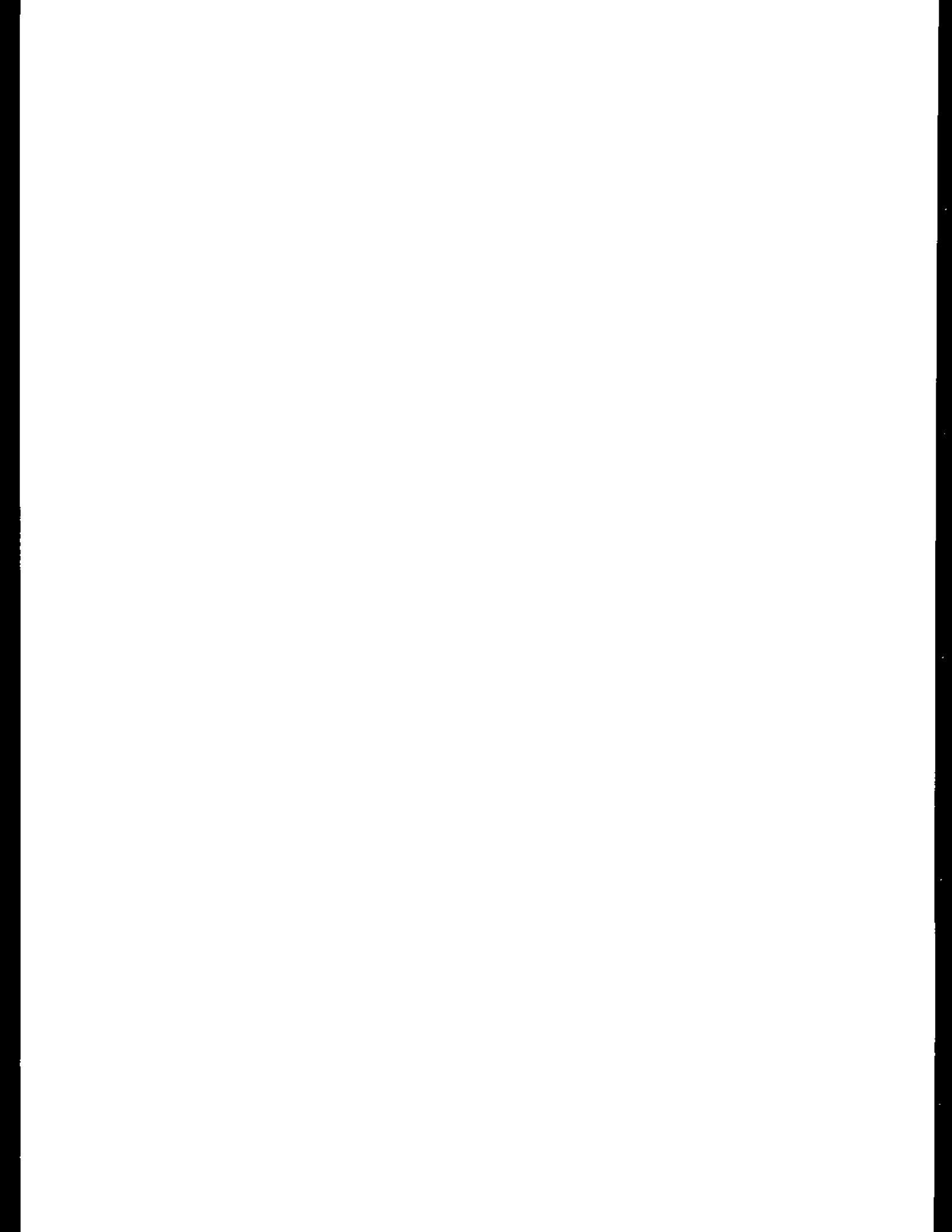
TABLE 9

NCHRP RESEARCH RESULTS DIGESTS<sup>a</sup>

DIGEST NO.	PROJ. NO.	TITLE	DIGEST NO.	PROJ. NO.	TITLE
3 <sup>b</sup>	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act	55 <sup>b</sup>	20-7	Side-Friction Factors in the Design of Highway Curves (Task 4)
6 <sup>b</sup>	20-6	Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administrative Discretion in Route Location of Federal-Aid Highways	58	9-4	Minimizing Premature Cracking in Asphaltic Concrete Pavement
14	12-3	Waterproof Expansion Joints for Bridges	59	12-15	Classification of Welded Bridge Details for Fatigue Loading
19 <sup>b</sup>	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968	60	12-12	Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings
20 <sup>b</sup>	19-1	Budgeting for State Highway Departments	63	10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position
22 <sup>b</sup>	20-6	Valuation in Eminent Domain as Affected by Zoning	66	12-15	Nondestructive Methods of Fatigue Crack Detection in Steel Bridge Members
25 <sup>b</sup>	20-6	Federal Environmental Legislation and Regulations as Affecting Highways	68 <sup>b</sup>	20-6	The Meaning of Highway Purpose
31 <sup>b</sup>	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way	69	3-7	Establishment of Standards for Highway Noise Levels
32 <sup>b</sup>	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970	72	1-14	Recommended Modification of Super-elevation Practice for Long-Radius Curves
35	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	74	10-10	Electroslag Weldments in Bridges
39 <sup>b</sup>	20-6	Legal Effect of Representations as to Subsurface Conditions	75	21-2, 21-2(2)	Development of Prototype Soil Moisture Sensors
40 <sup>b</sup>	20-6	Appeal Bodies for Highway Relocation Assistance	76 <sup>b</sup>	22-3, 22-3A	Field Evaluation of Vehicle Barrier Systems
41 <sup>b</sup>	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases	77 <sup>b</sup>	20-7	Earth-Berm Vehicle Deflector (Task 3)
42 <sup>b</sup>	20-6	Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation	78	3-20	Traffic Signal Warrants—A Bibliography
43	22-2	Evaluation of Breakaway Cable Terminals for Guardrails	79 <sup>b</sup>	20-6	Personal Liability of State Highway Department Officers and Employees
45 <sup>b</sup>	20-6	Exclusion of Increase or Decrease in Value Caused by Public Improvement for Which Lands Are Condemned	80 <sup>b</sup>	20-6	Liability of State Highway Departments for Design, Construction, and Maintenance Defects
46	3-18(1)	Control Logic for Traffic Signal Networks	81	22-1A	Crash Testing and Evaluation of Attenuating Bridge Railing System
47 <sup>b</sup>	20-6	Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation	82	1-15	Design of Continuously Reinforced Concrete Pavements for Highways
48	10-9	Surface Condition Rating System for Bituminous Pavements	83 <sup>b</sup>	20-6	Liability of State and Local Governments for Snow and Ice Control
51	3-18(2)	Traffic Control in Oversaturated Street Networks	84	22-2	Breakaway Cable Terminals for Guardrails and Median Barriers
53	22-2	Development of a Breakaway Cable Terminal for Median Barriers	85	12-16	Bridge Deck Repairs
54 <sup>b</sup>	20-6	Trial Strategy and Techniques Using the Income Approach to Valuation	86	3-22	Guidelines for Design and Operation of Ramp Control Systems
			87	3-24	Current Practices in Use of Retro-reflective Signing Materials
			88	3-18(3)	Summary of Project 3-18(3) Traffic Signal System Surveys
			89	1-12(3)	Guidelines for Skid-Resistant Highway Pavement Surfaces
			90	20-5	Continuing Project to Synthesize Information on Highway Problems

<sup>a</sup> 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.

<sup>b</sup> 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 CHIOE profilometer were involved in the comparison study.

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

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

Because the initial research resulted in sufficient data to permit calculation of elevation power spectra, the work was extended to consider specifically the problems associated with using these spectra as criteria of pavement condition. The report on the power spectra work was not published in the regular NCHRP series, but a summary was included in the "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967*. A paper on this work was also published in *Highway Research Record No. 189*.

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

##### Factors Influencing Pavement Performance—Regional

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

The degree of influence of various factors commonly assumed to affect pavement performance has not been suitably evaluated to allow translation of test results from

one geographic area to another. The objectives of this project were to identify factors that influence pavement performance, to determine the relative effect of each factor, and to correlate pavement design and performance with factors common to a number of regions of the United States.

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

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

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

#### Project 1-3(2) FY '63

##### Factors Influencing Pavement Performance—Local

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

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

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

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

#### Project 1-3(3) FY '64

##### Factors Influencing Pavement Performance

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

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

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

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

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

#### Project 1-4(1) FY '63

##### Extension of Road Test Performance Concepts

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

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

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

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

#### Project 1-4(1)A FY '64

##### Extension of Road Test Performance Concepts

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

This research was concerned with existing theories of structural behavior of rigid pavements. Available data on deflections, stresses, and observed structural failures of



rigid pavements during the AASHO Road Test were collected and critically reviewed. Rational correlations were developed for existing theories of mechanical behavior of rigid pavements.

The project report has been published as:

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

#### Project 1-4(2) FY '64

##### Extension of Road Test Performance Concepts

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

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

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

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

#### Project 1-5 FY '64

##### Detecting Variations in Load-Carrying Capacity of Flexible Pavements

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

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

This research approached the objectives in terms of investigating the displacement response of flexible pavements

to impulsive loadings as a measure of the seasonal changes in the elastic properties. The findings have been published as:

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

#### Project 1-5(2) FY '67

##### Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements

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

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

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

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

#### Project 1-6 FY '64

##### Standard Measurements for Satellite Program— Measurement Team

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

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

The measurement program considered minimal for a nationwide coordinated satellite program was outlined in the guidelines prepared under NCHRP Project 1-1, but the guidelines did not specify actual items of test equipment nor describe team personnel requirements or procedures in detail. In addition, it did not attempt to define the testing program for the measurement teams in terms of

frequency of visits to individual projects or schedules of measurements within projects.

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

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

#### Project 1-7 FY '65

##### Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces

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

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

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

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

#### Project 1-8 FY '65

##### Factors Involved in the Design of Asphalt Pavement Surfaces

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

Research is needed to improve the methods currently being used to design both asphalt concrete mixtures and thicknesses for flexible pavement surfaces. It is necessary that design methods take into consideration the many

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

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

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

#### Project 1-9 FY '67

##### Evaluation of Studded Tires

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

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

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

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

#### Project 1-10 FY '67 and FY '69

##### Translating AASHO Road Test Findings—Basic Properties of Pavement Components

*Research Agency:* Materials Research and Development  
*Principal Invest.:* B. A. Vallergera  
 F. N. Finn  
 Dr. W. R. Hudson  
 Dr. Keshavan Nair  
*Effective Dates:* Sept. 12, 1966 Dec. 1, 1968  
*Completion Dates:* Mar. 11, 1968 Dec. 31, 1970  
*Funds:* \$99,803 \$103,291

A wealth of useful design and performance information resulted from the AASHO Road Test; however, means do

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

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

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

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

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

#### **Project 1-10A** FY '72

##### **Systems Approach to Pavement Design— Implementation Phase**

*Research Agency:* Texas A & M University  
Research Foundation

*Principal Invest.:* R. L. Lytton  
W. F. McFarland

*Effective Date:* March 1, 1972

*Completion Date:* December 31, 1973

*Funds:* \$100,000

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

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

The primary objective of this project was the further development of the SAMP5 program to field application

stage and its pilot testing in one or more state highway departments.

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

The project report has been published as:

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

#### **Project 1-10B** FY '73

##### **Development of Pavement Structural Subsystems**

*Research Agency:* Materials Research and  
Development

*Principal Invest.:* F. N. Finn

*Effective Date:* February 1, 1974

*Completion Date:* September 30, 1976

*Funds:* \$250,000

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

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

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

- (a) Cracking from repetitive traffic loading.

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

Research has been completed and the objective accomplished in the form of two computer programs, one referred to as PDMA (Probabilistic Distress Models for Asphalt Pavements) for fatigue cracking and permanent deformation, and the second referred to as COLD (Computation of Low-Temperature Damage) for low-temperature cracking. The programs are capable of simulating the occurrence of pavement distress and can be used in pavement management systems, diagnostic investigations, formulation of design criteria, and preparation of material and construction specifications. They have been successfully executed on the computer equipment of several state highway and transportation departments. The primary need is for additional calibration verification, and implementation at the user level.

The final report is in the review and revision process.

The NCHRP '77 program allocates continuation funding in the amount of \$150,000 for assisting several state highway agencies during calibration and implementation of the findings of this project.

#### Project 1-11 FY '68

##### Evaluation of AASHO Interim Guides for Design of Pavement Structures

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

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

To achieve the objectives, information on current pavement design procedures was collected from 50 state highway departments, the District of Columbia, and Puerto Rico. This was analyzed along with the original AASHO Road Test data and the findings of other research work

in the problem area. For the purpose of providing State highway departments with maximum benefits from the project, a continuation contract was executed with the agency with the objective of drafting revised Guides based on suggested revisions contained in the project report.

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

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

"AASHO Interim Guide for Design of Pavement Structures," published by the American Association of State Highway and Transportation Officials, Washington, D. C.

#### Project 1-12 FY '70

##### Determination of Pavement Friction Coefficients Required for Driving Tasks

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

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

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

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

The project report has been published as NCHRP Report 154, "Determining Pavement Skid Resistance Requirements at Intersections and Braking Sites."

**Project 1-12A** FY '74

**Wet-Weather Skidding Accident Reduction at Intersections**

*Research Agency:* Ohio Department of Transportation  
*Principal Invest.:* R. D. Paddock  
*Effective Date:* July 1, 1975  
*Completion Date:* September 30, 1977  
*Funds:* \$199,955

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

One area of continuing research is that of pavement skid resistance. Although the inherent complexities in this area have long been recognized, the establishment of universal minimum pavement surface skid resistance (Skid Number) requirements is often considered to be the primary approach to solution of the problem. However, realistic skid resistance requirements should be based on actual traffic needs at each particular site. Research conducted under NCHRP Project 1-12 indicates that longitudinal accelerations can be used to predict the relative traffic demand for tire-pavement interface friction at braking sites. Refinement and field validation of longitudinal acceleration assessment is needed to provide highway agencies with additional tools for determining types of corrective actions needed at high or potentially high accident sites.

This project is directed toward the examination of methods developed under NCHRP Project 1-12 for determining vehicular longitudinal acceleration forces and to relate these forces to the incidence of vehicle skidding through loss of traction at the tire-pavement interface. The over-all objective is to provide highway agencies with practical methods needed for determining where longitudinal acceleration demand exceeds available tire-pavement interface friction. It is anticipated that these methods will provide a basis for relating specific acceleration demand at particular sites to other factors such as geometric design features, driver behavior, tire frictional parameters, climate, traffic and pavement surface characteristics.

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

1. Improve, refine and simplify the data collection system developed under NCHRP Project 1-12, with special emphasis on improved service durability of the detection apparatus under heavy traffic and adverse weather conditions.
2. Calibrate the improved data collection system (a) by conducting field tests using accelerometers installed in automobiles or (b) by comparable direct methods.
3. Conduct field studies under dry- and wet-weather conditions to determine the relationships between longi-

tudinal acceleration values, traffic conflicts, and frequency of skidding events. This should include a mathematical analysis to provide statistically valid results.

4. Prepare a procedural manual for implementation of the system, including detailed descriptions of the equipment, measurements, analyses, and limitations.

Research is in progress. Automated equipment has been developed for the collection and analysis of vehicle acceleration data at intersections. During the calibration task it was determined that the desired level of accuracy was not being obtained. Data are being collected at a number of intersection sites with the automated equipment. Following analysis, a determination will be made concerning the acceptability of degree of accuracy.

**Project 1-12(2)** FY '71

**Locked-Wheel Pavement Skid Tester  
Correlation and Calibration Techniques**

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

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

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

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

The project report has been published as NCHRP Report 151, "Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques."

**Project 1-12(3) FY '72****Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces**

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

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

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

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

The research has been completed. The essential findings have been published as NCHRP Research Results Digest 89. The final report, covering both objectives, is in the process of being prepared for publication.

**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 ban-

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

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

**Project 1-13(2) FY '72****Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions**

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

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

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

Project work has been completed, and has offered some insight into the magnitude of the further investigational work required to quantify the many stud-related influences on highway safety. The final report is in the NCHRP editorial and publication process.

**Project 1-14 FY '73****Influence of Combined Highway Grade and Horizontal Alignment on Skidding**

*Research Agency:* University of Michigan  
*Principal Invest.:* Paul Fancher

*Effective Date:* October 15, 1972  
*Completion Date:* January 14, 1974  
*Funds:* \$69,968

A variety of factors have contributed to the rise in number and severity of highway accidents, with attendant loss of life, injury, and property damage. It is recognized that the highway accident problem is an extremely complex one, involving all aspects of the system. Thus, continuing research is needed on all facets of the problem.

At present, "A Policy on Geometric Design of Rural Highways" (AASHTO, 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.

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

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

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

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

#### **Project 1-15**    FY '73

##### **Design of Continuously Reinforced Concrete Pavements for Highways**

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

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

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

Research has been completed. The essential findings of the study have been published as NCHRP Research Results Digest 82. The agency report has been distributed to the Program sponsors and other interested persons. It will not be published in the regular NCHRP Report series but is available on a loan basis upon request to the NCHRP Program Director. Copies may be obtained from Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Mich. 48106.

#### **Project 1-16**    FY '74

##### **Evaluation of Winter-Driving Traction Aids**

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

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

There is also a need for a comprehensive investigation of currently available devices for improving vehicle performance on ice- and snow-covered roads.

The objectives of this project are to:

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

Research is in progress. A set of vehicle performance evaluation test procedures has been developed. They are based on measuring traction-aid performance in a manner specific to the way the aid influences braking, traction, and controllability. Consequently, tires are evaluated on their ability to generate braking, traction, and lateral forces. Aids that modify the application of torque to the drive wheels are evaluated on the basis of vehicle straight-line traction (draw-bar pull) and controllability during combined cornering and braking or acceleration. Methods have been selected for characterizing ice- and snow-covered surfaces. The experimental program is being conducted on an indoor ice rink and outdoor snow-covered surfaces. A vehicle simulation program is being used to study the effects of various drive-train configurations on vehicle controllability. Tire characteristics for use in the simulation studies are obtained from the tire evaluation testing. A work plan has been prepared for a cost-effectiveness type of analysis of traction-aid use.

**Project 1-17**    FY '77

### **Guidelines for Recycling Pavement Materials**

*Research Agency:*    Texas A&M University  
    Research Foundation  
*Principal Invest.:*    Dr. John A. Epps  
*Effective Date:*        November 1, 1976  
*Completion Date:*     January 31, 1979  
*Funds:*                    \$200,000

State and local agencies responsible for the construction, rehabilitation, and maintenance of transportation facilities are faced with inflation, reductions in available funds, reductions of material supplies, and curtailment of energy use. Because of these, an urgent need exists to examine the use

of materials, energy, and funds in order to further optimize their utilization. One approach toward meeting this need is to reuse or recycle existing pavement materials for reconstruction and rehabilitation of portland cement concrete and bituminous pavements.

The over-all objective of this project is to develop realistic guidelines for the recycling of pavement materials for the rehabilitation and reconstruction of existing pavements. It is anticipated that this objective will be met through the conduct of the two tasks described below, major emphasis being placed on consideration of the factors stated in Task 1. Category 3.

#### *Task 1.*

Develop guidelines for recycling pavement materials that consider, as a minimum, the factors in the following categories:

1. Existing pavement structure and geometry:
  - a. Conditions indicating feasibility of recycling.
  - b. Material resources available in pavements.
  - c. Methods for sampling, testing, and evaluating recyclable pavement materials.
2. Various recycling approaches:
  - a. Equipment needs.
  - b. Environmental effects.
  - c. Energy requirements.
  - d. Economics.
3. Recycling procedures and processes:
  - a. Material properties requirements.
  - b. Material testing procedures.
  - c. Additives.
  - d. Pavement mix design.

#### *Task 2.*

Evaluate the practicability of the guidelines developed under Task 1.

It is intended that this evaluation be accomplished by analyzing and interpreting information from ongoing pavement recycling projects not only concurrently with the development of the guidelines but also near the completion of the project.

## **AREA 2:        ECONOMICS**

**Project 2-1**    FY '63 and FY '64

### **Criteria for Highway Benefit Analysis**

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

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



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

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

#### **Project 2-2 FY '63**

##### **Guidelines for the Determination of Community Consequences**

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

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

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

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

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

#### **Project 2-3 FY '63 and FY '64**

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

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

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

Phase 1 was accomplished with highway and accident data from California, Louisiana, and Ohio. The highway data were the highway networks divided into a multitude of short segments, each of known length, each with a

known ADT, and each homogeneous with respect to number of lanes, access control, and median. Data of the accidents that had occurred on a particular highway segment were affixed to that segment. By grouping the highway data according to highway type and ADT, the various accident and severity rates could be computed.

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

The project report has been published as:

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

#### **Project 2-4 FY '63 and FY '64**

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

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Dr. W. G. Adkins  
*Effective Date:* June 1, 1963  
*Completion Date:* August 31, 1966  
*Funds:* \$77,100

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

The final report for this project has been published as:

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

#### **Project 2-5 FY '63 and FY '64**

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

*Research Agency:* The Catholic University of America  
*Principal Invest.:* Dr. Paul J. Claffey

<i>Effective Date:</i>	June 1, 1963	June 1, 1965
<i>Completion Date:</i>	Aug. 31, 1964	Dec. 31, 1966
<i>Funds:</i>	\$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**

<i>Research Agency:</i>	Paul J. Claffey and Associates	
<i>Principal Invest.:</i>	Dr. Paul J. Claffey	
<i>Effective Date:</i>	July 1, 1967	Aug. 11, 1969
<i>Completion Date:</i>	Dec. 31, 1968	Aug. 10, 1970
<i>Funds:</i>	\$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**

<i>Research Agency:</i>	Stanford University
<i>Principal Invest.:</i>	Prof. C. H. Oglesby
<i>Effective Date:</i>	June 1, 1963
<i>Completion Date:</i>	September 30, 1966
<i>Funds:</i>	\$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**

<i>Research Agency:</i>	The Catholic University of America
<i>Principal Invest.:</i>	Dr. Paul J. Claffey
<i>Effective Date:</i>	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 nation-

wide 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 commodi-

ties were projected to 1975. The research results have been published as:

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

#### Project 2-11 FY '67

##### Summary and Evaluation of Economic Consequences of Highway Improvements

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

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

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

The project report has been published as:

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

#### Project 2-12 FY '73

##### Highway User Economic Analysis

*Research Agency:* Stanford Research Institute  
*Principal Invest.:* D. G. Andersen  
*Effective Date:* Apr. 1, 1974 Oct. 11, 1976  
*Completion Date:* Oct. 31, 1975 Jan. 5, 1977  
*Funds:* \$90,074 \$9,995

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

The 1960 AASHO "Informational Report by Committee on Planning and Design Policies on Road User Benefit Analyses for Highway Improvements" (updated revision of the original 1952 report) was written to provide a simple, easy-to-use method for carrying out economic analyses on highway alternatives by those having only basic knowledge of principles of economics. The objective of this research

was to employ, to the best possible extent, current empirical data on highway user benefits and costs (such as from NCHRP Report 122 and other research) to provide a revised and updated version of the 1960 AASHO publication. The revised version will include a selected analysis methodology based on sound economic theory and suitable for immediate, direct application. The methodology provides a means of evaluating public transit operating on public highways. This evaluation allows comparisons between transit operation and additional highway improvements. Further, procedures were developed that provide the user with a means for periodic updating of the numerical factors and cost coefficients through utilization of commonly available economic data. Although it was recognized that environmental and social factors are significant items of input to the decision-making process, this research was limited to road user benefits and costs only.

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

A revision of the report prepared under the original contract is completed and is being reviewed for publication by AASHO and NCHRP. Loan copies of the agency draft report are available from NCHRP.

### AREA 3: OPERATIONS AND CONTROL

#### Project 3-1 FY '63 and FY '64

##### Development of Criteria for Evaluating Traffic Operations

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

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

The final report was not published in the NCHRP report

series; however, a summary of the report is available in *Highway Research Record No. 211* and also in the *NCHRP Summary of Progress to June 30, 1967*.

### Project 3-2 FY '63 and FY '64

#### Surveillance Methods and Ways and Means of Communicating with Drivers

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

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

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

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

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

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

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

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

### Project 3-3 FY '63 and FY '64

#### Sensing and Communication Between Vehicles

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

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

Evaluation and comparative examinations of four inter-vehicular communication systems were completed. These involved both night and day study of car-following for no signal display, for the conventional brake light, for the tri-

light system denoting brake and accelerator action and an acceleration information display of horizontal rows of green and red lights to indicate the magnitude of the vehicle's acceleration or deceleration. Studies of lane changing decisions were also made. Taxonomies of functional groupings of conceptual rear-end visual display components were studied for the various signal systems previously tested. A prototype infrared sensing system was developed and tested to indicate distance and relative velocities between vehicles. Field studies of traffic dynamics were analyzed to determine the data which should be transferred by the sensing and communication system to increase traffic volume and improve safety and speed of traffic flow. Model development studies were made to quantitatively evaluate possible improvements which may be obtained through improved communication between vehicles.

The final report has been published as:

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

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

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

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

This study was directed toward 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-voltaic 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 Date:* 3/1/63 7/1/66 8/1/68  
*Completion Date:* 12/31/65 7/31/67 12/31/69  
*Funds:* \$123,030 \$48,155 \$93,717

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

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

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

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

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

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

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

The final report has been published as:

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

**Project 3-6** FY '63, FY '64, and FY '66**Effect of Regulatory Devices on 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 capac-

ity and operations and on systems of traffic facilities. The effects of stop and yield signs were investigated as they apply to capacity, traffic operations, safety, driver acceptance, and the traffic operations of the area of influence.

The initial phase of research has been published as:

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

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

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

The final report has been published as:

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

**Project 3-7** FY '64, '65, '67, '71, and '73**Establishment of Standards for Highway Noise Levels**

*Research Agency:* Bolt Beranek and Newman  
*Principal Invest.:* Andrew Kugler  
*Effective Date:* 2/1/64 10/14/68 4/1/71 9/1/72  
*Completion Date:* 4/30/67 1/15/70 6/30/72 11/30/74  
*Funds:* \$144,920 \$69,930 \$49,927 \$316,011

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

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

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

The Phase II research objective was to prepare a highway design noise manual for the practicing highway engineer. In addition, a magnetic tape recording was produced to demonstrate basic elements of highway noise and to present examples illustrating changes in traffic noise. Loan copies of the tape recording are available on request to the 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 reduc-

tion treatments under a variety of traffic and environmental conditions. This research developed a tie between field data and analytic approaches so that the performance of noise reduction treatments may be more accurately predicted.

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

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

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

The research has been completed. Final report materials include a computer program for use with the design guide and a 17-min color film entitled "Quiet Highway Design." The film is available on a loan basis, and copies of the computer program can be supplied upon request to the Program Director. The final report on the concluding phase of this research has been published in two volumes:

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

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

The report on a study task related to "Time-Varying Highway Noise Criteria" is not being published, but is summarized in "Summary of Progress Through 1976."

#### **Project 3-8**    FY '64 and FY '65

##### **Factors Influencing Safety at Highway-Rail Grade Crossings**

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

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

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

Later work involved the development and testing of improved grade-crossing protective devices and several experimental devices were studied by the agency. A human

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

The project report has been published as:

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

#### **Project 3-9**    FY '66

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

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

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

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

The project report has been published as:

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

#### **Project 3-10**    FY '66

##### **Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations**

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

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

Elements of geometric design and traffic operations pre-

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

The final report has been published as:

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

### Project 3-11 FY '67

#### Optimizing Street Operations Through Traffic Regulations and Control

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

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

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

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

The final report has been published as:

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

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

#### Development of Information Requirements and Transmission Techniques for Highway Users

*Research Agency:* Airborne Instruments Laboratory  
*Principal Invest.:* M. A. Warskow G. F. King G. F. King  
*Effective Date:* 10/1/66 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:* \$149,293



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

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

The project report has been published as:

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

### Project 3-14 FY '68

#### Optimizing Flow on Existing Street Networks

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

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

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

Consideration of the limitations of a direct capacity-volume approach to analysis of downtown traffic flows led to investigations of developing other means for quantifying and describing traffic flow of a downtown area. These included studies of acceleration noise, mean velocity gradient, and travel time, together with several elements related to travel time such as delay time, average speed, running speed, number of stops, and the number of saturated cycles at signalized intersections. These analyses indicated that a comprehensive analysis of travel time was the best medium for understanding and classifying traffic flow in the downtown area. Using the voluminous travel time and intersection study data accumulated on the project, regression analyses were performed to demonstrate the relationships which exist between various elements of

travel time. It was also demonstrated that these relationships are fairly constant for arterial streets of the two study areas, in spite of their widely differing characteristics. The delay ratio—the ratio of delay time to total travel time—was developed and used in a level-of-service definition for arterial roadways of the downtown area.

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

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

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

The Network Assignment Model may be used to determine the over-all efficiency of the network. The over-all average travel speed developed from total trip time and total trip mileage outputs of the network can be used to develop a network level of service. It is anticipated that the network level of service may become a useful measure for determining priorities for the allocation of funds in relation to need.

The final report has been published as:

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

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

### Project 3-15 FY '70

#### Weaving Area Operations Study

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

Design criteria for weaving sections on multilane

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

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

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

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

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

#### Project 3-16 FY '70

##### Freeway Lane Drops

*Research Agency:* System Development Corp.

*Principal Invest.:* Antranig V. Gafarian  
Diane N. Goodwin

*Effective Date:* Nov. 1, 1969      May 1, 1972

*Completion Date:* Apr. 30, 1971      Oct. 31, 1973

*Funds:* \$99,789      \$76,815

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

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

In the first phase, three lane-drop sites with different geometric configurations were studied intensively to determine traffic operations and safety effects. The report on this initial phase was not published; however, a summary of the Phase I report is included in *NCHRP Summary of Progress Through 1971*.

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

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

NCHRP Report 175, "Freeway Lane Drops."

#### Project 3-17 FY '71

##### Improving Traffic Operations and Safety at Exit Gore Areas

*Research Agency:* The Pennsylvania State University

*Principal Invest.:* James I. Taylor

*Effective Date:* January 1, 1971

*Completion Date:* November 30, 1972

*Funds:* \$79,983

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

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

The final report has been published as:

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

#### Project 3-18(1) FY '70

##### Improved Control Logic for Use with Computer-Controlled Traffic

*Research Agency:* Stanford Research Institute

*Principal Invest.:* Dr. Dale W. Ross

Dr. Thomas L. Humphrey

*Effective Date:* July 15, 1971      April 15, 1975

*Completion Date:* May 15, 1974      Aug. 31, 1976

*Funds:* \$323,998      \$52,912

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

The object of this research has been to study traffic flow and control interaction, and to develop an advance control concept, strategy, and computer program. The research has included development of an operational control program that has the capability of calculating optimal offset patterns for a network of signalized intersections and deter-

mining independent and variable signal split adjustments. The program, designed for application under all levels of network traffic volumes, including oversaturated conditions, has been tested and evaluated with actual traffic in the San Jose traffic control system.

A final report describing the ASCOT program system has been submitted and is available on a loan basis upon request to the NCHRP Program Director. A 20-min color film describing the program and its functions is also available upon request.

**Project 3-18(2) FY '71**

**Traffic Control in Oversaturated Street Networks**

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

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

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

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

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

A continuation phase with the following objectives was initiated: to carry out further studies in minimal-response signal policies, nonsignal effects and remedies, and highly responsive policies; to produce a set of recommendations and guidelines for applying solutions to the problems of oversaturation. The research has been completed, and the final report covering the entire project is in the NCHRP

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

**Project 3-18(3) FY '75**

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

*Research Agency:* JHK & Associates  
*Principal Invest.:* Thomas L. Stout  
*Effective Date:* May 1, 1975  
*Completion Date:* July 31, 1976  
*Funds:* \$100,000

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

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

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

The project's revised final report and user manual have been submitted. While they are under review and in the editorial and publication process, copies of both documents may be obtained on a loan basis upon request to the NCHRP Program Director.

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

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

#### Project 3-20 FY '73

##### Traffic Signal Warrants

*Research Agency:* KLD Associates  
*Principal Invest.:* Edward B. Lieberman  
*Effective Date:* Sept. 1, 1972      Nov. 1, 1974  
*Completion Date:* Apr. 15, 1974      July 31, 1976  
*Funds:* \$120,000      \$80,000

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

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

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

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

Pending review and acceptance of the report and its recommendations, copies are available on a loan basis upon request to the NCHRP Program Director.

#### Project 3-21 FY '74

##### Motorist Response to Highway Guide Signing

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

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

The first research phase under this project was directed, therefore, to identification of promising measures of driver response to guide signing and to development and validation of such measures. The research has been completed, and the final report is in the editorial and publication process. Copies of the agency report are available, prior to publication, on a loan basis upon request to the NCHRP Program Director.

A second phase of the project is being initiated, with emphasis on applications of variable-message signs. It is expected to begin with a synthesis of both current practice and past research that will also include an identification of apparent research needs. This will be followed by definition of a specific research project directed toward the most pressing needs that can be investigated within the constraints of available funds.

#### Project 3-22 FY '74

##### Guidelines for Design and Operation of Ramp Control Systems

*Research Agency:* Stanford Research Institute  
*Principal Invest.:* Dale P. Masher  
*Effective Date:* April 15, 1974

*Completion Date:* December 31, 1975  
*Funds:* \$199,030

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

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

More specifically, the following tasks were addressed:

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

Research activities included: (a) visits to a number of ramp-metering installations; (b) study of control device configurations, selection criteria, and system hierarchies; (c) development of preliminary guidelines to assist traffic engineers in the selection of ramp control systems. The final report will not be published in the regular NCHRP series; but copies of the draft report, "Guidelines for Design and Operation of Ramp Control Systems," December 1975, are available from Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48103. Loan copies are available from NCHRP.

**Project 3-22A** FY '77

### **Guidelines for Design and Operation of Ramp Control Systems**

*Research Agency:*

*Principal Invest.:*

*Effective Date:* Contract pending

*Completion Date:*

*Funds:*

Preliminary guidelines have been developed in NCHRP Project 3-22 for designing and operating ramp control systems. Specific guidelines for evaluating cost-effectiveness are needed to determine what level of control is appropriate and what incremental benefits are obtained by selecting higher levels of control. Typically the designer must choose between local pretimed and traffic-responsive controls, as well as systemwide types of control, without knowing the relative cost-effectiveness of each control alternative proposed for the given freeway application. A comprehensive evaluation procedure is needed to assist designers and traffic engineers in selecting the appropriate control and associated hardware needed for implementation. In developing the guidelines for cost-effectiveness evaluation, the basic considerations that need to be addressed include: (1) incremental benefits associated with each level of control; (2) staffing requirements; (3) freeway safety; (4) user costs, such as vehicle delays, emissions, and fuel consumption; (5) maintenance and system operation costs; and (6) installation costs.

The objective of this research is to develop an analytic procedure and guidelines for comparative evaluation of alternative ramp control system designs. This procedure shall be applicable in determining whether or not ramp control can be employed beneficially and, if so, the type of control system that is most appropriate. The selection methodology must consider local pretimed and responsive control as well as systemwide control. Furthermore, the benefit and performance data base necessary to permit comparative analysis and design must be obtained by the research team by analyzing available data and conducting appropriate field research. Analysis procedures for quantifying benefits, performance, and costs, as well as specific data for use in comparing alternate designs, are required. To meet this objective the following tasks are to be accomplished:

Task 1. Identify and define variables that affect the benefits attributable to the three basic types of ramp control. These include, but are not limited to, variations in flow characteristics, freeway geometrics, frequency of incidents, quality and availability of alternate routes, metering rate constraints, and vehicle occupancy.

Task 2. Develop and describe in detail a method to conduct a benefit and cost analysis for each increment of ramp control. The costs to be considered include initial, operating, and maintenance costs. The benefits to be considered include changes in: (a) over-all delay, (b) incident potential, (c) fuel consumption, (d) vehicle emissions, (e) diverted traffic, and (f) other direct and indirect user benefits.

Task 3. Based on the variables identified in Task 1 and the methodology developed in Task 2, obtain the various types of data required to develop the desired guidelines. Techniques will include analysis of available data, collection of new data, and field evaluations.

Task 4. Develop a comprehensive set of guidelines to assist the traffic engineer in selecting the appropriate type of freeway ramp control. The methodology developed in Task 2 is to be refined to permit direct field application by an engineer. Specific design data needs are to be clearly defined. The guidelines are to be concise and prepared as a separate document from the research report.

Research is to be initiated in early 1977.

#### Project 3-23 FY '74

##### Guidelines for Uniformity in Traffic Control Signal Design Configurations

*Research Agency:* KLD Associates  
*Principal Invest.:* Gerhart F. King  
*Effective Date:* April 8, 1974  
*Completion Date:* February 28, 1977  
*Funds:* \$300,000

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

The purpose of this study 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.

All research associated with the preceding objectives has been completed and the final report on the project is under-going review. It is anticipated that a revised report will be available on a loan basis in early 1977.

#### Project 3-24 FY '75

##### Determine the Luminous Requirements for Retroreflective Highway Signing

*Research Agency:* University of Michigan  
*Principal Invest.:* Dr. Paul L. Olson  
*Effective Date:* September 1, 1974  
*Completion Date:* March 2, 1977  
*Funds:* \$100,000

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

###### Phase I

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

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

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

4. Identify and describe problems pertinent to this investigation arising from activities conducted in Objectives 1, 2, and 3; specifically, (a) outline the information necessary to specify the luminosity values needed for proper traffic engineering decisions, (b) indicate those problem areas in which the necessary information is still lacking, (c) rank these problem areas in order of their relative criticality to proper conclusion of the current investigation, and (d) indicate the relative probability of obtaining research solutions to these problem areas within the time and budget constraints of the current investigation.

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

###### Phase II

1. Conduct the approved field and/or laboratory re-

search in order to develop the ranges of acceptable luminosity values to include:

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

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

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

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

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

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

### **Project 3-25 FY '76**

#### **Cost and Safety Effectiveness of Highway Design Elements**

*Research Agency:* Roy Jorgensen Associates, Inc.

*Principal Invest.:* Joseph F. Banks, Jr.  
Dr. Richard L. Beatty  
Dr. David B. Brown

*Effective Date:* July 15, 1975

*Completion Date:* September 16, 1977

*Funds:* \$260,000

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

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

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

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

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

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

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

Westat, Inc., and Auburn University are serving as sub-contractors on this project.

The Phase I effort has been completed, and work is under way on Phase II. Design elements selected for detailed study include roadway width, median width, median-barrier type, and shoulder-surface type.

### **Project 3-26 FY '77**

#### **Investigation of Selected Noise Barrier Acoustical Parameters**

*Research Agency:* The Pennsylvania State University

*Principal Invest.:* Dr. Sabih I. Hayek  
Dr. James M. Lawther

*Effective Date:* November 1, 1976

*Completion Date:* February 28, 1978

*Funds:* \$74,795

Noise barriers are becoming increasingly important as noise abatement measures along new highways as well as along existing highways. Predicting their effectiveness has been difficult, however, because analytical and predictive measures have had some limitations. Even though new barrier design guides are becoming available, there is still a need to examine certain acoustic parameters. Research is needed to assess the importance of these parameters and to determine how they may best be included in analysis procedures. Specifically, the potential effects of barrier cross-sectional shape, barrier surface

characteristics, and barrier influence on ground cover effects are not considered in currently used procedures. Inasmuch as these parameters have been recognized as possible causes of differences between the predicted and measured performances of noise barriers, it is necessary to determine whether they should be included in future design guides.

The basic project objective, therefore, is to complete an analysis of cross-sectional shape, surface characteristics, and the influence on ground cover effects. The significance of these parameters will be evaluated in terms of the sensitivity of barrier effectiveness to each, and the bounds of their effects will be delineated.

#### **Project 3-27**    FY '77

##### **Guidelines for Selecting Traffic Control at Individual Intersections**

*Research agency:*     Alan M. Voorbees & Associates, Inc.  
*Principal Invest.:*    Philip J. Tarnoff  
*Effective Date:*        November 15, 1976  
*Completion Date:*      November 15, 1978  
*Funds:*                    \$150,000

Adequate guidelines are not currently available to compare the three basic traffic signal control types: pretimed, semi-traffic-actuated, and full-traffic-actuated. Although traffic engineers recognize that each type of control has its appropriate use, selection of control type is generally determined without a comprehensive analysis because of the lack of guidelines and data. To properly evaluate and determine the best type of traffic signal control to use at an intersection, some of the basic considerations that need to be addressed are (a) maintenance requirements, (b) vehicle delays on the major and minor streets, (c) over-all traffic safety, (d) coordination adaptability, and (e) cost effectiveness.

The objective of this research is to develop guidelines for selecting the most appropriate type of traffic signal control for an individual intersection in both urban and rural areas. Consideration of the case of adjacent intersections will be included in the guidelines in regard to the selection of coordinated versus independent operation.

To accomplish this objective, the following specific tasks are to be conducted:

Task 1. Review and summarize relevant literature and research findings.

Task 2. Identify and define the study variables for each of the three basic types of traffic signal controls. The variables include: (a) a representative selection of various intersection configurations, (b) an appropriate selection of phasing alternatives, (c) a range of volumes.

Task 3. Develop and describe in detail a methodology for a cost-effectiveness evaluation. The methodology is to provide the basis for determination of the type of traffic signal control to be used and will include such items as (a) initial costs, (b) maintenance costs, (c) over-all delay, (d) percentage of traffic stopped, (e) vehicle emissions, (f) fuel consumption, and (g) other direct and indirect user

costs. Special emphasis is to be placed on the relationship of the incremental benefits of more sophisticated types of traffic signal control to the associated costs and maintenance requirements. Operating reliability of the traffic signal control equipment will be fully considered.

Task 4. Based on the variables identified in Task 2 and the methodology developed in Task 3, obtain the various types of data required to develop the desired guidelines.

Task 5. Develop a comprehensive set of guidelines to assist the traffic engineer in selecting the appropriate type of traffic signal control for individual intersections. The methodology developed in Task 3 is to be refined to permit its application by an engineer without his having to refer to other documents. Data needs are to be clearly defined.

Research on this project was initiated recently.

#### **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 sub-base course.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

#### **Project 4-4 FY '63**

##### **Synthetic Aggregates for Highway Uses**

*Research Agency:* Battelle Memorial Institute  
*Principal Invest.:* M. J. Snyder  
 F. F. Fondriest  
*Effective Date:* March 1, 1963  
*Completion Date:* April 15, 1964  
*Funds:* \$14,790

In an effort to determine potential sources of aggregates, this study was authorized to explore the feasibility of utilizing artificial aggregates in highway construction. The study involved a survey of various industries regarding their production of potential aggregates, particularly as by-products. Inquiries were made of such users as highway departments as to desirable characteristics for aggregates. Consideration was given to the production of synthetic aggregates by nuclear or other new techniques.

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

NCHRP Report 8, "Synthetic Aggregates for Highway Construction."

**Project 4-5** FY '63**A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture**

*Research Agency:* Michigan Technological University  
*Principal Invest.:* Dr. W. M. Haas  
*Effective Date:* February 15, 1963  
*Completion Date:* August 31, 1965  
*Funds:* \$64,105

This project involved an extension of present knowledge and understanding of the phenomena of the action of frost and moisture in bases and subbases. Initially, laboratory models were developed which incorporated significant variables as an aid in analyzing the mechanism of frost action and its relation to strength. Hypotheses evolving from the laboratory were checked in the field.

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

**Project 4-6** FY '65**Protective Coatings for Highway Structural Steel**

*Research Agency:* Steel Structures Painting Council  
*Principal Invest.:* John D. Keane  
*Effective Date:* March 1, 1965  
*Completion Date:* November 30, 1966  
*Funds:* \$25,000

Considerable information exists in the literature concerning the protection of structural steel from corrosion. This, however, is widely scattered, often contradictory, and has never been critically reviewed and reported on as to which of the numerous coating formulations, coating systems, and practices are best in conjunction with environmental differences. This research involved a state-of-the-art review, field exposure testing on which definitive rankings may be based, and the development of plans for research to acquire needed information where adequate coatings are not available.

Information necessary to review, summarize, and evaluate the current state of the art of protection of structural steel was secured from a search of some 2,000 pieces of technical literature and by correspondence and discussions with numerous individuals, organizations, and societies both in the United States and abroad. A parallel experimental study was conducted to determine the effects of surface preparation on the performance of coatings.

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

NCHRP Report 74, "Protective Coatings for Highway Structural Steel."

In addition, the following documents have been published in extremely limited quantities:

NCHRP Report 74A, "Protective Coatings for Highway Structural Steel—Literature Survey."

NCHRP Report 74B, "Protective Coatings for Highway Structural Steel—Current Highway Practices."

**Project 4-7** FY '68, '69**Fatigue Strength of High-Yield Reinforcing Bars**

*Research Agency:* Portland Cement Association  
*Principal Invest.:* Dr. John M. Hanson  
 Dr. Thorsteinn Helgason  
*Effective Date:* Oct. 1, 1967 Feb. 1, 1971  
*Completion Date:* Feb. 28, 1970 Aug. 31, 1973  
*Funds:* \$100,000 \$50,000

The 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 (generally Grades 60 and 75) to support realistic design criteria. This was approached through the design and execution of a statistically valid experiment.

Phase I experimental work consisted of repeated-load tests on rectangular and T-shaped concrete beams reinforced with a single longitudinal bar. These specimens contained bars ranging in size from No. 5 to No. 11 and having nominal yield stresses from 40 to 75 ksi. Major emphasis in the Phase I study was on stress range, minimum stress, bar diameter, type of specimen, and grade of bar.

Phase II had the objectives of (1) determining the effect of surface geometry (deformation pattern and details) and (2) incorporating the results of Phases I and II into a single final report. A total of 353 fatigue tests was conducted in the two phases of work.

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

Research has been completed and the project report published as:

NCHRP Report 164, "Fatigue Strength of High-Yield Reinforcing Bars."

**Project 4-8** FY '68**Research Needs Relating to Performance of Aggregates in Highway Construction**

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

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

aggregates where necessary to make them acceptable for a particular use, and (3) adapting construction practices to permit use of available aggregates.

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

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

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

#### **Project 4-8(2) FY '71**

##### **Density Standards for Field Compaction of Granular Bases and Subbases**

*Research Agency:* Clemson University  
*Principal Invest.:* J. P. Rostron  
*Effective Date:* April 1, 1971  
*Completion Date:* June 30, 1973  
*Funds:* \$95,248

Information is needed on the degree of compaction that should be attained during the construction of highway granular base and subbase courses as a function of such factors as nature of the material, environment, traffic, subgrade conditions, thickness of layer, and location of layer within the system. Density standards that provide for these factors are needed. Test procedures used to develop data to set such standards must be suitable for various materials, however they may be used, and must account for these factors as may be appropriate. Often the so-called "degree of compaction" (such as 95% 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 were:

1. To evaluate current and proposed procedures and criteria for the setting of density standards.
2. To illustrate examples of inadequate standards and the consequences of such inadequacy.
3. To develop new or revised procedures and criteria for more appropriate density standards.
4. To illustrate that the new or revised procedures and criteria would yield adequate density standards.
5. To draft, in a form suitable for adoption or adaptation by highway departments, proposed new or revised procedures and criteria for the setting of density standards to control compaction during the construction of granular bases and subbases.

The research included a literature review, an information survey, interviews with highway personnel, laboratory tests, and prototype tests.

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

NCHRP Report 172, "Density Standards for Field Compaction of Granular Bases and Subbases."

#### **Project 4-8(3) FY '72 and FY '76**

##### **Predicting Moisture-Induced Damage to Asphaltic Concrete**

*Research Agency:* University of Idaho  
*Principal Invest.:* Dr. Robert P. Lottman  
*Effective Date:* Sept. 1, 1971      Aug. 1, 1975  
*Completion Date:* Mar. 31, 1974      Jan. 31, 1982  
*Funds:* \$190,177      \$71,652

The loss of bond (stripping) due to the presence of moisture between the asphalt and the aggregate in asphaltic concrete is a problem in many areas of the country and is severe from the standpoint of highway pavement performance in some instances. The problem is influenced by many factors, such as asphalt characteristics, aggregate properties, mix design, construction procedures, environmental conditions, and traffic; however, field experience has indicated almost invariably that the presence of moisture in combination with the other factors is critical with regard to the loss of adhesion between the asphalt cement and the aggregate particles.

Ultimately, the aggregate properties and the asphalt cement characteristics that affect adhesion must be identified. This knowledge is basic to the development of techniques that are needed for optimizing the choice of materials or for specifying appropriate corrective measures where loss of bond is likely to be a problem. However, the accomplishment of these ultimate objectives requires fundamental studies that are time consuming and necessitate the development of test systems for correlating the findings with field performance. The objective of this project is to meet an interim need for a laboratory testing system that will quantitatively predict the ability of asphaltic concrete to resist the detrimental effects of moisture under field conditions.

Research in Phase I included sampling and laboratory testing of mixtures composed of materials from many pavements in service, some of which were experiencing moisture damage and some not. Effort was made to reproduce in the laboratory the observed response to moisture in the field. The study produced a tentatively proposed system of tests for determining the moisture susceptibility of asphaltic concrete mixtures and a detailed work plan for a field evaluation of the system. The primary research program was conducted by the University of Idaho, with assistance by Battelle-Northwest and the University of Washington.

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

The objective of the Phase II research is to provide field verification of, or suitable modifications thereto, the test system tentatively proposed under Phase I for predicting

the susceptibility of asphaltic concrete mixtures to moisture damage. Cooperative arrangements have been made with six state highway and transportation agencies and with Region 10 of the Federal Highway Administration for experimental construction, testing, and performance observations over a five-year period to evaluate the proposed test system.

Research is in progress on the Phase II program. Construction of the pavement test sections has been completed in Arizona, Colorado, Georgia, Idaho, Montana, Virginia, and FHWA Region 10. Initial cores have been taken and laboratory specimens prepared for most of the test sections. Data are being received and analyzed on a continuous basis. No findings are available at this point in the Phase II study.

#### **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. The field sampling program has been completed through the 36-month period. All seals have developed some permanent set but the seal material appeared to be in good condition. Bond was nonexistent in many cases, resulting in fine material becoming lodged between the seal and the pavement. The importance of the lubricant adhesive as an integral part of the sealing process is becoming more evident with each sampling period. The importance of extending the seals down the side of the pavement to prevent the intrusion of water is also becoming apparent.

An interim report covering the first two years of exposure has been received and reviewed. The resulting information will be incorporated in the final report.

#### **Project 4-10      FY '70**

##### **Promising Replacements for Conventional Aggregates for Highway Use**

<i>Research Agency:</i>	University of Illinois
<i>Principal Invest.:</i>	Dr. C. R. Marek
<i>Effective Date:</i>	October 15, 1969
<i>Completion Date:</i>	March 31, 1971
<i>Funds:</i>	\$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 port-

land cement concrete, bituminous mixes, and base courses.

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

NCHRP Report 135, "Promising Replacements for Conventional Aggregates for Highway Use."

**Project 4-10A** FY '70

**Waste Materials as Potential Replacements for Highway Aggregates**

*Research Agency:* Valley Forge Laboratories  
*Principal Invest.:* Richard H. Miller  
*Effective Date:* Sept. 1, 1972  
*Completion Date:* Nov. 30, 1973  
*Funds:* \$53,663

Although an abundant supply of conventional aggregates suitable for highway construction exists nationally, there are localized areas, and in some cases regions, in which aggregates are not economically available or are becoming depleted. The problem is compounded by the loss of existing sources through zoning restrictions, pollution controls, and appreciating land values.

The use of waste material as aggregate offers one method of alleviating this problem in highway construction where suitable sources are available in significant quantities. Such utilization will serve the public interest by providing ecologically and economically acceptable means for disposal of wastes in addition to providing replacements for needed aggregates in urban areas where the shortage is often most severe. Research is needed now to determine the types, sources, and quantities of waste materials potentially useful as replacements for highway aggregates.

NCHRP Project 4-10, "Promising Replacements for Conventional Aggregates for Highway Use," identified the potential for using waste materials as aggregate in highway construction. The objectives for Project 4-10A, as developed from the prior effort, were to:

1. Provide an inventory of the types, sources, and quantities of waste materials potentially suitable for the production of synthetic aggregates or for otherwise replacing conventional aggregates in highway construction.
2. Provide an assessment of the prospects for practical use of specific waste materials for production of synthetic aggregates or otherwise replacing the need for conventional aggregates in highway construction, particularly where aggregate supplies are scarce.

Accomplishment of project objectives involved:

1. Identification of all types and locations of waste materials available or anticipated to be available in the future in significant quantities that are considered potentially suitable for use in highway construction as replacements for conventional aggregates.
2. Compilation of information essential to evaluating the technical and economic feasibility of using the most promising waste materials as replacements for aggregates in highway construction.

3. Based on the information compiled in Task 2, an assessment of the technical and economic feasibility of current and future use of the waste materials having the greatest potential for use as replacements for aggregates in highway construction, particularly where conventional aggregates are not economically available or are becoming depleted.

4. Determination of the status of use of waste materials in highway construction as replacements for aggregates.

Based on technical, economic, and environmental evaluations, 30 waste materials were found to have some potential for use as highway aggregates. The basic technology was judged to exist for converting any one of the materials into aggregate, but in most instances much experimentation remains to be done.

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

NCHRP Report 166, "Waste Materials as Potential Replacements for Highway Aggregates."

**Project 4-11** FY '75

**Buried Plastic Pipe for Drainage of Transportation Facilities**

*Research Agency:* Simpson Gumpertz & Heger  
*Principal Invest.:* Frank J. Heger  
*Effective Date:* September 16, 1974  
*Completion Date:* March 15, 1978  
*Funds:* \$200,000

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

*Objectives:*

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

The specific objectives of Phase I are to:

1. Identify the types, sizes, and physical and chemical characteristics of plastic pipe products currently available and considered suitable for use as underdrains, storm sewers, culverts, and other drainage structures.
2. Based on available research and experience with buried plastic pipe: (a) evaluate the current state of the

art; (b) appraise the performance with regard to abrasion, frost action, temperature variations, and other environmental considerations; and (c) prepare tentative guidelines for recommended design and installation procedures.

3. Outline an experimental program, (intended to be performed under Phase II) to improve the understanding of (a) the time-dependent soil-structure interaction of buried plastic pipe subjected to earth and live loads and (b) any other performance factors that appear to need further study.

The specific objectives of Phase II are to:

4. Conduct the experimental program outlined in Objective 3, subject to approval by the NCHRP.

5. Analyze and interpret the information obtained from the experimental program, synthesize the data with other available information, and evaluate the tentative guidelines prepared under Objective 2.

6. As part of the final report, prepare a manual on the use of buried plastic pipe for drainage of transportation facilities, with particular attention to permissible loads and deflections, use limitations, material specifications, acceptance tests, construction and maintenance techniques, and inspection criteria.

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

Research is in progress on Phase II of the study. Several types of plastic pipe have been installed in Maine and New Hampshire under various bedding and loading conditions. Cover over the pipe varies from 2 ft to 22 ft. Several sections of pipe are instrumented with strain gauges. Deflections are being measured. Some pipe sections will be removed for physical testing and others will remain in place permanently. Recommended specifications for use of plastic pipe under transportation facilities are being prepared for consideration by AASHTO and ASTM.

#### Project 4-12 FY '77

##### Upgrading of Poor or Marginal Aggregates For PCC and Bituminous Pavements

*Research Agency:* The Pennsylvania State University  
*Principal Invest.:* Dr. Philip D. Cady  
*Effective Date:* December 1, 1976  
*Completion Date:* February 28, 1979  
*Funds:* \$150,000

The performance of high-type pavements, of either PCC or bituminous concrete, is influenced by many factors. Some of these are materials, environment, traffic loading, construction practices, and maintenance. One of the most important factors in the satisfactory performance of a pavement is the incorporation of coarse aggregate consisting of sound, durable particles free from objectionable coatings. The rapid depletion or inaccessibility of such high-quality aggregates requires that methods be devised for upgrading poor or marginal materials.

The over-all objective of this study is to advance methods of upgrading poor or marginal-quality coarse aggregates to acceptable durability and structural levels for use in high-type bituminous and PCC pavement mixtures. The procedures for upgrading aggregates in this study are limited to the use of different types of coatings, chemical treatments, or impregnation with plastics or other materials.

The beneficiation will address recognized problems such as free-thaw damage, stripping, degradation, inadequate soundness, alkali-aggregate reactions, destructive volume changes, and objectionable coatings. In addition, but of secondary importance, the economic feasibility of blending satisfactorily coated or impregnated aggregates with untreated aggregates will be considered.

This study does not address itself to pavement surface characteristics, such as skid properties, texture and roughness, or mixtures applied as seal coats or thin surface treatments.

The research will include the following tasks:

Task 1. (a) Identification of aggregate problems that may be mitigated by beneficiation.

(b) Review of literature and research in progress.

(c) Identification of current and potentially available practices and methods for upgrading aggregate quality.

Task 2. Preliminary analysis of practices and methods.

Task 3. Preparation of an interim report that includes the findings from Tasks 1 and 2 and provides recommendations for the evaluation in Task 4 of procedures that appear to be technically and economically feasible.

Task 4. Laboratory development and evaluation of candidate procedures with selected aggregates.

Task 5. Preparation of a final report that includes findings of research and recommendations for possible field evaluation (i.e., pilot study) of selected procedures.

Through December 31, 1976, efforts have been directed at the completion of Task 1.

#### Project 4-13 FY '77

##### Temporary Pavement Marking Systems

*Research Agency:* Southwest Research Institute  
*Principal Invest.:* John M. Dale  
*Effective Date:* November 1, 1976  
*Completion Date:* February 28, 1978  
*Funds:* \$49,500

Maintenance and construction operations on all classes of highways frequently require temporary pavement markings to provide motorist guidance and safe traffic movement. When existing pavement marking materials, devices, and techniques are used for this purpose, they are difficult to remove in a cost-effective manner without leaving scars on the pavement that may mislead the motorist. There remains a continuing need, for all types of pavement surfaces under all environmental and traffic conditions, for a temporary pavement marking system. Temporary marking systems are defined as those either easily applied and easily

removed or those easily applied and self-destructible under controlled conditions.

The general objective of this research is to explore the feasibility of one or more candidate solutions by awarding one or more contracts within the limits of available funds. The specific objectives are: (1) To examine one or more concepts, existing or new, that offer promise for development into workable temporary pavement marking systems. The desired characteristics of these systems include delineation quality, ease of installation and removal, absence of adverse environmental effects, ease of implementation, and cost-effectiveness. (2) To analyze the feasibility of the concept or concepts in comparison with existing practice with reference to, but not limited to: (a) manpower, equipment, and material costs (application and removal), (b) effect on traffic during application and removal, (c) traffic control effectiveness, (d) system durability, (e) material and process availability, and (f) hazards to workmen during application and removal.

The analysis will include field testing of promising systems, guided by case and laboratory studies, to the extent that project resources permit.

## AREA 5: ILLUMINATION AND VISIBILITY

### Project 5-2(1) FY '63

#### Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents

*Research Agency:* Yale University,  
Bureau of Highway Traffic

*Principal Invest.:* Fred W. Hurd

*Effective Date:* Feb. 15, 1963      Feb. 1, 1967

*Completion Date:* May 31, 1966      July 31, 1967

*Funds:* \$124,319      \$21,530

Because of insufficient information on the requirements in freeway illumination, thorough research needs to be performed. A scientific basis for warrants and design criteria for use in installing continuous and localized lighting on freeways is needed, as is evaluation in terms of benefits and costs.

A 5-mile segment of the Connecticut Turnpike in the Bridgeport area was selected for the study site. The light intensity was changed to reflect illumination at both the 0.2 and 0.6 average horizontal footcandle levels. The same study area has been used for Projects 5-2(2) and 5-2(3).

Yale University has evaluated the day and night operating characteristics of traffic flow, driver behavior, and accidents. Traffic characteristic data from more than 400,000 picture frames were transferred to punched cards, and analyzed by an electronic computer. Information was obtained on lane use, variation of placement and velocity, headway distributions, vehicle clustering by type, and use of the on-ramp. Evaluations of day and night accident data and traffic volume data have been made.

The project report has been published as:

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

### Project 5-2(2) FY '63

#### Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort

*Research Agency:* The Ohio State University

*Principal Invest.:* Dr. Thomas H. Rockwell  
Dr. H. Richard Blackwell

*Effective Date:* February 15, 1963

*Completion Date:* August 31, 1965

*Funds:* \$81,187

The objectives of this research supplemented Project 5-2(1), the accent in this contract being on the characteristics of driver response, visibility, and visual discomfort.

In conducting its research, Ohio State made interdisciplinary personnel and resources available. The instrumented vehicle utilized in Project 3-3 was also used in this project, as were various types of lighting and optical instruments developed by The Ohio State University. This project was coordinated with Project 5-2(1) for the phases of the work that were conducted on the Connecticut Turnpike site.

The driver response and roadway luminance data were transformed from the oscillograph record from the survey vehicle to numerical records for the studies conducted on the Connecticut Turnpike. Analytical procedures were prepared to provide a cross-correlation of driver control activity with roadway geometry, traffic density, subject characteristics, and illumination levels. The analysis tested the correlation of driver variables with the severity of disability glare, and studies were conducted to see if any change in the visual environment was effected by the light intensity change.

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

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

### Project 5-2(3) FY '63

#### Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort

*Research Agency:* The Institute for Research at  
State College, Pennsylvania

*Principal Invest.:* Dr. Paul M. Hurst

*Effective Date:* February 20, 1963

*Completion Date:* February 28, 1966

*Funds:* \$37,460

As with Project 5-2(2), this research complemented that of Project 5-2(1). This study was concerned with only one aspect, that of driver comfort as related to anxiety as measured under various lighting conditions. The Institute for Research, a private research agency located at State College, Pennsylvania, obtained research data from motorists driving through the test area of the Connecticut Turnpike. Driver-questionnaire information was used to determine apprehension based on a numerical score and also to locate

those events related to illumination which appeared to be most vexing to drivers.

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

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

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

### Project 5-3 FY '64

#### Visual Information Needed by the Driver at Night

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

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

The project report has been published as:

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

### Project 5-4 FY '64

#### Economic Study of Roadway Lighting

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

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

The researchers collected data for economic comparisons, including costs for hardware, installation, useful operating life, power, maintenance, depreciation, taxes,

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

The project report has been published as:

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

### Project 5-5 FY '65

#### Nighttime Use of Highway Pavement Delineation Materials

*Research Agency:* Southwest Research Institute  
*Principal Invest.:* John M. Dale  
*Effective Date:* Mar. 1, 1965      July 15, 1967  
*Completion Date:* Dec. 31, 1966      Sept. 15, 1969  
*Funds:* \$50,000      \$100,000

In this study, ways of improving delineation of roadways under wet and dry conditions by either improving techniques utilizing existing materials or developing new materials and techniques were investigated.

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

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

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

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

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

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

In addition to the final report, a motion picture film 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. The final report has been submitted but will not be published in the NCHRP Report series. A summary of the final report is presented in "Summary of Progress Through 1976."

**Project 5-5B** FY '72**Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing is Prevalent**

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Dr. William M. Moore  
*Effective Date:* September 1, 1971  
*Completion Date:* December 31, 1974  
*Funds:* \$200,000

Conventional reflectorized pavement marking systems in common use lose their effectiveness markedly during periods of darkness in rainy weather. Raised reflectorized markers are quite effective under such circumstances and

are in use where exposure to snowplows is not a factor. However, such markers may be quickly dislodged or destroyed in a large part of the U. S. where snowplowing is common during the winter months.

Accordingly, the objectives of this research were:

1. Develop one or more innovative concepts for pavement marking systems that are practical, economical, and effective under nighttime wet-pavement conditions and compatible with snowplowing.

2. Conduct a laboratory and controlled field evaluation of the system(s) developed in objective 1 and demonstrate its (their) practical and economic feasibility.

Interim reports submitted in September 1972 and October 1973 described the development and testing of the "first generation" markers and the development of the "second generation" markers modified in accordance with the findings from the first winter field tests. The second generation marking systems were tested at sites in Colorado, New York, Pennsylvania, Virginia, and Texas.

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

**Project 5-6** FY '68**Highway Fog**

*Research Agency:* Cornell Aeronautical Laboratory  
*Principal Invest.:* W. C. Kocmond  
 K. Perchonok  
*Effective Date:* October 2, 1967  
*Completion Date:* April 30, 1969  
*Funds:* \$99,955

The objectives of this research were: (1) to review past and current research of warm and cold fog as it affects highway operation; (2) to prepare a state-of-the-art summary of the review to include, but not be limited to, fog abatement, guidance systems, measures of visibility, and effect on traffic operations; (3) to determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations; (4) to explore the feasibility of warm and cold fog abatement and vehicular guidance systems under highway conditions; and (5) to suggest ways and means of obtaining maximum effectiveness of systems to combat reduced visibility due to fog.

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

NCHRP Report 95, "Highway Fog."

**Project 5-6A** FY '70**Highway Fog**

*Research Agency:* Sperry Rand Corporation  
*Principal Invest.:* James O. Dyal  
 Richard T. Brown  
 William H. Heiss

*Effective Date:* September 1, 1970  
*Completion Date:* May 31, 1973  
*Funds:* \$93,540

This research was a continuation of NCHRP research in the general area of highway fog. The major objectives of the research were to:

1. Analyze the highway fog problem and determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations.
2. Explore the feasibility of active and passive guidance systems for freeways and expressways that will inform and warn the motorist of prevailing roadway fog and traffic conditions ahead, and guide and control traffic more safely and conveniently through the fog area.

The research was addressed principally to the first objective and developed a measurable fog visibility index and related this index to potential actions that can be taken to eliminate or minimize the detrimental effects of fog.

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

NCHRP Report 171, "Highway Fog Visibility Measures and Guidance Systems."

#### **Project 5-7 FY '69**

##### **Roadway Delineation Systems**

*Research Agency:* The Pennsylvania State University  
*Principal Invest.:* Dr. J. I. Taylor  
*Effective Date:* October 1, 1968  
*Completion Date:* June 30, 1971  
*Funds:* \$469,526

Vehicles running off the road constitute a substantial portion of the accidents on the nation's highways. Improved pavement and roadway delineation treatments may aid drivers in controlling their vehicles, thus improving the safety aspects of the highway and easing the driving task, especially during adverse weather conditions and at night.

Accordingly, the objectives of this research were: (1) to review past and current research pertaining to roadway delineation; (2) to prepare a state-of-the-art summary of the review; (3) to determine the driver's delineation requirements during various conditions, such as traffic, weather, highway geometry, and illumination; (4) to establish rational technique(s) for determining the effectiveness and any detrimental side effects of delineation treatments and, using the technique(s) established, evaluate existing and proposed delineation systems; (5) to test the more promising delineation systems; (6) to develop practical criteria for the selection of delineation treatments, including factors of cost effectiveness and maintenance problems; and (7) to compare the physical characteristics and performance of colored pavements with those of conventional asphalt and portland cement pavements.

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

NCHRP Report 130, "Roadway Delineation Systems."

#### **Project 5-8 FY '70**

##### **Warrants for Highway Lighting**

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Neilon J. Rowan  
 Ned Walton  
*Effective Date:* March 16, 1970  
*Completion Date:* February 15, 1973  
*Funds:* \$199,627

A need existed to establish warrants for fixed roadway lighting on the various classes of roadways in both urban and rural areas; to determine whether the lighting should be continuous or just at specific locations; and to prepare guidelines for the design of lighting. Benefits from fixed-source roadway illumination, including driver performance, comfort, convenience and accident prevention, have needed evaluation.

Warrants for fixed lighting on specific roadway classes and at local highway situations should include consideration of benefits and costs of lighting (initial and operating) to satisfy the visual requirements of the driver. A method or methods of evaluating costs and benefits of roadway lighting to maximize returns on the investment should be developed for the designer in order to determine the specific design.

The specific objectives of this project were to:

1. Review and analyze world-wide research and practice in roadway lighting. Prepare a state-of-the-art summary of the review.
2. Develop requirements for a suitable visual environment to be obtained by fixed roadway lighting for safe and efficient traffic operations. Provide guidelines for the design of fixed roadway lighting to obtain this environment.
3. Evaluate the possible benefits derived when a suitable visual environment is provided by fixed roadway lighting.
4. Determine warrants (the minimum conditions) for where fixed roadway lighting systems should be installed for continuous lighting and at specific locations including, but not limited to, interchanges and intersections.
5. Analyze the role of cost-effectiveness and other evaluation techniques in (a) establishing the need for fixed roadway lighting, (b) setting priorities for fixed lighting projects, and (c) evaluating alternative designs of lighting.
6. Recommend a method of setting priorities for the installation of fixed lighting.
7. Provide typical example(s) of where lighting is warranted and demonstrate the practical application of objectives 1 through 6.

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

NCHRP Report 152, "Warrants for Highway Lighting."

## AREA 6: SNOW AND ICE CONTROL

### Project 6-1 FY '63

#### Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles

*Research Agency:* IIT Research Institute  
*Principal Invest.:* D. B. Boies  
*Effective Date:* February 15, 1963  
*Completion Date:* September 30, 1964  
*Funds:* \$40,000

Research was directed to the development of chemical agents that are not only economical and effective when used as deicing agents but also have minimal harmful effects on metals and concrete. Consideration was given to the relatedness of laboratory tests to field conditions.

The project report has been published as:

NCHRP Report 19, "Economical and Effective Deicing Agents for Use on Highway Structures."

### Project 6-2 FY '63

#### Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures

*Research Agency:* Roy Jorgensen and Associates  
*Principal Invest.:* R. E. Jorgensen  
 R. D. Johnson  
*Effective Date:* February 15, 1963  
*Completion Date:* February 29, 1964  
*Funds:* \$25,000

This study was primarily one of searching the literature and appraising the current status of knowledge of the subject. In addition to a literature survey, contacts were made with highway departments and other agencies that have been confronted with the problem. Designs for structure heating systems as used in the U.S. and other countries have been evaluated, as have other nonchemical methods. The researchers have included in their studies the effectiveness of nonchemical methods and economic losses due to structure deterioration.

The project report has been published as:

NCHRP Report 4, "Non-Chemical Methods of Snow and Ice Control on Highway Structures."

### Project 6-3 FY '63

#### Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents

*Research Agency:* Battelle Memorial Institute  
*Principal Invest.:* M. J. Snyder  
*Effective Date:* March 1, 1963  
*Completion Date:* February 28, 1965  
*Funds:* \$58,557

Investigations on this project were oriented toward developing new and evaluating existing materials to be applied to concrete surfaces to inhibit concrete deteriorations from deicing agents. Consideration was given to fresh as well as hardened concrete.

The project report has been published as:

NCHRP Report 16, "Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals."

### Project 6-4 FY '63

#### Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel

*Research Agency:* Battelle Memorial Institute  
*Principal Invest.:* A. B. Tripler, Jr.  
*Effective Date:* March 1, 1963  
*Completion Date:* April 30, 1965  
*Funds:* \$39,330

Research investigations for this project related to an appraisal of existing methods for inhibiting corrosion of reinforcing steel in concrete. Consideration was given to such methods as (1) coatings on reinforcing bars, (2) inhibitors in concrete mixtures, (3) inhibitors in deicing chemicals, and (4) cathodic protection.

The project report has been published as:

NCHRP Report 23, "Methods for Reducing Corrosion of Reinforcing Steel."

### Project 6-5 FY '63

#### Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents

*Research Agency:* University of Illinois  
*Principal Invest.:* Prof. C. E. Kesler  
*Effective Date:* March 1, 1963  
*Completion Date:* August 31, 1965  
*Funds:* \$72,500

This research concerned the relationships between the physical characteristics of concrete and the susceptibility of concrete to damage from freezing and thawing in the presence of free moisture and deicing agents. Studies were made of the effects of varying concrete production methods on potentially durable concrete. Variations in the surface porosity, strength, and air-void system produced by differing finishing techniques were evaluated for typical air-entrained concretes. Large- and small-scale specimens were cast and effects of period and time of finishing, environmental conditions, and additions of water during finishing were evaluated using surface scaling tests, surface tensile strength tests, and microscopical determination of surface air-void parameters.

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

NCHRP Report 27, "Physical Factors Influencing Resistance of Concrete to Deicing Agents."

**Project 6-6** FY '63**To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete**

*Research Agency:* The Ohio State University  
*Principal Invest.:* Prof. R. W. Bletzacker  
*Effective Date:* March 1, 1963  
*Completion Date:* February 28, 1966  
*Funds:* \$69,393

In order to insure that finished concrete will conform to those specifications selected to produce adequate resistance to deicing agents, this study was initiated to evaluate and/or develop methods for securing pertinent quality control information at the earliest desirable or feasible age in order that any necessary corrective measures can be applied to the work in progress. Specifically, the study concerned the factors of (1) air content and uniformity of distribution, (2) cement content and uniformity of distribution, (3) water content and uniformity of distribution, and (4) thickness of cover over reinforcement.

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

**Project 6-7** FY '63**Estimation of Disintegration in Concrete Structures**

*Research Agency:* Geotechnics  
*Principal Invest.:* Floyd O. Slate  
*Effective Date:* March 1, 1963  
*Completion Date:* August 31, 1964  
*Funds:* \$8,547

This study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

The contract was terminated with no project report. Research was resumed under Project 6-7A.

**Project 6-7A** FY '63**Estimation of Disintegration in Concrete Structures**

*Research Agency:* IIT Research Institute  
*Principal Invest.:* Dr. W. J. McGonnagle  
*Effective Date:* February 1, 1965  
*Completion Date:* July 31, 1966  
*Funds:* \$44,614

This research study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

Research has been completed. The project report will

not be published in the regular NCHRP report series, but a summary is included in the *NCHRP Summary of Progress to June 30, 1967*.

**Project 6-8** FY '63**Evaluation of Methods of Replacement of Deteriorated Concrete in Structures**

*Research Agency:* Bertram D. Tallamy Associates  
*Principal Invest.:* Dr. B. D. Tallamy  
*Effective Date:* February 15, 1963  
*Completion Date:* February 29, 1964  
*Funds:* \$25,000

This study was directed toward a search of available literature and a canvass of agencies that have been known to employ methods of repair of structural concrete. The researchers attempted an evaluation of the economics and adequacy of the various methods to accomplish the job. Recommendations were made of areas requiring further study.

The project report has been published as:

NCHRP Report 1, "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures."

**Project 6-9** FY '64**Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks**

*Research Agency:* University of Illinois  
*Principal Invest.:* Prof. Clyde E. Kesler  
*Effective Date:* January 1, 1965  
*Completion Date:* June 15, 1968  
*Funds:* \$200,000

Some present bridge designs allow a degree of flexibility, which, under traffic and other environmental forces, may cause cracking and opening of existing cracks. This of itself may be structurally unimportant, but in the presence of deicing chemicals may contribute to corrosion of the reinforcing and spalling of the concrete by providing access channels for the corrosive agents. Stresses induced by traffic may augment those of frost action sufficiently to cause scaling in cases where a satisfactory performance would otherwise be expected. The objectives of this research were to establish by laboratory studies the relationships between performance and displacement in bridge-deck slabs. Air-entrained reinforced concrete deck slabs with restraints similar to those experienced by slabs on structural steel and reinforced concrete beam-type bridges were investigated, and tests were conducted on replicas of actual bridge-deck slabs. Loading and environmental conditions in these tests simulated those encountered in the field.

The final report has been published as:

NCHRP Report 101, "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks."

**Project 6-10** FY '68 and FY '69**Develop Improved Snow Removal and Ice Control Techniques at Interchanges**

*Research Agency:* Bertram D. Tallamy Associates  
*Principal Invest.:* L. G. Byrd  
*Effective Date:* September 1, 1967  
*Completion Date:* September 30, 1970  
*Funds:* \$95,000

The variety of geometrical shapes of interchange ramps, with associated structures, and their urban or rural locations invariably creates problems with respect to optimum snow removal and ice control techniques in the interchange areas. Furthermore, alternate freezing and thawing of plowed or unplowed snow across superelevated ramps contributes to problems in snow and ice control. Drifting may further aggravate this problem. Improved snow removal and ice control techniques in interchange areas are vital to the safety of highway traffic.

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

The project report has been published as:

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

**Project 6-11** FY '71**Economic Evaluation of the Effects of Ice and Frost on Bridge Decks**

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

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

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

**AREA 7: TRAFFIC PLANNING****Project 7-1** FY '64 and FY '65**The Influence of Land Use on Urban Travel Patterns**

*Research Agency:* Louis E. Keefer  
*Principal Invest.:* Louis E. Keefer  
                                  David K. Witheford  
*Effective Date:* Feb. 1, 1964      Apr. 1, 1966  
*Completion Date:* Jan. 31, 1966      Sept. 30, 1967  
*Funds:* \$62,674      \$66,894

This project sought to determine the criteria or values concerning travel patterns created by major traffic generators. Such information is useful in forecasting the effect of various land uses on street networks and in providing a better basis for facility design, as well as for the control of various land uses. The nature or relationship between travel patterns and influencing factors (i.e., travel time, traffic generator characteristics such as location, size, type and intensity of land use, modes of travel, and other pertinent variables) were evaluated.

A report on the initial research has been published as:

NCHRP Report 24, "Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants."

Origin and destination data for 12 commercial airports, 28 shopping centers, and 51 industrial plants from various cities in the United States were used in the analysis.

A report on the continuing phase of the research has been published as:

NCHRP Report 62, "Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols."

This report presents trip characteristics for four specific uses of land. The travel information on hospitals has been derived from the study of data for 77 hospitals located in 16 different metropolitan areas. The findings for college and university travel were developed from 38 institutions located in 16 metropolitan areas. Travel patterns for six state capitol complexes are presented. The trip characteristics for 20 office buildings located in 9 cities comprise the fourth type of land use studied and reported in the continuation research phase.

**Project 7-2** FY '64 and FY '65

**Traffic Attraction of Rural Outdoor Recreational Areas**

*Research Agency:* IIT Research Institute  
*Principal Invest.:* Andrew Ungar  
*Effective Date:* Feb. 1, 1964      May 1, 1965  
*Completion Date:* Mar. 15, 1965      May 31, 1966  
*Funds:* \$24,652      \$24,844

This research was concerned with determining the traffic attraction and generation of rural outdoor recreational areas, such as those created in many places by the creation of artificial lakes. Knowledge of the traffic patterns generated by such recreational areas would enable rational planning of highway access and parking facilities.

The final report evaluates the attractiveness characteristics and location of 18 Indiana state parks and compares the results to a similar study of reservoir recreational areas in Kansas. A predictive model suitable for application to the planning of new recreational areas is described utilizing trip distribution, a socio-economic activity index of the contributing area, and an estimate of the attractiveness based on the facilities to be provided.

The project report has been published as:

NCHRP Report 44 "Traffic Attraction of Rural Outdoor Recreational Areas."

**Project 7-3** FY '64 and FY '65

**Weighing Vehicles in Motion**

*Research Agency:* The Franklin Institute  
*Principal Invest.:* R. Clyde Herrick  
*Effective Date:* February 1, 1964  
*Completion Date:* August 31, 1967  
*Funds:* \$73,391

The purpose of this research was to develop new or improved methodology for weighing vehicles in motion with review and study of existing or new equipment. The ultimate aim was to obtain load magnitudes automatically in a way similar to obtaining traffic volumes by traffic counters.

Franklin Institute's approach to this problem served to complement the studies performed by others rather than to duplicate existing research. The data processing system in block form only was developed on the project. It was planned that no full-scale or field testing would be performed under this contract. Study was primarily given to

methods that will allow static weights of the axle to be calculated from a limited number of dynamic load observations.

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

The project report has been published as:

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

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

**Factors and Trends in Trip Lengths**

*Research Agency:* Alan M. Voorhees & Associates  
*Principal Invest.:* Alan M. Voorhees  
 Salvatore Bellomo  
*Effective Date:* Feb. 1, 1964      Oct. 23, 1967  
*Completion Date:* Oct. 31, 1966      Jan. 10, 1969  
*Funds:* \$89,250      \$61,730

This research involved the establishment of the characteristics of trends in trip lengths. Knowledge of such trends is needed to determine future urban travel demands. It was expected that characteristics of trip lengths will be influenced by factors such as trip purpose, level of service, size and spatial characteristics of urban areas, socioeconomic characteristics, and trip-generating activity location.

The results of the first two years of this research have been published as:

NCHRP Report 48, "Factors and Trends in Trip Length."

This report provides empirical and theoretical analyses from data collected from several transportation studies. Trip length guidelines have been developed to provide transportation planners with tests of reasonableness for travel forecasts.

The project was continued to enable the study of trip length in subareas within metropolitan areas. The objectives of the second phase were to establish various relationships to assist planners in minimizing trip length on a subarea basis, and to provide guidelines for checking metropolitan trip length forecasts.

Data were collected for analysis from the two separate origin-and-destination studies conducted in each of the following cities: Detroit, Mich. (1953 and 1965); Sioux City, Iowa (1955 and 1965); Reading, Pa. (1958 and 1964).

The final report provides results of hypotheses formulated and tested to state the relationship over time between trip length and influencing factors. Simulation studies are reported of home-based work-trip analyses for certain hypothetical urban forms and transportation systems.

The results of the continuation phase of the project have been published as:

NCHRP Report 89, "Factors, Trends, and Guidelines Related to Trip Length."

**Project 7-5** FY '64 and FY '65**Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage**

*Research Agency:* Yale University,  
Bureau of Highway Traffic  
*Principal Invest.:* M. J. Huber  
H. B. Boutwell  
*Effective Date:* February 1, 1964  
*Completion Date:* November 30, 1966  
*Funds:* \$99,675

This project involved the development of better methods for forecasting and assignment of traffic. Various methods in current use were investigated. Methods were developed to determine the effects a new facility has on the traffic pattern of existing facilities. A major emphasis of the research was to determine the accuracy of the predicted use as compared to the actual use of highway facility.

The project report describes various electronic computer traffic assignment methods with test results compared to actual survey data obtained along the Connecticut River. Pittsburgh Area Transportation Study data and network assignments were obtained to study several forecasts made 15 to 20 years ago.

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

The project report has been published as:

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

**Project 7-6** FY '66**Multiple Use of Lands Within Highway Rights-of-Way**

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

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

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

The project report has been published as:

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

**Project 7-7** FY '66**Motorists' Needs and Services on Interstate Highways**

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

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

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

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

The project report has been published as:

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

**Project 7-8** FY '71**User Cost and Related Consequences of Alternative Levels of Highway Service**

*Research Agency:* Stanford Research Institute  
*Principal Invest.:* David A. Curry  
*Effective Date:* September 1, 1970  
*Completion Date:* April 15, 1972  
*Funds:* \$99,070

Techniques for conducting comprehensive economic analyses of planned highway projects can be slow and cumbersome. In view of the evolving nature of the highway planning process, a need exists for an economic analysis supplement to the *Highway Capacity Manual* utilizing the manual's definitions of highway types, levels of highway service, and other key concepts. The *Highway Capacity Manual* describes six levels of service for each of five types of highway facilities and provides detailed procedures for determining levels of service under various conditions. At present, however, these levels of service

have not been quantified with respect to user costs and related consequences.

The objectives of this project were to evaluate data related to user costs on various highway facilities under different levels of service, volumes, and other conditions, and to develop a methodology that will relate these variables to user costs. Through the means of sensitivity analyses, highway design and situation variables were identified that have major impact on output variables that can be of use to highway decision-makers.

Motor vehicle running cost data were compiled and updated for use in calculating relative road user costs at different levels of highway service and as affected by details of geometric design and traffic performance. By use of Appendix A of the *Highway Capacity Manual*, relationships were derived for peak-hour volume per lane in conjunction with AADT per lane pair. Queuing was analyzed based on the shock-wave method for uninterrupted flow and the deterministic method for interrupted flow. A methodology for estimating vehicle emissions was developed based on a "typical" vehicle configuration.

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

NCHRP Report 133, "Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects."

#### Project 7-9 FY '73

##### Development of Models for Predicting Weekend Recreational Traffic

*Research Agency:* Midwest Research Institute  
*Principal Invest.:* Walter R. Benson  
*Effective Date:* September 1, 1972  
*Completion Date:* May 15, 1974  
*Funds:* \$74,983

Traffic congestion occurs frequently on weekends at the fringes of urban areas as well as at recreation sites. For a number of highways serving recreational travel, it has been found that the peak hours of the year are concentrated on weekends. This weekend dilemma is of increasing concern to highway officials particularly, because it is expected to increase with increasing personal income and work-free time. Urban transportation studies, charged with forecasting future travel patterns, have excluded weekend travel.

The objective of this research was to develop techniques for the prediction of weekend recreational traffic capable of responding to changes in recreation demand, recreation supply, and transportation supply.

The principal development was a computer program RTPM (Recreational Traffic Prediction Model). RTPM operates in conjunction with the Urban Planning Battery in a three-stage process as follows:

1. Urban Planning Battery programs are employed to create a highway network representing the primary roads in an area selected for study and to determine travel times between all zones in the network.

2. RTPM generates a trip file consisting of all origin-destination weekend recreational travel for which either

the origin or the destination point is within the area selected.

3. These trips, within a user-specified time-of-weekend period, are loaded onto the highway network by Urban Planning Battery programs to provide estimates of traffic on any one or more individual highway segments.

The research has been completed and a summary of the major findings is included in the NCHRP "Summary of Progress Through 1976."

#### Project 7-10 FY '74 and FY '75

##### Peak-Period Traffic Congestion

*Research Agency:* Remak-Rosenbloom  
*Principal Invest.:* Sandra Rosenbloom  
 Roberta Remak  
*Effective Date:* Apr. 1, 1974  
*Completion Date:* Mar. 31, 1975  
*Funds:* \$49,624

Peak-period traffic congestion in urban areas is a critical transportation problem. Congestion is due primarily to the inability of transportation systems to meet concentrated spatial and temporal travel demands. The continued building of capital-intensive systems to effect solutions is often controversial in light of economic, social, and environmental impacts. Research was needed to evaluate the full range of possible options to improve peak-period efficiency of transportation systems in large and small urban areas.

The objectives of this project were to (1) conduct a state-of-the-art survey to identify methods currently used or envisioned to alleviate the problem, (2) evaluate methods to ameliorate peak-period traffic congestion and to combine promising mutually supportive approaches into packages, and (3) develop research problem statements in the areas of institutional, energy, and social impacts associated with potentially effective congestion reduction packages.

Techniques to ameliorate peak-period traffic congestion were classified as social, socioeconomic, sociotechnical, and technical. They have been summarized in a state-of-the-art report. Experience with each technique has been described under the following categories: concepts, costs, time frame, funding source, political feasibility, and impact.

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

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

Two reports describe the findings from this project. Volume I, entitled "Peak-Period Traffic Congestion: State of the Art and Recommended Research," is available either on loan from the NCHRP Program Director or by pur-



chase from Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Mich., 48106. Volume 2, entitled "Peak-Period Traffic Congestion—Options for Current Programs," has been published as:

NCHRP Report 169, "Peak-Period Traffic Congestion—Options for Current Programs."

Research is continuing as described in NCHRP Project 7-10(2).

**7-10(2)** FY '75

### The Institutional Aspects of Implementing Congestion-Reducing Techniques

*Research Agency:* Remak-Rosenbloom  
*Principal Invest.:* Roberta Remak  
 Sandra Rosenbloom  
*Effective Date:* April 1, 1975  
*Completion Date:* September 15, 1977  
*Funds:* \$68,903

Project 7-10(2) is a study of the institutional aspects of the congestion-reducing techniques and packages of techniques identified in Project 7-10. To implement the techniques and/or packages, all institutional factors need to be known, especially those that can help and those that can hinder.

The general objective of Project 7-10(2) is to develop strategies for assuring that congestion-reduction packages are considered rationally within today's institutional framework.

Specific objectives are:

1. To identify and evaluate the institutional factors that appear to be significant in implementing congestion-reducing techniques and packages. Research will include, but not be limited to, synthesizing the information and observations from case studies involved in implementing any of the individual techniques and combination packages identified in NCHRP Project 7-10. These institutional aspects will include economic costs and impacts, politics, vested interests, jurisdiction constraints, and funding sources.

2. To recommend appropriate strategies for implementation of congestion-reducing techniques and packages. Development of an appropriate implementation strategy for each technique and package will include identification of sponsor(s), extent of government involvement, extent of private sector involvement, funding source(s), and specific potential institutional barriers to implementation. Specific efforts will be made to identify particular categories of interest groups, specify barriers to implementation, specify factors to encourage implementation, determine the degree of applicability (i.e., local or national), determine the perception of interest groups to the technique/packages, identify specific aspects of institutional coordination, and identify reasons for a resistance to change.

Research is in progress. Initially, resources were utilized to advance and complete Project 7-10 to a logical conclu-

sion; that is, recommendations on packaging congestion-reducing techniques and on needed research. Further work has identified institutional constraints from several case histories described in the literature. Information on institutional constraints from ongoing programs has been obtained through telephone and personal interviews. Those constraints critical to the implementation of specific techniques have been identified. Work has begun on the analysis of problems and design of strategies to overcome them. It is anticipated that the final recommendations will be based partly on observed cases and partly on hypothetical cases.

## 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 information and estimating bases are needed in order to obtain broad community agreement on plans for transit and highway improvement.

The final report was not published, but a summary is included in the *NCHRP Summary of Progress to June 30, 1967*.

**Project 8-4** FY '65**Criteria for Evaluating Alternative Transportation Plans**

*Research Agency:* Northwestern University  
*Principal Invest.:* Dr. Edwin N. Thomas  
 Dr. Joseph L. Schofer  
*Effective Date:* February 1, 1965  
*Completion Date:* August 1, 1967  
*Funds:* \$89,900

Present benefit-cost and other evaluative techniques do not take into account a number of costs, benefits, and broad policy matters which do not easily lend themselves to numerical computation. This project was intended to identify and evaluate the broad array of factors which should be considered in making an intelligent choice among alternative transportation plans. A system for using these factors should be devised.

To identify and evaluate the broad array of factors which reflect the user's and community's scale of values, the researchers took a systems-analysis approach. A home interview was conducted as a pilot effort to establish user and community values in specific cities. The perceptions and attitudes of the driver were derived, as well as the citizen's views about the transportation system in general. Models were developed to be able to match potential transportation system consequences with specific planning goals. Problems associated with predicting system consequences were studied.

The multi-volume report consists of a section in three parts entitled "Strategies for the Evaluation of Alternative Transportation Plans," and a section entitled "Evaluation of Engineering Projects Using Perceptions of and Preferences for Project Characteristics."

In response to comments of the advisory panel, some additional material was found to be desirable to be added to the final report. Certain modifications were deemed necessary to relate the findings of the research more closely to the immediate needs of transportation planners.

A continuation contract was executed under NCHRP Project 8-4A for the purpose of modifying the final report for publication.

**Project 8-4A** FY '65**Criteria for Evaluating Alternative Transportation Plans**

*Research Agency:* University of Illinois  
*Principal Invest.:* Dr. Joseph L. Schofer  
*Effective Date:* October 14, 1968  
*Completion Date:* January 10, 1969  
*Funds:* \$5,000

See Project 8-4 for general scope and objective of the research.

To improve the flow of ideas throughout the document, the final report of Project 8-4 was modified. In addition, more extensive descriptions of strategies for treating streams of cost and effectiveness indicators were prepared and inte-

grated into the text. Also, several illustrative examples of the application of cost-effectiveness analysis to transportation-plan evaluation were prepared to demonstrate the use of the methodology, as well as to support some of the broader concepts described in the final report.

The project report has been published as:

NCHRP Report 96, "Strategies for the Evaluation of Alternative Transportation Plans."

#### Project 8-5 FY '65 and FY '68

##### Transportation Aspects of Land-Use Controls

*Research Agency:* Victor Gruen Associates  
*Principal Invest.:* Harold Marks  
*Effective Date:* April 1, 1965 Aug. 7, 1967  
*Completion Date:* May 31, 1966 Jan. 15, 1970  
*Funds:* \$25,967 \$99,571

Proper land-use controls, properly administered, protect and enhance the public investment in transportation. Zoning, subdivision regulations, and all other land-use controls are intended to shape the pattern of the urban development. The objective of this research was to provide a better understanding of the effectiveness of existing land-use controls on the continuing utility of transportation systems.

The initial research primarily consisted of a literature search and a canvass of selected highway departments and other agencies concerned with transportation planning in areas of rapid growth and intensive development. The effects of zoning and general plans were studied, as were highway geometry and access control, in regard to protecting the investment of the highway systems.

A first technical report has been published as:

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

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

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

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

NCHRP Report 121, "Protection of Highway Utility."

#### Project 8-6 FY '66

##### Individual Preferences for Alternative Dwelling Types and Environments

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

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

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

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

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

The project report has been published as:

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

#### Project 8-7 FY '69

##### Evaluation of Data Requirements and Collection Techniques for Transportation Planning

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

Urban transportation planning studies require travel, transportation facility, land-use, and various socioeconomic data. Techniques for obtaining these data are slow and costly. The accuracy, utility, and adequacy of the data and the methods employed for their collection and assembly need to be evaluated in the light of the evolving transportation planning process.

The purpose of the research project was to see what data were needed, first, for the basic transportation planning process such as was required to be undertaken for metro-

politan areas by the Highway Act of 1962, and, second, for new kinds of transportation planning that are developing. A very limited number of transportation studies were selected for careful and detailed data analysis to establish recommendations on guidelines for data requirements and collection techniques. The project defined data requirements for both basic and continuing urban transportation studies with regard to travel, transportation facility, land-use, and socioeconomic data. Sensitivity analysis was performed to examine variations of the transportation data for assessing the impact that data errors have on the output of the transportation planning process.

The research included a comprehensive study of the transportation planning process in five cities to determine data collected, how they were used for planning and research, and their times and costs. Sensitivity tests of these data were conducted. Studies of data needs for new types of transportation-planning processes and alternate means of collecting data were also undertaken. Research was conducted on data needs of related planning processes, such as TOPICS Planning and Transit Planning.

The project report has been published as:

NCHRP Report 120, "Data Requirements for Metropolitan Transportation Planning."

**Project 8-7A** FY '71

**Data Requirements and Transportation Planning Procedures in Small Urban Areas**

*Research Agency:* University of Tennessee  
*Principal Invest.:* Dr. William L. Grecco  
*Effective Date:* June 1, 1973  
*Completion Date:* June 14, 1975  
*Funds:* \$99,968

Urban transportation planning studies in urban areas of less than 250,000 population have evolved as miniature versions of the transportation planning process in large urban areas. These studies have been time consuming and costly and have had inordinate data requirements. The complexity and expense of these procedures was of increasing concern to highway officials because of the need to establish ongoing, continuing transportation planning processes in small urban areas.

The initial focus of this research was to develop a simplified transportation planning process for small urban areas of less than 250,000 population that is sufficiently flexible so that travel forecasts can be based on a small-sample home-interview survey or simulation. It was found that the existing standardized procedures were incompatible with the possible variations in the nature of the problems, available resources, and expectations of the participants. The digest of responses from the small urban areas examined typifies the difficulty faced when attempting to adapt the planning problem to the planning process, rather than fitting the process to the specific problem. The need for a customization of planning procedures was established, and the current organizational framework and technical practices in both land-use and transportation planning were evaluated from that standpoint.

Land-use planning in small communities was found to be highly standardized in format and content, but not in procedures, which varied significantly in terms of sophistication. It was found to be appropriate for planners to forego elaborate procedures in favor of various hand methods that are heavily dependent on the planner's knowledge of the community and the exercise of professional judgment in an ad hoc or opportunistic fashion. The transportation planning procedures appeared to be relatively more standardized.

The research identified and presented four types of transportation planning techniques for application in small urban areas: (a) network simulation based on synthetic models and a small-sample household survey, (b) consumer-oriented transit planning procedure, (c) simple techniques for corridor analysis, and (d) hand-computation-oriented procedure for estimating localized impacts of major traffic generators. Existing techniques were reviewed and tested (to varying levels) within each category. Examples include cross-classification and synthetic models, corridor-growth traffic-forecasting models, use of work-trip data from employers to update continuing transportation studies, development of a consumer-oriented approach to determining local transit needs and providing activity-center traffic estimates to assist in assessing the localized impact of land-use changes on the transportation system.

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

NCHRP Report 167, "Transportation Planning for Small Urban Areas."

**Project 8-8(1)** FY '69

**The Impact of Highways upon Environmental Values (Study Design)**

*Research Agency:* Massachusetts Institute of Technology  
*Principal Invest.:* Dr. Marvin L. Manheim  
*Effective Date:* September 16, 1968  
*Completion Date:* March 14, 1969  
*Funds:* \$29,654

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design has been completed and the report has been received, but will not be published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

**Project 8-8(2)** FY '69

**The Impact of Highways upon Environmental Values (Study Design)**

*Research Agency:* Daniel, Mann, Johnson & Mendenhall  
*Principal Invest.:* S. R. Sludikoff

*Effective Date:* September 9, 1968  
*Completion Date:* March 7, 1969  
*Funds:* \$28,950

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design has been completed and the report has been received, but will not be published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

### **Project 8-8(3) FY '69**

#### **The Impact of Highways upon Environmental Values**

*Research Agency:* Massachusetts Institute of Technology  
*Principal Invest.:* Dr. Marvin L. Manheim  
*Effective Date:* September 15, 1969  
*Completion Date:* July 31, 1974  
*Funds:* \$470,000

The increasing emphasis on social and environmental values has focused attention on the need for improving integration of a transportation facility with both the natural and the human environment. To achieve desirable levels of integration, research was programmed by AASHTO to (a) develop a practical method for evaluating the immediate and long-term effects of highways on the social and environmental considerations of communities and (b) test, evaluate, and refine the method by applying it to specific cases covering a range of situations. Because the design process must maximize the probability that significant community values will be considered, even if the state of the art does not allow all of these values to be measured quantitatively or precisely, the research emphasizes development of an approach in the context of the location process. Although the scope encompasses all types of highways, the study findings are applicable to all types of transportation facilities, many other public works projects, and all phases of planning.

In the initial phase, funded in 1969, MIT prepared a study design that served as the working plan to develop a pragmatic approach to the problem. The conclusion to the first phase was an unpublished draft report, "Community Values in Highway Location and Design: A Procedural Guide."

The second, and final, phase included (1) working with selected state highway departments to implement the proposed approach and adapt it to specific situations; (2) extending the approach for use in metropolitan area and statewide multimodal, systems-level planning; (3) extending, testing, and refining the techniques set forth in the draft Procedural Guide; and (4) revising the Procedural Guide to reflect the additional knowledge.

The approach developed recognizes and considers ten elements basic to the consideration of environmental and social values in transportation planning. They are:

- (1) Differential effects.
- (2) Community values.
- (3) Community interaction.
- (4) Evaluation and reporting.
- (5) Consideration of alternatives.
- (6) Identification of impacts and affected interests.
- (7) Process management.
- (8) Interrelation of system and process planning.
- (9) Institutional arrangements and decision making.
- (10) Implementation of the approach.

These elements are described in an overview and discussed individually in detail. To assist in incorporating these elements into the transportation planning process, specific immediately implementable techniques that can be used by transportation agencies are described. Most of the techniques can be adopted individually without difficulty. (They are intended for use in developing and evaluating alternative transportation plans with the participation of other state and federal agencies and local citizens and officials.) Some of these techniques are already current practice in some agencies. Several have been tried in other professions; others have been recommended in the published literature or were suggested in discussions with federal and state highway officials. Many more stemmed from direct observation of the problems transportation agencies are facing.

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

NCHRP Report 156, "Transportation Decision-Making—A Guide to Social and Environmental Considerations."

The report is closely related to the requirements of the Process Guidelines for the development of Environmental Action Plans as specified in Volume 7, Chapter 1, Section 1 of the Federal Highway Administration's *Federal-Aid Highway Program Manual*. It is structured to assist in the revision and implementation of Action Plans. The overview discussion of the ten elements is roughly analogous in scope and level of detail to the FHWA Process Guidelines. The remaining sections of the report correspond in many ways to the content of an Action Plan.

### **Project 8-9 FY '72**

#### **Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems**

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

Economic evaluation of proposed new highway facilities traditionally has been on a cost-benefit basis, as is common with other public works projects. On the other hand, evaluation of proposed new transit facilities, as an action of a private company or a public utility, has too often been on a cashbox-revenue return basis. From the point of view of public investment, it is necessary to view these ex-

penditures within a comparable evaluation framework so that the measures of benefits and costs are interchangeable. Such a framework for the economic evaluation of multimodal passenger transportation systems has immediate applicability to urban transportation studies.

The objective of this research was to develop improvements and expansion of existing processes that evaluate alternative multimodal transportation system plans. These improvements were sought on the basis of increasing the number of relevant criteria used in the evaluation framework and ensuring that the measuring techniques (economic evaluation criteria) developed represented accurately the impacts of alternative transportation plans.

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

NCHRP Report 146, "Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis."

#### Project 8-10 FY '72

##### Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities

*Research Agency:* Wilbur Smith and Associates  
*Principal Invest.:* Herbert S. Levinson  
*Effective Date:* September 1, 1971  
*Completion Date:* July 31, 1973  
*Funds:* \$149,907

Highways are capable of moving large numbers of persons on buses, but in high-volume corridors transportation service deteriorates due to peak traffic congestion. In order to move more people at an acceptable level of service, special facilities and control measures can be employed. The desired goal is rapid, convenient, reliable bus transit. Thus, a highway transportation system can be designed to offer a high level of service for peak commuter loads.

Research has been completed. It was designed to develop a single reference source of bus priority measures to increase the person-carrying capacity of urban highways.

The interim report, "Bus Use of Highways—State of the Art," published as NCHRP Report 143, contains a literature search and correlative analysis of more than 200 bus priority treatments throughout the world.

The final report, "Bus Use of Highways—Planning and Design Guidelines," published as NCHRP Report 155, contains planning and design guidelines for efficient bus use of highways based on the experience gained from the literature search and state-of-the-art survey. It identifies significant policy implications, contains relevant planning criteria and warrants for various bus priority treatments, suggests measures of effectiveness, presents bus design parameters, and sets forth detailed planning and design guidelines for both freeway-related and arterial-related bus priority treatments and for terminals. For measuring effectiveness, it was found that the variance of bus times is an important descriptor of bus reliability.

To aid the designer, vehicle design and performance characteristics are given, together with bus capacity con-

siderations. These include queue behavior parameters, bus unloading and loading times, and bus capacity ranges.

Bus priority treatments should be complemented by appropriate policies that encourage and reinforce transit use, such as low bus fares, downtown commuter parking supply and rate adjustments, and strict enforcement of bus priority treatments. Within this policy framework, that recognizes public transport as an essential community service, various types of bus preferential treatments can be applied to specific urban situations.

#### Project 8-11 FY '74

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

*Research Agency:* DACP, Inc.  
*Principal Invest.:* Jonathan S. Lane  
*Effective Date:* September 16, 1974  
*Completion Date:* February 28, 1977  
*Funds:* \$249,753

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. Interim guidelines for the analysis of the NCTF alternative have been developed as a result of considerable research into the experience to date in analyzing and portraying the social and economic consequences of the NCTF alternative. The guidelines designate six project prototypes that are described by attributes such as urbanization, size of project, and regional significance. For each prototype, a range of assumptions for NCTF definition is designated. These assumptions or definitional components describe the scope of impacts to be evaluated for the prototype. Impact categories within the over-all classification of transportation, social, economic, and environmental are designated, with appropriate evaluation techniques for each. Finally, guidance is given on methods to evaluate alternative plans that include the NCTF alternative.

The interim guidelines and research report identifying deficiencies in evaluation techniques may be purchased from the Program Director, NCHRP, at a cost of \$9.50 (plus \$2.00 for postage and handling if first-class postage is desired).

Research is continuing in an effort to improve the usefulness of the guidelines. As a result of agency reviews the guidelines have been extensively revised. They are presently under test by user agencies.

**Project 8-12 FY '75**

**Travel Estimation Procedures for Quick Response to Urban Policy Issues**

*Research Agency:* Metropolitan Washington Council of Governments  
*Principal Invest:* George V. Wickstrom  
 Arthur B. Sosslau  
*Effective Date:* September 3, 1974  
*Completion Date:* December 31, 1975  
*Funds:* \$39,895

Historically, urban travel estimating procedures 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. 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. Most present procedures are just inappropriate to permit an analytical response to the issues raised within the time constraints.

The over-all objective is provision of field-tested, operational, travel estimation procedures for quick response to urban policy issues. Research to satisfy this objective is being conducted in two separately funded phases. Phase I and Phase II are designated 8-12 and 8-12A, respectively. The following specific objectives and tasks were accomplished in Phase I:

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

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

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

B. Travel estimation procedures were evaluated as to their ability to satisfy the requirements of policy issues. The evaluation criteria were based on the policy issue analysis and include timeliness, needed accuracy, cost, utility, etc.

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

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

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

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

C. A set of recommendations for Phase II of the project was developed.

Phase I (Project 8-12) has been completed; a summary report providing a description and evaluation of numerous urban travel estimation procedures is available from NCHRP: "Travel Estimation Procedures for Quick Response to Urban Policy Issues." Wickstrom, G. V., and Sosslau, A. B. Cost \$4.00. All orders less than \$7.50 *must* be prepaid and directed to Mr. L. M. MacGregor, Administrative Engineer, NCHRP, 2101 Constitution Avenue NW, Washington, D.C. 20418. Telephone orders are discouraged unless the total order exceeds \$7.50. Please make check or money order payable to *Transportation Research Board*.

**Project 8-12A FY '75 and FY '76**

**Travel Estimation Procedures for Quick Response to Urban Policy Issues**

*Research Agency:* Comsis Corporation  
*Principal Invest.:* Arthur B. Sosslau  
 George V. Wickstrom  
*Effective Date:* November 1, 1975  
*Completion Date:* April 30, 1977  
*Funds:* \$160,000

The continuation phase of Project 8-12 will provide a manual (guide) of travel estimation techniques having quick response capabilities. The techniques will be applicable for use by transportation and/or land-use planners to respond to issues identified in Phase I, giving emphasis to the impacts of land-use changes on transportation alternatives and the magnitude of urban activities consistent with differing levels of transportation service. Problems of scale are to be addressed; e.g., the applicability of techniques to regions, subregions, corridors. Specific objectives are as follows:

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

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

3. Include by reference additional data and techniques,

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

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

The selection of applicable existing techniques and the development of additional techniques to fill the identified gaps are completed. Test scenarios are being conducted in three urban areas to illustrate the usefulness of the package of quick-response techniques.

#### Project 8-13 FY '75

##### Disaggregate Travel Demand Models

*Research Agency:* Charles River Associates  
*Principal Invest:* William B. Tye  
*Effective Date:* Sept. 15, 1974 May 1, 1976  
*Completion Date:* Jan. 31, 1976 Apr. 30, 1977  
*Funds:* \$100,000 \$87,000

The urban transportation planning process, as it has developed over the past two decades, is characterized by the creation of long-range systems plans based on simulations of regional travel patterns using models developed and calibrated with aggregate zonal data. Three of the basic criticisms that have been made of the regional simulation and planning process have been that the presently used aggregate models cannot be readily used for subregional and project planning; they are not responsive to the policy issues that planners are being asked to address; and they require expensive large travel surveys for model calibration.

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

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

To meet the described need, the over-all objective of this research is to develop, in separately funded phases extending over several years, operational travel demand forecasting models consistent with travel choice behavior and with coefficients estimated by use of data at the level of house-

holds or individual travelers. It is anticipated that such models will form the basis of improved travel demand estimation procedures.

Models were developed in Phase I using existing urban transportation study survey data, suitably augmented, to describe the travel choice environment. A Phase I report presenting the major findings to date is available from NCHRP: "Disaggregate Travel Demand Models: Phase I Report," Tye, W. B., and Sherman, L. Cost \$6.00. All orders less than \$7.50 *must* be prepaid and directed to Mr. L. M. MacGregor, Administrative Engineer, NCHRP, 2101 Constitution Avenue, NW, Washington, D.C. 20418. Telephone orders are discouraged unless the total order exceeds 7.50. Please make check or money order payable to *Transportation Research Board*.

Phase II is currently under way and extends the research program: (1) to develop improved models, especially of travel choices other than mode choice for the worktrip; (2) to conduct one or more demonstrations of the interim project results on a test basis to policy issues at a state or local planning agency; and (3) to determine an approach to be used in solving problems that will be incurred in application (such as application of disaggregate models to aggregate data and aggregate forecasting).

Phase III will accomplish (1) model development using disaggregate data collected by Charles River Associates for the U.S. Department of Transportation, (2) demonstration(s) of the new models using case studies at a transportation planning agency, and (3) preparation of a manual for users to be published in the formal NCHRP publication series.

#### Project 8-14 FY '75

##### New Approaches to Understanding Travel Behavior

*Research Agency:* Boston College  
*Principal Invest:* Marc A. Fried  
 John Havens  
*Effective Date:* January 1, 1975  
*Completion Date:* December 31, 1976  
*Funds:* \$149,860

Current urban travel estimating procedures have been developed, for the most part, on the basis of identification of associative relationships, without concern for the causal processes from which travel behavior patterns arise. As a result, the procedures may produce reasonably satisfactory estimates of travel under conditions that are essentially unchanged from those existing at calibration, but are largely unable to provide satisfactory estimates of travel behavior under conditions representing significant change from the status quo. For example, decision makers are asking: (1) the consequences of no-build options; (2) the relevance of low-capital options, in and of themselves, and as alternatives to freeway systems; (3) the congestion and energy effects on the level of travel and mode choice; and (4) traveler responses to hypothetical systems with specified performance characteristics. Furthermore, existing procedures are unable to provide information on why a trip is



made and are, hence, also unable to provide a means for estimating, under a variety of assumptions, changes in the number and characteristics of trips that an individual will make.

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.

A careful review and evaluation has been made of the transportation planning, economics, sociology, geography, and psychology literature to identify theoretical elements related to individual travel. This work has been synthesized into a travel behavior theory comprised of two components—a microtheory and a macrotheory. The microtheory concept proposes that individuals in similar social status positions, in similar life stages, living in similar environments, will adapt in similar and partially predictable ways. Important to this theory are role patterns and attitude structures. The macrotheory is concerned with how the existence of activity opportunities and constraints modifies or reinforces behaviors specified in the microtheory. The microtheory deals with the individual's demand for activity opportunities; the macrotheory, with the generation of the activity opportunity sets (i.e., transportation supply).

The report from Phase I is available from the Program Director, NCHRP, at a prepaid cost of \$6.00. Please make check or money order payable to *Transportation Research Board*.

Research is expected to continue on a Phase II that will incorporate key elements of the synthesized theory into present travel demand forecast methods.

#### Project 8-15 FY '75

#### State and Regional Transportation Impact Identification and Measurement

*Research Agency:* Bigelow-Crain Associates  
*Principal Invest:* Charles D. Bigelow  
*Effective Date:* September 1, 1974  
*Completion Date:* May 31, 1976  
*Funds:* \$80,000, 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. To achieve the stated objective, the research is being conducted in two phases.

The research is directed primarily at statewide and regional-scale planning, program development, and policy analyses involving movement of passengers and commodities rather than urban area (3-c), intra-urban, or detailed project studies.

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

Phase I of this project documents technical methodologies to assist the states in their decision-making processes. Specific identification and measurement techniques were examined in contrast to issues of impact evaluation and design of the over-all planning and policy-making process.

The Phase I investigation considered the direct and indirect impacts of economic development; land use and housing; air, noise, and water quality; energy utilization; natural resources and ecosystems; and social and community structure. Consideration was given in each of the described methodologies to identifying distributional effects.

Phase I tasks included:

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

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

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

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

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

F. Prepare a Phase I 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.

Phase I has been completed and the scope of work for the Phase II effort is now being developed. The Phase I report, "State and Regional Transportation Impact Identification and Measurement," Bigelow, C. D., is available from NCHRP. Cost \$8.00. All orders less than \$7.50 *must* be prepaid and directed to Mr. L. M. MacGregor, Administrative Engineer, NCHRP, 2101 Constitution Avenue, NW, Washington, D.C. 20418. Telephone orders are discouraged unless the total order exceeds \$7.50. Please make check or money order payable to *Transportation Research Board*.

**Project 8-16** FY '76**Guidelines for Public Transportation Levels of Service and Evaluation**

*Research Agency:* University of Tennessee  
*Principal Invest.:* Ray A. Mundy  
 Kenneth W. Heathington  
*Effective Date:* January 1, 1976  
*Completion Date:* March 31, 1978  
*Funds:* \$480,000

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

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

The specific objectives of Phase I are:

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

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

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

Research is in progress. The research approach is to explore the application of Market Opportunity Analysis to public transportation. A demonstration is planned for three U.S. cities. Data collected from visits to 19 U.S. cities will form the basis for selection of the three cities and for preliminary tests of the Market Opportunity Analysis concept.

**Project 8-17** FY '76**Freight Data Requirements for Statewide Transportation Systems Planning**

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

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

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

The general objective of this research is first to determine the type, amount, and relative importance of freight data required to develop statewide transportation system plans; and, second, to design and develop techniques, methods, and procedures for assembling these data.

This research was conducted in two phases. Specific tasks completed in Phase I were to:

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

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

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

Specific tasks completed in Phase II included:

1. Prepare a manual describing in detail appropriate techniques for the assembly and understanding of existing freight data and the collection and understanding of such additional data as may be required by statewide transportation systems planning. Such a manual should include specification of data acquisition, processing, verification, and maintenance procedures.

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

Research is completed and the preliminary draft final report is in the review stage. The firm of R. L. Banks Associates is serving as a subcontractor on this project.

#### **Project 8-18 FY '76**

##### **Techniques for Evaluating Options in Statewide Transportation Planning/Programming**

*Research Agency:* Planning Environment International,  
A Division of Alan M. Voorhees  
& Associates

*Principal Invest.:* Dr. Salvatore J. Bellomo  
Dr. Joseph R. Stowers

*Effective Date:* September 1, 1975

*Completion Date:* February 28, 1978

*Funds:* \$300,000

Evaluation techniques have traditionally been thought of in the context of "plan evaluation" (i.e., comparison of alternative system networks), or "route evaluation" (i.e., comparison of locations for a given proposed facility). Although these evaluations and the techniques applied to them (such as user costs and benefits; balancing of travel demands assigned to a network with network capacity; and, more recently, localized corridor impact analyses) may still be valid for certain planning needs, the techniques suffer from a combination of large expenditures of time, high cost, extensive data requirements, and complex simulations. Such techniques do not begin to cover the range of options that face today's decision makers; neither do they enable quick response. Several issues have evolved that place today's transportation decision makers in the position of making trade-offs and choices from among a range of options and values not previously considered. These issues include new environmental concerns, changing social equity concerns, major decreases in available revenue, increased costs due to inflation, unified transportation funds and multimodal financial programming, energy shortages and energy cost increases, public interest in pricing mechanisms

(e.g., tolls and fares) to influence travel, and federal interest in "low capital-intensive" options.

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

Specific tasks of Phase I were to:

1. Identify and classify major transportation issues facing decision-makers at the statewide level.

2. Identify and categorize data and methodologies available to meet the needs of decision makers in addressing transportation issues identified in Task 1.

3. Evaluate and document methodologies most likely to provide early usefulness.

4. Develop a study design to test several high-priority methodologies (identified in Task 3) in states willing to participate and commit resources. At least four states should be identified as candidates in the study design.

The specific tasks of Phase II are to:

1. Develop a draft procedural manual for test application of techniques identified in Phase I.

2. Conduct the testing in the approved study design developed in Phase I, Task 4.

3. Document the results of the testing and revise manuals developed in Phase II, Task 1.

4. Based on the experience gained in Phase II, Task 2, and deficiencies recognized in Phase I, Task 3, evaluate the importance of the deficiencies and suggest new methodologies where appropriate.

Phase I is completed and the draft final report is being reviewed for publication in the regular NCHRP series. Test applications of the selected techniques are under way in Phase II. The firm of System Design Concepts is serving as a subcontractor.

#### **Project 8-19 FY '77**

##### **The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel**

*Research Agency:* Cambridge Systematics, Inc.

*Principal Invest:* Earl R. Ruiter

*Effective Date:* December 1, 1976

*Completion Date:* June 30, 1978

*Funds:* \$199,954

The concept that highways generate their own demand and subsequent vehicle-miles of travel (VMT) has been so widespread over the past several years that it has gained legitimacy if only by sheer repetition. Yet studies conducted to estimate future travel demand have not conclusively shown significant correlation between VMT and highway supply variables.

Proposed highway improvements are being challenged

from both an air quality and energy conservation perspective. VMT reduction requirements have been placed on many transportation planning agencies, resulting in implementation plans being promulgated. Highway agency attempts at both air quality improvements and energy conservation efforts have been based on the argument that increased highway supply frees traffic flow and leads to more efficient operation of the system. Critics argue, however, that increased highway capacity aimed at reducing congestion induces sufficient VMT to offset any gains, resulting in greater levels of energy consumption and pollutant emissions. A clear understanding of the effect of highway supply on VMT is needed to adequately address the interrelationship of transportation, air quality, and energy issues.

The objective of this project is to determine whether a relationship exists between measures describing urban highway supply and VMT. If the research establishes that no significant relationship exists, this fact will be carefully documented. If, however, a relationship is established, the research will quantify and compare the relative significance of highway supply to other factors influencing VMT.

To accomplish this objective the following specific tasks are to be accomplished:

Task 1. Planning activities in selected states and/or urbanized areas involving the relationship of VMT and highway supply will be identified and reviewed. Federal policies and procedures having impact on these planning activities will also be documented.

Task 2. Supply measures are to be identified that can be directly related to VMT to assist in the analysis of major system changes, such as construction of new facilities or adding lanes to existing facilities. The supply measures chosen will also be capable of reflecting the impact on VMT of operational changes such as ramp metering, preferential treatment of multiple-occupancy vehicles, exclusive bus lanes, and signal progression.

Task 3. Relationships between the selected supply measures and VMT are to be investigated. The primary concern in the development of the relationships is the need to provide a mechanism to identify the level of induced VMT, which is defined as VMT that would not have existed without the change in supply. Sensitivity to factors such as level of congestion on the highway system and the intensity and distribution of land use are to be fully analyzed and documented.

Task 4. The appropriate relationships developed in Task 3 will be applied to several actual case studies to demonstrate their usefulness in addressing specific major system changes and operational changes as discussed in Task 2.

## 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

<i>Principal Invest.:</i>	Dr. A. W. Sisko	
	L. C. Brunstrum	
<i>Effective Dates:</i>	Feb. 1, 1964	Nov. 1, 1965
<i>Completion Dates:</i>	July 31, 1965	Apr. 30, 1967
<i>Funds:</i>	\$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

<i>Research Agency:</i>	Montana College of Mineral Science and Technology
<i>Principal Invest.:</i>	D. W. McGlashan
<i>Effective Date:</i>	January 1, 1965
<i>Completion Date:</i>	October 31, 1967
<i>Funds:</i>	\$101,903

This research was concerned with asphaltic concrete pavement performance, particularly with regard to the influence of asphalt-aggregate adhesion. The research approach was based on the principle that interfacial activity occurring at the boundary between an asphalt cement and an aggregate is influenced by the characteristics of the particular asphalt and aggregate and that this activity, measured in electrical quantities, provides a comparative assessment of the adhesion between the asphalt and the aggregate.

A data acquisition system was developed for making electrokinetic measurements of interfacial activity when asphalt cements were forced through porous plugs under controlled temperature and pressure conditions. The porous plugs contained aggregates that were being tested for adhesion. Data were collected and analyzed using 15 asphalt cements and a number of different aggregate types to demonstrate the ability of the procedure for assessing the adhesion of an asphalt-aggregate mixture.

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

**Project 9-3** FY '65**Evaluation of Pavement Joint and Crack Sealing Materials and Practices**

*Research Agency:* Rensselaer Polytechnic Institute  
*Principal Invest.:* Dr. John P. Cook  
*Effective Date:* June 1, 1965  
*Completion Date:* June 30, 1966  
*Funds:* \$24,996

Under environmental, structural, and traffic requirements, highly variable and inadequate performance may result from the materials and construction practices regarding the sealing of joints in new pavements and the maintenance of joints and cracks in old pavements. All aspects of the sources of the deficiencies need to be identified so that corrective measures may be established either in terms of improved materials or improved construction practices. The objectives of this research were to (1) prepare a state-of-knowledge report on joint and crack sealing materials, joint design, specifications, test methods, and construction practice; (2) make a critical analysis of the information and define needs to improve performance; and (3) recommend a feasible research program. Bituminous and nonbituminous materials were included, and due consideration was given to such factors as economics and practicalities of usage.

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

NCHRP Report 38, "Evaluation of Pavement Joint and Crack Sealing Materials and Practices."

**Project 9-4** FY '72**Minimizing Premature Cracking of Asphaltic Concrete Pavements**

*Research Agency:* Materials Research & Development  
*Principal Invest.:* F. N. Finn  
 Keshavan Nair  
*Effective Date:* November 1, 1971  
*Completion Date:* June 30, 1973  
*Funds:* \$99,560

The premature cracking of asphaltic concrete pavements is a continuing problem and often results in large expenditures of money to maintain a necessary level of pavement serviceability. Many factors, such as asphalt properties, mix design, construction procedures, aggregate properties, subgrade support, environmental conditions, and traffic loadings, influence the ability of the pavement to resist cracking.

The objective of this project was the determination of suitable materials specifications, paving mix design criteria, and construction requirements that will result in the ability to design and construct asphaltic concrete pavements to carry design traffic with a minimum of premature cracking.

Research has been completed. Tentative recommendations have been prepared to minimize cracking of asphaltic concrete pavements and a plan has been prepared for verifying or modifying these tentative recommendations. The

essential findings of the study have been published as NCHRP Research Results Digest 58. The project report is in the NCHRP editorial and publication process.

**Project 9-4A** FY '76**Bayesian Analysis Methodology for Verifying Recommendations to Minimize Asphalt Pavement Distress**

*Research Agency:* Woodward-Clyde Consultants  
*Principal Invest.:* F. N. Finn  
 W. S. Smith  
*Effective Date:* September 15, 1975  
*Completion Date:* December 14, 1977  
*Funds:* \$199,994

Cracking of the surface course is generally considered to be the most significant manifestation of asphaltic concrete pavement distress. Many factors, such as asphalt properties, mix design, construction procedures, aggregate properties, subgrade support, environmental conditions, and traffic loadings, influence the ability of the pavement to resist cracking. Premature cracking (that occurring at an early life or after less accumulated traffic than anticipated during design) is particularly troublesome. Considerable research effort has been and continues to be directed toward development of more mechanistic procedures for flexible pavement design to reduce cracking that will be applicable to all locations, environments, and traffic loadings.

NCHRP Project 9-4 findings contain recommendations intended to reduce possibility of premature cracking of asphaltic concrete pavements and a proposed verification program. The generally accepted approach to verification has been to monitor performance using statistical analysis for evaluation of the variables. An alternate approach has been to verify an analytical model using a small experimental program and case histories of in-service pavements. One of the findings of NCHRP Project 9-4 indicates that these two approaches are not realistic for verification of the project recommendations because the cost, time, and scope required for such a program to reach definitive conclusions would be excessive.

In the same report, the Bayesian approach is suggested as an alternate for verification and updating of project recommendations. It uses the past experience of engineers in a meaningful statistical format combined with experimental data and experience gained from observation of field performance of new construction.

The objectives of this project are (1) development of a procedure based on Bayesian statistical concepts for verifying recommendations to minimize pavement distress and (2) pilot implementation of the verification procedure for the specific distress mode of cracking from repetitive traffic loading. It is expected that the researchers will use the recommendations of Project 9-4 as a basis for the verification procedure.

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

1. Prepare a plan for obtaining the subjective informa-

tion on factors affecting distress of asphaltic pavements from experienced engineers, including a suitable questionnaire and interview procedure.

2. Implement the plan prepared under Task 1 to collect the subjective information in two climatic regions of the contiguous United States and develop "priors" for at least cracking from repetitive traffic loading.

3. Develop the framework for acquisition of "data" compatible with mechanistic models for asphaltic pavements. The framework must accommodate objective field measurements on existing pavements and test roads and be suitable for combining with the "priors" obtained from Steps 1 and 2 describing (a) what should be measured, (b) how it should be measured, and (c) how it should be analyzed when it has been obtained.

4. For pilot implementation of the verification procedure for a specific distress mode, collect field data on cracking from repetitive loading of pavements in the same two climatic regions in which the interviews were conducted.

5. Complete the analysis by combining the "priors" and the "data" to illustrate the methodology.

A preliminary questionnaire has been circulated to engineers in Arizona, Colorado, Florida, Louisiana, Utah, and Virginia to obtain information for selection of the damage factors to be used in collection of the subjective data (priors), and to identify participants for the subsequent interview program. The four variables selected as damage factors are (1) asphalt consistency, (2) asphalt content, (3) proportions of asphaltic concrete in the structural section, and (4) untreated base density. Interview forms have been prepared, pilot tested, and used in the collection of subjective data in the six participating states. The data are in the process of being analyzed.

## 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 Date:* Oct. 22, 1963            Oct. 15, 1964  
*Completion Date:* Apr. 30, 1964        Oct. 16, 1965  
*Funds:* \$25,000                        \$30,000

The difficulties associated with producing aggregates and providing them at the job site within desirable specification limits have been recognized for many years. To provide further knowledge for a possible solution to these difficulties, the over-all objectives of this research were to (1) find the effects of stockpiling and handling on the properties of an aggregate, including segregation and degradation, and (2) establish suggested procedures for better practices in stockpiling and handling.

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

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

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

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

#### **Project 10-4    FY '64 and FY '65**

##### **Rapid Test Methods for Field Control of Construction**

*Research Agency:* Clemson University  
*Principal Invest.:* Dr. A. E. Schwartz  
*Effective Date:* Feb. 1, 1964            May 1, 1965  
*Completion Date:* Feb. 28, 1965        Feb. 28, 1967  
*Funds:* \$30,000                        \$69,320

It has been recognized that there is a need for improved methods of sampling and testing to keep pace with accelerated production rates and increased volumes of materials being used in highway construction. In an effort to fulfill this need, this research project proposed to seek out areas in which rapid test needs are most critical and to explore and summarize existing knowledge in these areas with the ultimate aim of accelerating the development of new methods of meeting these needs.

Work in the initial phase of this project consisted of a survey of the state of the art in the development, need,

and use of rapid test methods for field control of construction. Areas of greatest need were determined; the present knowledge and state of development of various methods for meeting these needs were investigated; and those methods with greatest promise for satisfying the needs in the areas of bituminous paving mixtures, base course construction, and soil compaction were selected for detailed study and development. An additional study was made of quality control and acceptance sampling plans in respect to the number of tests required to provide adequate statistical information for acceptance or rejection of highway materials within given limits of risk and confidence.

During the continuation phase, emphasis was placed on further development and evaluation of improved test procedures in the areas of asphalt content of bituminous paving mixtures, density of aggregate base courses and bituminous layers, gradation of aggregates, and soil compaction.

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

NCHRP Report 103, "Rapid Test Methods for Field Control of Highway Construction."

#### **Project 10-5    FY '64 and FY '65**

##### **Density and Moisture Content Measurements by Nuclear Methods**

*Research Agency:* Research Triangle Institute  
*Principal Invest.:* Dr. R. P. Gardner  
*Effective Date:* Jan. 15, 1964            Apr. 1, 1965  
*Completion Date:* Jan. 31, 1965        Oct. 7, 1966  
*Funds:* \$28,801                        \$59,835

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

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

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

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

objectives, calibration standards were developed which are applicable to nuclear gauges currently in use.

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

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

**Project 10-5A** FY '68

**Optimization of Nuclear Density and Moisture Content Measurement Methods**

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

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

The essential objective of this study was to optimize nuclear gauge calibration methods and thus improve operational performance of the gauges for control of moisture and density during construction of highway subgrade, subbase, and base components. 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 over-all problem, was not included in the research conducted under this project.

The objective of this research was limited to the field evaluation of available nondestructive systems of inspection testing for determining pavement thickness and reinforcing steel position at the construction site, either before or soon after the concrete has hardened, to permit the elimination of, or substantial reduction in, the coring of pavements.

To accomplish this objective, the research agency:

1. Conducted a state-of-the-art study and a preliminary evaluation to select the devices and procedures for determining concrete pavement thickness and reinforcing steel placement that have been developed to the point that field evaluation is now feasible.

2. Selected candidate procedures for field evaluation.

3. Developed and conducted a field evaluation program in cooperation with several state highway agencies.

4. Analyzed and compared field data with current practices with regard to such considerations as practicality, accuracy, ease of operation, and nondestructiveness.

All research on the project has been completed. The Ohio State ultrasonic gauge was found to be capable of measuring the thickness of both plain and reinforced concrete pavements with sufficient accuracy for construction control, as was also an eddy current proximity gauge for use with plain (nonreinforced) pavements only. A pachometer was found to determine steel depth with sufficient accuracy for construction control. Statistical-type specifications were found to be required when the devices are used in construction control.

Research has been completed and the project report published as:

NCHRP Report 168. "Rapid Measurement of Concrete Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems."

#### Project 10-9 FY '70

##### Criteria for Need of Seal Coats for Bituminous Pavements

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

In order to most economically maintain bituminous-surfaced pavements in serviceable condition, seal coats may be periodically required. Determinations of the need for seal coats, the type required, and the proper time to apply are important. Premature sealing results in a needlessly early expenditure of funds, while tardy action may result in excessive deterioration or unsafe conditions and greater total maintenance expenditures. Currently available methods of rating pavements for the need of sealing are not totally adequate. They are time consuming, require the use of costly equipment and highly skilled personnel, rely on the judgment of experienced personnel, or are not reproducible. Methods and criteria for determining when seal-coat applications should be made are needed.

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

Research has been completed. The essential findings of the study have been published as NCHRP Research Results Digest 48. The agency report has been distributed to the Program sponsors and other interested persons and a summary is included in the *NCHRP Summary of Progress Through 1976*.

#### 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:* March 31, 1977  
*Funds:* \$300,000

Engineers are hesitant to permit use of the electroslag welding process for weldments subject to bridge loadings because sufficient research has not been conducted to determine their performance. Some states are permitting use of the electroslag process based on a very limited number of tests, some with borderline results. Most engineers will not permit its use on a bridge of major proportions because of the existing uncertainties; therefore, this program is of the utmost importance if this economical tool is to be widely used in the fabrication of bridges. The principal areas of concern are the physical and metallurgical properties of the weld and the heat-affected zones. The adequacy of current electroslag welding specifications for bridges has been questioned. Thus, a thorough analytical and experimental program of evaluation of all parameters is needed.

The over-all objective of this project 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 included 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 Phase I.

Phase I has been completed. The report prepared under Task 2 has been published as NCHRP Research Results Digest 74, "Electroslag Weldments in Bridges." Loan copies of the report prepared under Task 5 may be obtained from the NCHRP Program Director.

Phase II, now in progress, consists 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 work plan developed under Phase I.

The final report will 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, 1976, specimen fabrication and other preparations were completed for Phase II testing.

#### Project 10-11 FY '77

##### Development of a Performance Specification For Bridge Deck Joint-Sealing Systems

*Research Agency:* Howard Needles Tammen & Bergendoff  
*Principal Invest.:* Arthur Linfante  
*Effective Date:* December 1, 1976  
*Completion Date:* November 30, 1977  
*Funds:* \$29,996

A large majority of bridge deck joint-sealing systems in use today are proprietary products. These products are designed in companies and corporations where a full range of experience with bridge deck behavior, field installation conditions, dynamic loading effects, climatic conditions, and pavement maintenance procedures is often not available. As a consequence, these products do not always function in the structures as intended. Some require costly maintenance, and others actually fail to survive more than a few years. Because most of these sys-

tems are furnished without a guarantee of any kind, public agencies are forced to assume responsibility for their adequacy, even though they are furnished and installed by project contractors. To avoid the worst of the systems, most agencies specify what appear to be the most practicable proprietary systems for their installations.

This specifying practice, when combined with current contract bidding procedures, has an adverse effect on the quality of sealing systems. Because contracts are normally awarded to the low-bid contractor, all contractors must, if they are to survive, devise ways to furnish and install products that will satisfy contract requirements at the least cost. Because this procedure emphasizes least cost rather than quality, the manufacturers of sealing systems are also forced to modify their designs and procedures to be competitive. But a competitive position can generally be attained only by a reduction in performance and quality and by a corresponding increase in maintenance and replacement cost. After several product-modification and cost-reduction cycles, initial benefits achieved by the use of such systems do not justify their substantial ultimate costs.

Optimum cost, which considers long-term performance as well as first cost, should be the goal for bridge deck joint-sealing systems. This goal can be attained by applying an effective performance specification. A side advantage will be a reduction in the use of publicly funded structures for experimental installations for the development of proprietary products. Yet the private sector would be encouraged to design and develop the kind and quality of products that are needed today by most transportation agencies.

There is need to develop an effective performance specification for the joint-sealing systems being installed in the great majority of the bridge decks currently being built.

The ultimate objective of this research is to develop an effective performance specification for prefabricated, surface-mounted bridge deck joint-sealing systems designed for a total horizontal movement of 4 inches or less. It is envisioned that research will include at least the following tasks:

1. Review of available performance specifications applicable to bridge deck joint-sealing systems.
2. Assessment of the performance of currently used bridge deck joint-sealing systems.
3. Evaluation of present design, construction, and maintenance practices of the various transportation agencies with respect to the performance of present bridge deck joint-sealing systems.
4. Development of reasonable performance criteria for bridge deck joint-sealing systems.
5. Recommendation of a performance specification in a form suitable for consideration for adoption by AASHTO.
6. Identification of bridge deck joint-sealing system problems in need of further research.

Through December 31, 1976, efforts have been concentrated on a literature survey and collection of information from agencies using various products over the years.

**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 surround-

ing 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 Keuhle 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 condem-

nation, 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 divergencies. The alternative solutions explored include possible changes in the law, presentation and admissibility of valuation evidence, changes of appraisal concept, or methods of administration.

The project report has been published as:

NCHRP Report 126, "Divergencies in Right-of-Way Valuation."

#### **Project 11-5**    FY '71

##### **Valuation of Air Space**

*Research Agency:* Daniel, Mann, Johnson, & Mendenhall  
*Principal Invest.:* Daniel J. McNichol  
*Effective Date:* October 1, 1970  
*Completion Date:* May 31, 1972  
*Funds:* \$49,800

Use of air space over or under highways gives great promise as a major means of fitting highway transportation into the urban environment. However, difficulties in placing a proper valuation on rights in air space are hampering such developments in some areas. It is imperative that better methods for making such valuations be devised so that proper and orderly development can proceed without delay.

The objective of this study was to provide guidelines, procedures, and documentation for the right-of-way agent and lawyer in valuation, legal, and administrative problems as applied to air space acquisition and planning. The primary emphasis was on developing applicable valuation theory and criteria.

The research included an inventory and review of before-and-after case study material where air space had been bought, sold, or leased. An analysis was made in terms of factors common to all cases and of special factors relevant to various uses of air space and various types of highway structures.

The research also evaluated the adequacy of existing legislation and analyzed and reported on legal ramifications that influence the valuation process, taking into consideration legal constraints peculiar to air space valuation. A basic theory for the evaluation of air rights was developed.

The variables and factors that influence air space acquisition and the valuation processes were identified and analyzed. Matrices were developed to provide a comprehensive collection of relevant valuation factors, including economic feasibility analysis. The primary aim was to provide a clear and precise presentation of all factors considered in the valuation process and a basis for selecting the most desirable use.

The project report has been published as:

NCHRP Report 142, "Valuation of Air Space."

#### **Project 11-6**    FY '74

##### **Valuation and Compensability of Noise Pollution**

*Research Agency:* Jack Faucett Associates  
*Principal Invest.:* Dr. E. J. Mosbaek  
*Effective Date:* April 1, 1974  
*Completion Date:* July 31, 1975  
*Funds:* \$100,000

The view is widely held that highway noise has resulted in a deterioration in the quality of life along roadways. Although noise abatement procedures are being developed, their over-all effectiveness is still open to question and they are not always applicable to all situations.

Therefore, highway administrations in the several states are confronted with the need to consider various ways of dealing with the impact of noise pollution resulting from highway traffic. Methods for measurement and prediction of noise produced by highway traffic are reasonably well developed, as are criteria for the interference of this noise with various human activities. However, criteria for determining compensability where excessive noise levels are anticipated do not exist. Consequently, it is desirable to develop measures of compensability for damages resulting



from such noise. Such measures could be used, for example, in socio-economic environmental analyses or for assessing the comparative feasibility of abatement measures, as well as for establishing a basis for compensation.

The objective of this research was to identify and develop fair and equitable valuation methods and compensability criteria for the effect on adjacent areas of noise anticipated to be produced by traffic on proposed highway improvements. To accomplish these objectives, the research included the following tasks:

1. Review and summarize recent literature, including court decisions, pertaining to elements of damages arising from noise, and theories of compensation therefor, including methods of measurement and valuation of such damage.
2. Define measures and scales for quantifying the extent of potentially compensable damages resulting from exposure to highway traffic noise. Variables to be quantified should include such factors as impact on property values and interference with human activities.
3. Develop a compensation model or models that relate levels of compensation to varying levels of noise exposure and different land uses.
4. Apply and evaluate the use of the compensation models against a set of representative highway environments to assess the economic effects of noise compensation, and revise the compensation models on the basis of the evaluation.
5. Prepare a guide for determining rates of compensation for damages resulting from exposure to highway traffic noise, for practical application in planning and design of highways.

Research has been completed and copies of the agency's final report have been distributed to NCHRP sponsors. Loan copies of the report are available from the NCHRP Program Director.

## 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 AASHTO Road Test demonstrated that permanent deformations can occur in steel beams due to a combination of load, fabrication, and environmental stresses which totally exceed the yield point of the steel. The current AASHTO specifications permit overloads on the typical highway bridges in service, and the possible occurrence of similar permanent deformations in these could foreseeably affect the useful life of the structure.

This study was confined to simple-span composite and simple-span noncomposite steel-stringer highway bridges and is directed to a determination of the causes and magnitudes of fabrication and environmental stresses, of the possible existence of permanent deformations in existing bridges due to current specifications, and of the effect from cycles of overloading.

This research was initiated to study the magnitude and effect of permanent deformations in simple-span composite and noncomposite steel-stringer highway bridges. Included in the work was a study of the causes and magnitudes of stress which, in addition to normal load stresses, lead to yielding of the steel stringer at load stresses with calculated magnitudes lower than the yield point of the material. Such factors as residual stress distribution due to rolling and welding, effects of thermal gradients, and the effects of creep and shrinkage of the slab on the stress in the steel were considered.

The final report has been included in the report for Project 12-6, which will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1975*.

### Project 12-2 FY '66

#### Distribution of Wheel Loads on Highway Bridges

*Research Agency:* Iowa State University  
*Principal Invest.:* Dr. W. W. Sanders, Jr.  
*Effective Date:* June 1, 1966  
*Completion Date:* December 31, 1968  
*Funds:* \$79,512

The current AASHTO 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:*                    \$82,253

The present construction practices used in providing camber in rolled beams result in an unpredictable loss of camber during the early life of the bridge. This loss of camber occurs under loads lower than those causing strains equal to the yield point of the material. There is a need for a determination of the causes of the loss of camber when the camber was produced by heat, strain, restraint, or a combination thereof. Toward fulfilling this need, the primary objective of this research was to recommend a means of predicting the permanent camber in rolled beams resulting from specific fabrication methods and to include (1) a thorough survey of available data on residual stresses in rolled beams; (2) a survey of existing methods of cambering beams and a classification of methods into different categories, if possible, with cambering by both mechanical and thermal means being studied; (3) the determination of the magnitude and distribution of residual stresses in beams as rolled and delivered to the fabricator without camber, with the beams studied being of sizes representative of typical highway bridges; (4) the determination of the effect of the cambering methods investigated on residual stresses; (5) the determination of permanent deformations in rolled

beams without added camber when subjected to repeated loads at various levels with loads lower than those causing computed yield point stresses (this does not presume to be fatigue loading, but the number of cycles applied would be equal to six months service life of a bridge); (6) the determination of permanent deformations in rolled beams cambered by the methods investigated when subjected to repeated loads at various levels of loading lower than those causing computed yield point stresses, the number of cycles applied being equal to six months service life of a bridge; and (7) the formulation of a mathematical model (after the determination of objectives 5 and 6) for predicting the permanent camber.

The final report, which includes the findings of Project 12-1, will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1975*.

#### Project 12-7 FY '67

##### Effects of Weldments on Fatigue Strength of Steel Beams

*Research Agency:* Lehigh University  
*Principal Invest.:* Dr. John W. Fisher  
*Effective Date:* Oct. 1, 1966 July 1, 1970  
*Completion Date:* Jan. 31, 1970 Dec. 31, 1972  
*Funds:* \$199,023 \$200,000

The fatigue fractures observed in the coverplated steel beam bridges included in the AASHO Road Test, as well as those obtained in other similar structures, emphasize the important effect of welding and welded details on the life expectancy of highway beam or girder bridges. Also of great significance in these bridges are the loading history, the type of materials used, the design details, and the quality of fabrication. Among the more important design details are such factors as coverplates, stiffeners, attachments, and splices. Only approximate general mathematical design relationships have been possible on the basis of the limited existing experimental data. However, with the conduct of additional research, and an analysis and evaluation of the many interrelated fatigue parameters, suitable basic relationships can be developed to properly design welded bridges for a desired life expectancy.

The principal objective of Phase I of this research was to develop design relationships that define the basic behavior of welded coverplated beams under constant-amplitude fatigue loading. The results of the Phase I work have been reported in:

NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams."

The Phase II work had the objective of extending the basic knowledge obtained under Phase I into important design considerations, including stiffeners and/or lateral and transverse connections. Phase II included a continuing review of existing data and mathematical relationships defining the fatigue behavior of various details under constant-amplitude loading. It also included a statistically designed and controlled experiment that was intended

to provide new information for the development of suitable mathematical relationships that can predict the fatigue behavior of welded beams with stiffeners and/or lateral and transverse connections. Variables studied included applied stresses, design details, and type of steel.

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

NCHRP Report 147, "Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments."

#### Project 12-8 FY '66

##### Bridge Rail Service Requirements as a Basis for Design Criteria

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Dr. Robert M. Olson  
*Effective Date:* Mar. 1, 1968 Jan. 2, 1970  
*Completion Date:* Feb. 28, 1969 June 30, 1971  
*Funds:* \$28,793 \$69,753

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

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

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

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

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

tested bridge rail designs by a mathematical model for purposes of further validating the model and theoretically estimating the efficiency of the design.

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

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

#### Project 12-9 FY '67

##### Elastomeric Bearing Research

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

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

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

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

NCHRP Report 109, "Elastomeric Bearing Research."

#### Project 12-10 FY '70

##### Analysis and Design of Bridge Bents

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

The present strong emphasis on safe and aesthetic design of reinforced concrete highway bridges has resulted in substructure configurations that depart widely from the traditional footing-column-cap frame design. Aesthetic considerations often dictate the concealment of massive concrete caps and elimination of numerous vertical columns; however, design procedures in current use are not applicable

to these new configurations. There is a general feeling that current procedures result in oversized 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 accompanied the experimental work.

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

NCHRP Report 163, "Design of Bent Caps for Concrete Box Girder Bridges."

#### Project 12-11 FY '71

##### Waterproof Membranes for Protection of Concrete Bridge Decks

*Research Agency:* Materials Research & Development  
*Principal Invest.:* C. J. Van Til C. J. Van Til  
 B. J. Carr  
*Effective Date:* Aug. 1, 1970 July 15, 1973  
*Completion Date:* Mar. 31, 1973 June 30, 1978  
*Funds:* \$206,025 \$100,000

Many bridge decks suffer damage as a result of penetration of water and deicer solutions through the deck

surface. One possibility for providing the protection necessary to alleviate this damage is to place an impermeable membrane over the entire deck surface. To be effective, such a membrane must maintain bond with the deck surface and must have sufficient extensibility to bridge active cracks without rupture through the range of temperature and loads to which the deck is subject. It is likely that, in order to realize an acceptable degree of permanence, the membrane either will be protected by a wearing surface, such as asphaltic concrete, or will provide adequate wearing qualities within itself.

The objective of this research is to develop, or discover, one or more effective waterproofing membrane systems for use on concrete bridge decks.

The objective is being approached in a two-phase study. Phase I, now complete, was devoted to preliminary evaluation of all available membranes, selection of the most promising for field evaluation, and development of a field evaluation plan. Phase II, now in progress, is the field evaluation.

Phase I of the research consisted of conducting a detailed literature search; defining the service requirements for effective membrane systems; conducting sufficient field inspections to evaluate selected systems, including application techniques; conducting controlled laboratory studies to identify and define those properties that affect performance of membrane systems, and devising qualifying tests relative to field performance; developing a procedure for determining cost-benefit ratios associated with the use of membrane systems, and demonstrating the procedure by example cases; and devising an experimental program for evaluating the performance in the field of selected membrane systems under service conditions.

Of an initial group of 147 systems, 78 were selected for more detailed study. Characterization and performance data (from both laboratory and field) eventually produced five survivor systems that appeared to be the most promising candidates for further field evaluation. All of the survivors require a protective surfacing of asphaltic concrete to serve adequately, and all but one appear to require the application of an intermediate protective layer to avoid damage by construction operations subsequent to installation.

The results of Phase I have been reported in:

NCHRP Report 165, "Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase."

Under Phase II, the five systems selected as most promising were experimentally installed on new decks at each of four bridge sites in 1974 and 1975. Semiannual observations of performance of the installed systems are in progress.

*Completion Date:* October 31, 1975

*Funds:* \$310,000

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

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

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

The primary objective of this project is to develop information on the properties of welded steel bridge members under variable-cycle fatigue loadings and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The agency pursued the project objectives by: a study of pertinent past work, with particular emphasis on field measurements of stresses in bridges under traffic; a theoretical study to predict from existing hypotheses the fatigue behavior of small specimens and beams that were tested later in the study; variable-amplitude fatigue tests of small specimens simulating certain beam details for the purpose of verifying the variable-amplitude load spectra selected and crack propagation threshold assumptions; variable-amplitude fatigue tests of relatively large beams of various steels, with typical bridge details similar to those tested in NCHRP Project 12-7; and complete evaluation of the experimental results and development of methods of utilizing the results for design and specification purposes.

Research has been completed, and the final report is in the NCHRP editorial and publication process. NCHRP Research Results Digest 60, "Fatigue of Welded Steel Bridge Members Under Variable-Amplitude Loadings," containing some of the findings was published in April 1974.

#### **Project 12-12**    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

#### **Project 12-13**    FY '73

#### **Cathodic Protection for Reinforced Concrete Bridge Decks**

*Research Agency:* USS Engineers and Consultants

*Principal Invest.:* J. B. Vrable

*Effective Date:* October 1, 1972

*Completion Date:* July 31, 1974

*Funds:* \$174,601

Many reinforced concrete bridge decks experience damage because of corrosion of the reinforcing steel. One potential method for controlling this corrosion is the application of cathodic protection. Effective cathodic protection must provide proper current distribution and achieve protective polarization of the reinforcing steel. Therefore, there is a need to develop design criteria and optimum designs for cathodic protection systems that can arrest or control corrosion of reinforcing steel in concrete bridge decks, particularly in existing structures.

The objective of this research was to develop a technically and economically feasible cathodic protection system(s) for reinforced concrete bridge decks.

In this study, the two primary approaches to cathodic protection—the impressed current system and the sacrificial anode system—were investigated. Analog studies in the laboratory and prototype model studies were main features of the investigation. The feasibility of applying either approach to protecting bridge deck steel reinforcement against corrosion was demonstrated. A detailed work plan for a field evaluation of cathodic protection applying the results of the study was developed.

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

#### **Project 12-13A** FY '73

##### **Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks**

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

Many reinforced concrete bridge decks experience damage because of corrosion of the reinforcing steel. One method for controlling this corrosion is the application of cathodic protection. Effective cathodic protection must provide proper current distribution and achieve protective polarization of the reinforcing steel. There is a need to develop design criteria and optimum designs for cathodic protection systems that can arrest or control corrosion of reinforcing steel in concrete bridge decks, particularly in existing structures.

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

The objective of this research is to field evaluate the effectiveness of a zinc anode galvanic protective system applied to the surface of a bridge deck exhibiting active reinforcing steel corrosion. The research is to consist of the design and installation of two or more variations of the

zinc anode galvanic protective system on a bridge deck in regular service. A two-year performance monitoring program is to be conducted, as is a program to obtain cost and life data. One experimental area is to contain zinc anodes placed over each reinforcement bar in the top layer of reinforcement. A third experimental area is reserved for an innovative system that will be the option of the research agency. Asphaltic concrete will be placed over the electrical elements to protect them and to serve as a wearing course.

The research agency has entered into an agreement with the Illinois Division of Highways under which the experimental installations are to be placed in a bridge deck rehabilitation construction contract. Construction plans and specifications for the experimental installations have been prepared and the construction is to be placed under contract early in 1977.

#### **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  $-100^{\circ}\text{F}$  and room temperature by using standard impact Charpy V-notch specimens.

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

#### **Project 12-15 FY '73**

##### **Detection and Repair of Fatigue Cracking in Highway Bridges**

*Research Agency:* Lehigh University  
*Principal Invest.:* Dr. John W. Fisher  
*Effective Date:* October 1, 1972  
*Completion Date:* April 30, 1975  
*Funds:* \$100,000

Relatively large reductions in fatigue strength of many welded details occur when fatigue cracks initiate and grow from the small micro-size defects that exist at the weld periphery. This behavior has been well demonstrated by studies on coverplated beams and other comparable details and has been reported in NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams." Recently, fatigue cracking has been observed in the field where complete fracture of a tension flange was generated from fatigue crack growth at the toe of a transversely welded coverplate. In this instance, the bridge was only 13 years old. Subsequent inspection of 15 other coverplate ends revealed that the two beams adjacent to the cracked member were also cracked through about one-half the flange thickness. Smaller fatigue cracks were detected at several other coverplate ends.

When this research was initiated a review of available methods for the detection of fatigue cracks was needed. Typical details that are most susceptible to fatigue cracking needed also to be identified. In addition, methods were needed to improve the fatigue strength of severe notch-producing details of existing structures subjected to high volumes of heavy truck traffic.

The objectives of the study were to: (1) compile a

state-of-the-art review of existing methods of nondestructive inspection and evaluate their reliability and adaptability in the detection of fatigue cracks in welded highway bridges; (2) compile a state-of-the-art review of typical existing and currently designed welded bridge details and evaluate those most susceptible to fatigue crack growth; (3) review and evaluate methods for improving the fatigue life and arresting the progress of fatigue damage that occurs at the weld toes of severe notch-producing details where the probability of failure is greatest. The methods were evaluated by tests of "as welded" and of fatigue-damaged coverplate beam specimens of A36 steel. These tests were comparable to and correlated with those conducted in NCHRP Project 12-7 and reported in NCHRP Reports 102 and 147. The experimental variables include crack size at the time of treatment, methods of improvement, stress range, and minimum stress; and (4) recommend methods for improving the fatigue life of, and arresting the progress of fatigue damage to, welded highway bridges.

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

Research has been completed, and the project report is in the NCHRP editorial and publication process. Meanwhile, loan copies are available from the NCHRP Program Director.

#### **Project 12-15(2) FY '75**

##### **Retrofitting Procedures for Fatigue-Damaged Full-Scale Welded Bridge Beams**

*Research Agency:* Lehigh University  
*Principal Invest.:* John W. Fisher  
*Effective Date:* June 1, 1976  
*Completion Date:* August 31, 1978  
*Funds:* \$150,000

Relatively large reductions in fatigue strength of many welded details occur when cracks initiate and grow from the micro-sized defects that exist at the weld periphery. This behavior had been demonstrated by studies on coverplated beams and other structural details, and has been reported in NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams," and NCHRP Report 147, "Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments." Recently fatigue cracking has been observed in the field at a number of different structural details. In one instance, complete fracture of a tension flange followed fatigue crack growth at the toe of a transversely welded cover plate in a 13-year-old bridge. Subsequent inspection of 15 other cover-plate ends revealed that the two beams adjacent to the cracked member were also cracked through about one-half the flange thickness. Smaller fatigue cracks were detected at several other cover-plate ends.

This study builds on research completed earlier under NCHRP Project 12-15, "Detection and Repair of Fatigue Cracking in Highway Bridges." Project 12-15 demonstrated that peening the weld toe and applying a gas tungsten arc remelt process were successful in improving fatigue strength in the laboratory. The current study includes further work on these methods and is concerned with three major areas related to the retrofit or repair of fatigue-damaged members.

Task 1 is intended as a pilot study to demonstrate the applicability of peening and gas tungsten arc remelting in the field.

Task 2 is intended to provide supplemental information on the low stress range behavior of full-size bridge beams. These beams will be retrofitted and retested after various levels of fatigue crack growth.

Task 3 is intended to examine the fatigue strength of beams, with cracks at the ends of transverse stiffeners, that have subsequently been repaired by drilling holes at the crack tip. Five existing welded built-up beams are available for this study from an earlier test program.

Through December 31, 1976, most of the work in Task 1 was completed by carrying out repair procedures in the field on a fatigue-damaged bridge. Fabrication of beams to be tested in Tasks 2 and 3 is nearing completion. Analytical support studies continue to progress.

#### 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:* November 30, 1977  
*Funds:* \$214,912

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 methods currently used throughout the United States. The major emphasis of the project is on commonly used methods but some methods that have been used experimentally in the field are also being investigated.

The preliminary field survey sought to determine how well repair methods appear to be working and identify or "screen" methods for further study.

The laboratory evaluation is directed toward testing the observations and opinions obtained in the preliminary field survey and ranking the performance of the more successful repair methods. The evaluation includes work on laboratory specimens that simulate or reproduce the corrosion phenomena and repair methods identified in the preliminary field survey as being worthy of investigation. Investigative techniques include electrical measurements, chloride analyses, and other corrosion detecting procedures.

The field investigation will verify under service conditions the indications from the laboratory evaluations. Based on results of the laboratory evaluation, a limited number of decks selected so as to provide examples of the most important findings will be studied. In addition to visual examination, emphasis will be placed on techniques that indicate corrosion behavior (such as electrical measurements and chloride analyses).

The preliminary field survey has been completed, and the findings have been summarized in NCHRP Research Results Digest 85, "Bridge Deck Repairs." The laboratory evaluation will continue through mid-1977. The final part of the research will consist of data analysis and the field investigation.

#### Project 12-17 FY '77

##### Evaluation of Repair Techniques for Damaged Steel Bridge Members

*Research Agency:* Battelle Columbus Laboratories  
*Principal Invest.:* H. W. Mishler  
*Effective Date:* November 15, 1976  
*Completion Date:* November 14, 1977  
*Funds:* \$50,000

Steel bridge members often are subjected to damage due to accidental impact, mishandling, or fire. Methods used for repair of such members include: heat straightening, and welding or bolting splices, replacement components,



or reinforcement. The decision to repair a damaged member, and the techniques used, are determined on the basis of the inspector's or engineer's evaluation of the situation, with little sound engineering information available for guidance. To place this decision-making process on a more rational basis, it is necessary to assemble information concerning the effect of these repair techniques on the service life, safety, performance and maintenance of the structure. Decisions on method of repair must also consider the cost, user inconvenience, and esthetics of the repair technique.

A two-phase project is anticipated. Only Phase I is in progress at this time.

The over-all objective of this project is to provide guidance for the assessment of accidental damage to steel bridge members and to identify, develop, and evaluate the effectiveness of repair techniques. The specific objective of Phase I is to synthesize available information on the subject and to identify areas in need of investigation. The specific objective of Phase II is to evaluate the effect of the damage and the repair techniques identified in Phase I on the behavior of the structure, determine potential detrimental effects, and define the limits within which these repair techniques can be used. This is expected to be accomplished through application of selected techniques to damaged members and subsequent laboratory testing.

Phase I will include at least the following tasks:

Task 1. Identify and categorize common types of structural damage and frequencies of their occurrence.

Task 2. Analyze the state of the art of present practice and equipment used for assessing damage and making repairs on highway bridges, railroad bridges, and other steel structures. Included in the topics to be considered are heating temperature, jacking methods, straightening tolerance, limitation of methods, degradation of steel's mechanical properties due to heating and straightening, speed of repairs, relative cost, and influence on the service life of the structure.

Task 3. Based on existing experimental and field performance data, evaluate techniques that have been applied or may have application in correcting structural damage.

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

Through December 31, 1976, work has progressed on Task 1. Several state highway and transportation agencies have been visited.

## AREA 13: EQUIPMENT

Project 13-1 FY '65

### Equipment Rental Rates

*Research Agency:* Ernst & Ernst  
*Principal Invest.:* T. S. Dudick  
*Effective Date:* February 1, 1965

*Completion Date:* January 31, 1966  
*Funds:* \$22,800

This research dealt with the development of uniform methods and procedures for establishing construction equipment rental rates. It included the establishment of the purposes for which rental rates are used; the feasibility of determining equipment rental rates by type, use, and region; a formula for equitable rental rates; and recommended procedures for obtaining and evaluating all information required for the various factors in the formula.

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

NCHRP Report 26, "Development of Uniform Procedures for Establishing Construction Equipment Rental Rates."

## AREA 14: MAINTENANCE OF WAY AND STRUCTURES

Project 14-1 FY '65

### Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements

*Research Agency:* Bertram D. Tallamy Associates  
*Principal Invest.:* Dr. Bertram D. Tallamy  
*Effective Date:* March 1, 1965  
*Completion Date:* March 31, 1967  
*Funds:* \$205,128

This research involved an intensive study into typical maintenance operations on 28 Interstate test sections in several states for the purpose of satisfying the urgent need for a definitive system of determining maintenance requirements on a quantitative basis with due consideration being given to the requirements in terms of type, magnitude, and frequency. This system is applicable to Interstate highways within individual states and to comparable activities on the state highways. Attempts have been made to develop means for relating utilization of men, equipment, and material to production and maintenance operations and, further, to optimize efficiency in maintenance operations. The standards which were developed have been tested on a sample of maintenance operations on Interstate highways, and a unit maintenance cost index suitable for periodic updating was developed.

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

NCHRP Report 42, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index."

Project 14-2 FY '71

### Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities

*Research Agency:* Byrd, Tallamy, MacDonald, and Lewis

*Principal Invest.:* L. G. Byrd  
*Effective Date:* October 1, 1970  
*Completion Date:* March 31, 1973  
*Funds:* \$200,000

Highway maintenance activities often require occupancy of traffic lanes, structures, and shoulders of the roadway by men and equipment. This situation causes conflict between these activities and the traveling public, thus endangering both workmen and motorists and restricting the flow of traffic. The resulting development of hazardous situations and interference with the orderly flow of traffic is most pronounced where high-speed and/or high-density traffic conditions exist. There are several possible approaches to minimizing the problem and to providing a high level of safety, economy, and convenience for the highway user during required maintenance activities. At this time, utilization of techniques designed to reduce occupancy of the roadway by maintenance activities appears to offer potential for alleviation of the problem with least duplication of research efforts.

The objectives of this project were to identify and evaluate techniques that will significantly reduce the time of occupancy of the highway travel way and shoulders by maintenance forces for at least the following specific routine maintenance activities:

- (a) Bridge deck repairing.
- (b) Travel way patching.
- (c) Crack and joint sealing.
- (d) Mudjacking and subsealing.

Techniques for accomplishment of maintenance activities were intended to encompass the entire operation, including the necessary manpower, equipment, and materials. However, development of new materials or equipment was not considered to be within the scope of this study.

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

NCHRP Report 161, "Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities."

#### **Project 14-3 FY '73**

##### **Improved Pavement-Shoulder Joint Design**

*Research Agency:* Georgia Institute of Technology  
*Principal Invest.:* Dr. R. D. Barksdale  
*Effective Date:* September 15, 1972  
*Completion Date:* March 15, 1976  
*Funds:* \$100,838

The joint that results where portland cement concrete pavements and bituminous-surfaced shoulders interface has proved to be a prime contributor to pavement and shoulder distress and the need for costly maintenance. Leakage of surface water through the joint can lead to pumping, faulting at transverse joints, and shoulder cracking and settlement when in combination with other adversely contributing factors. Additionally, water penetrating through leaky joints and reaching some kinds of base materials and subgrade soils can cause swelling and frost damage (in cold

climates) with consequent pavement and shoulder damage.

Although the construction and maintenance of completely watertight pavement-shoulder joints for the life of the pavement is generally conceded to be impossible, it is believed that an effort should be made to minimize the passage of surface water through the joint. Because some water is therefore likely to enter through the joint at some time during the pavement life, provisions also should be made for subsurface drainage and/or treating the pavement layers to minimize the effects of the water. Consequently, there is need to develop reasonably adequate sealing systems for the joint, and to identify suitable design and construction techniques, including subsurface drainage, that will minimize the effects of the presence of some water.

The objectives of this project were to:

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

The research was conducted jointly with the University of Michigan.

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

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

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

#### **Project 14-4 FY '74**

##### **Reconditioning Heavy-Duty Freeways in Urban Areas**

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Dr. William B. Ledbetter  
 Dr. Alvin H. Meyer  
*Effective Date:* April 15, 1974  
*Completion Date:* March 24, 1976  
*Funds:* \$99,665

In the next decade, a considerable mileage of pavement

on the most heavily traveled freeways in urban areas will reach a condition where structural rehabilitation will be required to keep the freeways operable. Some pavements already have reached this state.

Today's commonly used repair methods of patching, removal and reconstruction, and the placing of thick overlays over the entire roadway are time consuming, disruptive of traffic flow due to blockage in the construction area, and generators of construction traffic for further interference. Patching rarely offers more than temporary relief. Removal for replacement has the disadvantage of wasting large quantities of existing pavement materials. Thick bituminous concrete and portland cement concrete overlays require wasteful coverage of the entire roadway although only a portion of the width may be structurally deficient. Vertical clearance requirements offer a further restraint in the use of thick overlays.

The duration and extent of interference to continuing use of the freeway facility during construction by current methods often create an impasse. Increased hazard to workmen and motorists makes timely, durable rehabilitation virtually impossible without closing or unacceptably restricting the freeway.

The overall objective of this project was development of a new technology for reconstituting and/or replacing all or part of the pavement structure on a heavily traveled urban freeway so that the finished product has a design service life equal to or greater than that of the original pavement, including restoration of riding and nonskid characteristics. The capabilities of producing substantial lengths of new or reconstituted pavement during off-peak hours, minimal interference with traffic during construction, and full reopening during the hours of maximum traffic flow, were required characteristics. The methods and procedures were evaluated in terms of economic feasibility for the rehabilitation of substantial segments of urban expressways. Lowest first cost per unit of repair or replacement is not a necessary limitation.

Research has been completed. The results are in the form of detailed management strategies for rehabilitation of 1/4-mile single-lane segments of pavement in 48 hr or less without using overlays. It was originally anticipated that the recommended rehabilitation strategy would be evaluated as part of a field evaluation phase. However, there does not appear to be a need for field evaluation of the recommended management strategies.

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

## AREA 15: GENERAL DESIGN

Project 15-1 FY '66

### Guardrail Design

*Research Agency:* Cornell Aeronautical Laboratory  
*Principal Invest.:* Raymond R. McHenry  
*Effective Date:* December 15, 1965  
*Completion Date:* June 14, 1966  
*Funds:* \$19,723

Many factors are involved when the highway design engineer is faced with the decision of when to install a guardrail. The decision should be based on rational warrants for their use, and the system should be effective and compatible with these warrants. A number of agencies have conducted tests on various systems. The resulting data on design and warrants need to be evaluated in order to provide the engineer with a choice of effective systems. Phase I of the project was directed toward the search and evaluation of existing data on design and warrants, a critical analysis of past and current research, and defining additional needed research.

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

NCHRP Report 36, "Highway Guardrails—A Review of Current Practice."

Project 15-1(2) FY '66 and FY '70

### Guardrail Performance and Design

*Research Agency:* Southwest Research Institute  
*Principal Invest.:* J. D. Michie  
*Effective Date:* July 1, 1967 May 1, 1970  
*Completion Date:* Aug. 31, 1970 Dec. 31, 1971  
*Funds:* \$280,000 \$100,000

Highway design engineers need a choice of effective guardrail systems. The considerable research already conducted on the more commonly used types (W-beam, standard cable, box beam) needed to be compared and analyzed critically for determination of further investigations necessary to refine structural details and to obtain more effective performance. A need for full-scale testing was apparent to fill in the gaps in previously concluded investigations. Accordingly, the objectives of the Phase I research were: (1) to critically analyze existing data on guardrail performance and identify additional needed research; (2) to conduct additional full-scale performance tests; and (3) to evaluate performance of various guardrail systems considering vehicle response and damage as a measure of accident severity and rail repair.

The Phase I findings have been published as NCHRP Report 54, "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers," and NCHRP Report 115, "Guardrail Performance and Design." A 10-min sound film 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 im-

proved transitions. Task 4 included the full-scale crash test evaluation of those promising concepts produced under Task 3.

The results of Phase II Tasks 1 and 2 have been published as NCHRP Report 118, "Location, Selection and Maintenance of Highway Traffic Barriers." The results of Phase II Tasks 3 and 4 have been published as NCHRP Report 129, "Guardrail Crash Test Evaluation—New Concepts and End Designs."

Additional work is under contract and, for administrative reasons, has been designated Project 22-2, "Traffic Barrier Performance and Design." Details will be found under that heading.

#### **Project 15-2 FY '66**

##### **Design to Control Erosion in Roadside Drainage Channels**

*Research Agency:* University of Minnesota  
*Principal Invest.:* Dr. Alvin G. Anderson  
*Effective Date:* July 1, 1966  
*Completion Date:* June 30, 1974  
*Funds:* \$97,300

The highway drainage engineer is required to provide designs to control erosion in roadside drainage channels over a wide range of conditions. Acceptable procedures have been developed for the design of channels for conditions where easily established grass cover will suffice and for conditions where paved linings are required. The objectives of this study were to establish criteria and extend existing procedures for conditions intermediate between these two. The major emphasis of the research will be placed on developing a procedure for the design of armored channels, with investigations into the critical tractive force of gravel and crushed stone.

Research has been completed, and the project report covering development of design procedures for armored channels has been published as:

NCHRP Report 108, "Tentative Design Procedures for Riprap-Lined Channels."

During an extension of the project, a limited field evaluation of the tentative design procedure was undertaken. The performance of four channels, designed and built in accordance with the procedures, was observed. Two of the four channels have been subjected to discharges approaching the design discharge and appear to be stable after the floods.

The essential findings of the field evaluation phase have been published as NCHRP Research Results Digest 67, "Field Evaluation of Tentative Design Procedure for Riprap-Lined Channels," and a summary is included in the *NCHRP Summary of Progress Through 1975*.

#### **Project 15-3 FY '68**

##### **Rational Structural Analysis and Design of Pipe Culverts**

*Research Agency:* Northwestern University

*Principal Invest.:* Dr. R. J. Krizek  
 Dr. R. A. Parmelee  
*Effective Date:* October 1, 1967  
*Completion Date:* December 31, 1968  
*Funds:* \$49,937

Various methods are currently being used in the design of pipe culverts, and considerable research is in progress that examines these methods. There is a general lack of agreement between theory and field experience. Current methods being used in design of culverts fail to reflect in a rational way many of the major aspects of behavior observed in the field.

The objective of this study was to evaluate previous research and current practice for the purpose of developing rational design methods for both rigid and flexible pipe culverts.

Research has been completed and a project report has been received containing an extensive bibliography and synthesis of current knowledge on the design and installation of pipe culverts. It is apparent that information is not available at this time to develop a completely rational structural design procedure, due largely to lack of a generally accepted definition of pipe failure. However, several specific factors, such as installation practices, construction techniques, soil type, and safety factor, can be given greater consideration in design criteria.

The project report has been published as:

NCHRP Report 116, "Structural Analysis and Design of Pipe Culverts."

#### **Project 15-4 FY '68**

##### **Estimating Runoff Rates from Small Rural Watersheds**

*Research Agency:* The Travelers Research Center  
*Principal Invest.:* Dr. Paul Bock  
 Isadore Enger  
*Effective Date:* September 1, 1967  
*Completion Date:* March 16, 1970  
*Funds:* \$299,902

A basic problem in designing highway bridges and culverts for stream crossings is the determination of the flow to be accommodated. This involves estimating the magnitude of peak flows at various frequencies for the drainage area under consideration. Most small rural watersheds are ungaged, thus the engineer is required to estimate the design flow for these areas on the basis of limited topographic and climatic data.

Many state highway departments and other agencies are participating with the U.S. Geological Survey in programs to collect runoff information from small rural watersheds that is intended to provide a better understanding of the generation of runoff. With this background, it appeared possible to develop improved procedures for estimating the magnitude and frequency of peak flows for small rural watersheds (approximately 20 sq mi or less). The objective of this project was to develop such procedures that (1) require only data readily obtainable by designers, (2) use parameters that are logically justified, (3) take cognizance

of differences due to geographic characteristics, and (4) present the results in readily usable form.

The objectives have been partially met in that methods for estimating the magnitude and frequency of runoff from small rural ungaged watersheds have been developed. The question of whether they provide better estimates of runoff than currently used methods for a given watershed is not easily answered. Indications are that they may provide better estimates in some cases. Of probably greater significance is the compilation of information for 493 rural watersheds with an area of 25 square miles or less and at least 12 years of surface runoff data that can be used by others to develop better methods of prediction for a particular locality.

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

NCHRP Report 136, "Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds."

#### **Project 15-5    FY '68**

##### **Dynamic Characteristics of Heavy Highway Vehicles**

*Research Agency:* General Motors Corporation  
*Principal Invest.:* D. E. Pollack  
*Effective Date:* August 15, 1967  
*Completion Date:* January 10, 1969  
*Funds:* \$135,000

The dynamic loading of bridges and pavements by heavy highway vehicles influences the life expectancy of these highway structures by an unknown amount. Increasing permissible vehicle loads and speeds may increase the dynamic loading and shorten the life of these structures.

Dynamic pavement loading is influenced by the pavement roughness characteristics and by certain characteristics of the vehicle. It is necessary to consider these factors in order to predict the loads that will be produced.

With the foregoing in mind, information was gathered on those vehicle characteristics that make a significant contribution to the dynamic forces. Equipment for measuring these characteristics was constructed and the characteristics of representative types of heavy vehicles were determined.

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

NCHRP Report 105, "Dynamic Pavement Loads of Heavy Highway Vehicles."

#### **Project 15-6    FY '68**

##### **Development of Criteria for Safer Luminaire Supports**

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Dr. T. C. Edwards  
*Effective Date:* September 1, 1967  
*Completion Date:* August 31, 1968  
*Funds:* \$147,254

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 results of the experimental phase have been published as:

NCHRP Report 170, “Effects of Deicing Salts on Plant Biota and Soils—Experimental Phase.”

**Project 16-2** FY '68

**Evaluation of Research on Roadside Development**

*Research Agency:* Western States Landscape Associates  
*Principal Invest.:* Wayne O. Earley  
*Effective Date:* October 1, 1967  
*Completion Date:* March 31, 1969  
*Funds:* \$100,000

The objective of this project was to review, interpret, and evaluate past and present research on roadside development, describe areas where additional or continued research is needed, and recommend procedures for resolving these needs. The study included, but was not limited to, consideration of the relationship of roadside development and (1) highway location and design; (2) vegetation (planning, establishment, and management by plant growth zones in consideration of erosion control and roadside plantings); (3) resource conservation; (4) rest areas, scenic turnouts, and overlooks; (5) safety; and (6) right-of-way, scenic areas, and adjacent land use. Recognition was given to research under way or accomplished in legal authority, but it was not evaluated in this project.

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

NCHRP Report 137, “Evaluation of Research on Roadside Development.”

**Project 16-3** FY '73

**Erosion Control During Highway Construction**

*Research Agency:* Utah State University  
*Principal Invest.:* Dr. Calvin G. Clyde  
 Dr. C. Earl Israelsen  
 Paul E. Packer  
*Effective Date:* November 1, 1973  
*Completion Date:* June 30, 1976  
*Funds:* \$179,224

Uncontrolled water and wind erosion resulting from construction activities causes significant damage to the environment. The sediment produced pollutes surface water, restricts drainage, fills reservoirs, damages adjacent land, and destroys the natural ecology of lakes and streams. Besides harming the environment, soil erosion during construction increases costs and causes extensive delays and repairs.

Research is needed to develop more effective techniques, devices, and materials to control erosion during construction activities. This need was documented in NCHRP Synthesis 18, “Erosion Control on Highway Construction.”

The synthesis study, while focusing attention on the need

for a major research effort, also uncovered a large quantity of information, often fragmented or underevaluated, on known erosion control measures likely to have application in highway construction. Because of the existence of this information, the urgency of the problem, and research funding limitations, a logical first step in the eventual solution of the total problem was the development of recommendations for an interim set of specific guidelines for erosion control based on existing information.

The objectives of this project were to:

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

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

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

Research has been completed. The final report is in the process of being prepared for publication.

**AREA 17: SAFETY**

**Project 17-1** FY '66

**Development of Improved Methods for Reduction of Traffic Accidents**

*Research Agency:* Cornell Aeronautical Laboratory  
*Principal Invest.:* John W. Garrett  
*Effective Date:* February 1, 1966  
*Completion Date:* May 31, 1968  
*Funds:* \$247,847

The objective of this research was to develop motor vehicle accident investigation procedures, records, and statistics, which will more accurately reveal accident causation than the current accident record system. An extensive review of the state of the art revealed that the current data collection forms and procedures do not meet research requirements; few statistically trained personnel are employed for data analysis. Also, safety findings are assimilated slowly by the agencies responsible for the design, maintenance, and operation of the highway system. Long-term recommendations included an improved centralized accident record system in which accident data were integrated with appropriate nonaccident data. Also

proposed was a multilevel accident reporting scheme providing minimum data on all accidents, intensive investigative data on a small percentage of accidents, and special study data collected for a statistical sample of accidents. Improved cooperation between operating agencies with similar objectives was regarded as essential. Short-term recommendations included increased dissemination and utilization of current safety knowledge; utilization of modern technology at all levels of the system through the initiation of continuing education seminars and a safety review board; use of trained statistical personnel and techniques for better utilization of data; and use of accurate accident location methods. Location methods were reviewed and evaluated for guidance. Demonstration studies were performed to illustrate the feasibility of the proposed system and the techniques required. The study demonstrated the use of police to gather factual data in a study where they were provided with special report forms, written instructions, special training, and equipment. Utilization of intensive accident investigation procedures and the use of both accident and nonaccident data in a study also were demonstrated.

The project report has been published as:

NCHRP Report 79, "Development of Improved Methods for Reduction of Traffic Accidents."

#### Project 17-2 FY '72

##### Methods for Evaluating Highway Safety Improvements

*Research Agency:* Operations Research Incorporated  
*Principal Invest.:* Harry Denning  
*Effective Date:* January 10, 1972  
*Completion Date:* June 20, 1972  
*Funds:* \$29,973

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for before-and-after and parallel studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do studies, a single document has not existed that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research was to provide a detailed technique in the form of guidelines from which calculations could be made that would allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

Activities prior to the contract's termination included detailed planning for the project and preparation of a detailed working plan. This research was resumed under Project 17-2A.

#### Project 17-2A FY '72

##### Methods for Evaluating Highway Safety Improvements

*Research Agency:* Roy Jorgensen Associates  
*Principal Invest.:* John C. Laughland  
*Effective Date:* February 1, 1973  
*Completion Date:* July 31, 1974  
*Funds:* \$98,403

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for before-and-after and parallel studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do studies, a single document has not existed that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research was to provide a detailed technique in the form of guidelines from which calculations can be made that will allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

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

NCHRP Report 162, "Methods for Evaluating Highway Safety Improvements."

### AREA 18: CONCRETE MATERIALS

#### Project 18-1 FY '68

##### Revibration of Retarded Concrete for Continuous Bridge Decks

*Research Agency:* University of Illinois  
*Principal Invest.:* Dr. H. K. Hilsdorf  
*Effective Date:* September 1, 1967  
*Completion Date:* December 1, 1969  
*Funds:* \$103,895

Transverse and longitudinal cracking of continuous concrete bridge decks can be caused by changes in deflection and rotation over supports during construction, in addition to the possible effect of restraint to subsidence (bleeding) afforded by the top reinforcing steel. Such cracking is of significance with respect to the development of spalling. Revibration of retarded concrete may be useful in eliminating such occurrences in continuous bridge decks placed in one operation; therefore, this research had the objectives of (1) conducting a survey to determine the extent to which either delayed vibration or revibration has been used in placing bridge deck concrete, including the purpose, conditions, and results; (2) determining by laboratory and/or field tests if transverse and longitudinal cracking can be significantly reduced by revibration after retarded concrete has been placed over the entire deck of a continuous bridge or a complete segment of several spans supported by a continuous girder system; (3) determining the effect of revibration and subsequent finishing on the durability of bridge

deck surfaces exposed to deicing chemicals; and (4) determining the most effective and practical means of revibration in the field.

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

NCHRP Report 106, "Revibration of Retarded Concrete for Continuous Bridge Decks."

#### **Project 18-2**      FY '73

##### **Use of Polymers in Highway Concrete**

*Research Agency:*      Lehigh University  
*Principal Invest.:*      Dr. John A. Manson  
*Effective Date:*        October 1, 1972  
*Completion Date:*      September 30, 1975  
*Funds:*                    \$300,000

Deterioration of concrete bridge decks, reduction of skid resistance on concrete surfaces, unacceptable concrete wear rates, and a need for thinner and stronger concrete slabs are problems that confront every state highway department. Among the major deficiencies of some of the concrete presently used are high permeability, low strength, cracking, low wearing ability, and spalling. The mechanisms causing deterioration include frost action, differential expansion and contraction, reinforcement corrosion, chemical attack, traffic loads, and wear.

Polymer-impregnated concrete has been reported to provide significant increases in strength and durability. However, present developments and techniques have not progressed to the extent that they are adequate for field use; therefore, more work in this area is required.

The over-all objective of this project was to develop the technology for the economical use of polymers to improve the serviceability of concrete in highways. The immediate goal concerned economically feasible methods for polymer impregnation of concrete bridge decks in place.

The program was conducted jointly by Lehigh University and The Pennsylvania State University.

The study included a state-of-the-art survey, laboratory development of engineering data on the penetration of candidate materials, testing of drying techniques and prototype impregnation equipment, durability studies, and experimental impregnations of two bridge decks. Final work centered on the use of methyl methacrylate and trimethylolpropane trimethacrylate (MMA/TMP/TMA) as the monomer system. Two methods of drying (propane-fired infrared and propane torch units), two methods of monomer application (soaking and pressure), and two methods of polymerization (hot water and steam) were used. Polymer penetration to depths of more than 4 in. was achieved. Extreme dryness was found to be the key to deep penetration. This was obtained with temperatures of about 250 F at 4-in. depths. The first successful penetrations of a bridge deck were achieved with equipment covering areas of only a few square feet. Field equipment was enlarged and up-graded, and successful impregnations were achieved over several 36-sq ft areas on two bridge decks—one a test-track deck and the other a deck in

regular service. A field manual describing the techniques that were developed and including suggested safety precautions and acceptance criteria is included in the final report.

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

## **AREA 19:      FINANCE**

#### **Project 19-1**      FY '68

##### **Budgeting for State Highway Departments**

*Research Agency:*      Ernst & Ernst  
*Principal Invest.:*      F. W. Hinck, Jr.  
*Effective Date:*        September 5, 1967  
*Completion Date:*      September 4, 1968  
*Funds:*                    \$45,000

Effective budgeting is interwoven with and is basic to the whole management and decision-making process. In seeking its fullest benefit, budgeting needs to be applied to all potential uses. The modern concept of the total budget process views budgeting as an integral part of planning, administration, and policy making.

Although budget plans of varying effectiveness now exist in the several state highway departments, there is no indication that highway administration recognizes and utilizes the budget process to its full potential.

Research is needed with the long-range objective of devising a concisely defined framework of budget systems, together with detailed documentation for implementing policies and procedures. To meet this need, the researchers analyzed the organization plans and funding arrangements controlling state highway departments. They determined in detail the prerequisites which must be satisfied and the problems requiring resolution for effective state highway budgetary systems to be instituted. Documented recommendations were developed for devising a concise universal state highway budgeting system with detailed aids for implementing appropriate policies and procedures.

Research has been completed. The project report will not be published in the regular NCHRP report series, but the essential findings from the report have been published in NCHRP Research Results Digest 20.

#### **Project 19-2(1)**      FY '69

##### **Develop Performance Budgeting System to Serve Highway Maintenance Management**

*Research Agency:*      Booz • Allen & Hamilton  
*Principal Invest.:*      H. L. Wilsey  
*Effective Date:*        September 2, 1968  
*Completion Date:*      October 31, 1968  
*Funds:*                    \$6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increas-



ingly 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. Trick  
*Effective Date:* March 16, 1964  
*Completion Date:* October 31, 1967  
*Funds:* \$455,000

The objectives of the Highway Research Information Service were: (1) to select and store input information from current and past highway research that will be of value to users of highway information, (2) to disseminate current information to users, and (3) to retrieve relevant information on request.

All storage and retrieval procedures are now operational. The service, available to anyone interested, includes abstracts of publications, new reports on research in progress,

and the updating of previously stored reports for ongoing research.

### Project 20-2 FY '66

#### Research Needs in Highway Transportation

*Research Agencies:* Bertram D. Tallamy Associates  
 Wilbur Smith and Associates  
*Principal Invest.:* Lloyd G. Byrd  
 Paul E. Conrad  
*Effective Date:* April 1, 1966  
*Completion Date:* December 31, 1967  
*Funds:* \$98,760

This project developed a coordinated framework of needed short- and long-range research in the field of highway transportation. Major areas of needed research were identified and arranged in the general framework. Technical priorities of need and an estimate of the appropriate level of funding for each are included. The framework was designed in such a manner as to permit updating with minimal effort.

The project report gives method or concept for structuring research as developed by the research, which includes a method for assigning priorities and costs to proposed research. The methods developed under this research were applied to 900 proposed research project statements considered in the study to formulate an example research program.

The final report has been published as:

NCHRP Report 55, "Research Needs in Highway Transportation."

### Project 20-3 FY '67 and FY '68

#### Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

*Research Agency:* Texas A & M University  
 Research Foundation  
*Principal Invest.:* Dr. J. A. Wattleworth  
 Kenneth G. Courage  
*Effective Date:* Dec. 15, 1966 Jan. 1, 1967  
*Completion Date:* Jan. 31, 1969 Dec. 31, 1968  
*Funds:* \$394,016 \$200,540 \*

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Practical measures for increasing operational efficiency by judicious application of traffic surveillance, communication, and control were studied for the heavily traveled corridor of the John C. Lodge Freeway in Detroit.

The initial research program included an evaluation of the effectiveness of the existing National Proving Ground surveillance, communication, and control system, and its

\* 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.

individual components. Methods were determined for increasing the effectiveness of the freeway and surface street system, and equipment configurations were recommended to improve the system based on a cost-effectiveness study.

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

The major work items proposed for completion in 1968 were a pilot study of a freeway-frontage road driver information system, further freeway operations studies using improved detection and refined control techniques, environmental effects studies, pilot equipment studies for traffic-responsive signal control throughout the corridor, and a preliminary design for a more extensive driver-communication system to include the surface streets within the corridor. The project report for the 1968 work, "A Freeway Corridor Surveillance, Information, and Control System," was accepted but not published. A summary of the work has been provided in the report prepared under Project 20-3C.

At the end of 1968 the research agency requested, due to extensive other research commitments, to be relieved of further work. A continuation proposal was requested from the University of Michigan. The research was continued under Project 20-3A.

#### Project 20-3A FY '69 and FY '70

##### Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

*Research Agency:* University of Michigan  
*Principal Invest.:* Dr. Donald E. Cleveland  
*Effective Date:* Nov. 20, 1968 Jan. 1, 1969  
*Completion Date:* May 31, 1971 Dec. 31, 1969  
*Funds:* \$505,631 \$20,000 †

This project was a continuation of the 1967 and 1968 research conducted by the Texas Transportation Institute under Project 20-3.

The basic tasks and their respective components of the 1969 research work were designed to develop information required for the ultimate synthesis of a traffic surveillance, driver information, and control system capable of real-time control of traffic throughout an entire network of arterial streets and freeways. The topics included (1) detection of capacity-reducing incidents, (2) improved ramp control techniques and environmental effects, (3) pilot studies of freeway-frontage road informational system, (4) an experiment in traffic routing within the freeway corridor, and (5) observation of freeway operations. Draft reports on the topics of the 1969 research work have been accepted by the advisory committee.

† 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.

The 1970 research had the general objective of improving the combined level-of-service on the Freeway and the supporting street network. The work was divided into four principal tasks, all of which were completed: (1) improvement of ramp metering and freeway corridor flow; (2) improvement of Davison-Lodge interchange operation; (3) determination of the effect of weather on freeway corridor operations; and (4) long-term motorist response to the information system.

Draft final reports on the results from the work under the tasks were accepted and are available on a loan basis on request to the Program Director. They, along with the 1969 reports, have not been published, but are summarized in the report prepared under Project 20-3C.

#### Project 20-3B FY '70

##### Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting

*Research Agency:* Patrick J. Athol  
*Principal Invest.:* Patrick J. Athol  
*Effective Date:* July 1, 1972  
*Termination Date:* September 27, 1974  
*Funds:* \$31,116

Because a substantial body of knowledge relative to more efficient operation of systems made up of freeways and adjacent streets has been acquired through NCHRP Projects 20-3, 20-3A, and studies under other programs, Project 20-3B was established with the following objectives:

1. Preparation of a report summarizing the main findings of freeway surveillance and control on the John C. Lodge Freeway in Detroit. The end product of this synthesis was to have been one report that summarized all historic and technical activities of the research conducted by the State of Michigan, and under the NPG and NCHRP Projects 20-3 and 20-3A. The major emphasis was to be placed on reporting on usable results that have been found to be practical on the Lodge project.

2. Preparation of a report in the vein of "Getting the Most Service from Freeways," using published research reports and the experience available from past and ongoing freeway traffic operations projects.

Objective 1 was advanced only to the point of a preliminary report that was submitted to the TRB advisory committee for an acceptance review. Based on this review, extensive revisions were required. They were begun but were never completed; therefore, a revised report was never submitted. Some work was carried out toward Objective 2, but, although the original completion date had been overrun by a year, it was not substantial and never progressed to the point of a preliminary report. Still another extension was imminent; however, the contractor chose to quit without fulfilling the objectives set forth in his proposal. By mutual agreement, the project was terminated. This research was resumed under Project 20-3C.

**Project 20-3C** FY '70**Summary of the Lodge Freeway Research**

*Research Agency:* Asriel Taragin  
*Principal Invest.:* Asriel Taragin  
*Effective Date:* November 15, 1975  
*Completion Date:* July 15, 1976  
*Funds:* \$10,375

This project was initiated to prepare a summary report outlining the main findings from a long series of freeway surveillance and control studies on the John C. Lodge Freeway in Detroit. The historical research has been completed, and a report has been submitted. It covers the objectives, organization, and data, as well as the results, conclusions, and recommendations associated with each stage of the traffic research studies. References to all published and unpublished reports as well as file documents pertinent to the background of the studies have been appropriately identified.

The report has been distributed to the sponsoring agencies. A limited number of copies are available for sale or on a loan basis upon request to the NCHRP Program Director.

**Project 20-3D** FY '70**Summary of All Freeway Surveillance, Communication and Control Experience**

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

This project complements Project 20-3C. It was established to prepare a summary report of all experience with the surveillance, communications, and traffic control aspects of freeway operations. The project will draw on both published research reports and other experience available from relevant research projects. The final report is intended, therefore, to synthesize past and present practices and to provide judgmental values on their merits and successes in order to aid highway administrators in decisions related to freeway operation problems.

**Project 20-4** FY '68**Public Preference for Future Individual Transportation**

*Research Agencies:* Chilton Research Services (CRS)  
 National Analysts (NA)  
*Principal Invest.:* Robert K. McMillan  
 James M. Marshall  
*Effective Date:* May 2, 1967  
*Completion Date:* January 21, 1969 (CRS)  
 January 2, 1968 (NA)  
*Funds:* \$279,171

Reliable information is needed on public attitudes and

behavior relating to transportation and the factors that influence these, to permit more effective planning for the allocation of resources for transportation purposes. The objective of this research was to determine the attitudes and behavior of the public related to transportation, and identify the factors that influence such attitude and behavior.

To determine the foregoing, two independent national samples of 2,500 interviews each were surveyed in May 1967 by the two separate agencies. The surveys used the same questionnaire, so that after an initial statistical evaluation between the two surveys the results could be combined for a more detailed analysis. The survey was designed to determine what people think about the importance of various transportation modes and the sources and distribution of transportation financing. Attitudes were related to people characteristics, transportation and community values, transportation needs, and recorded behavior. This project presents a valid national description of transportation attitude and behavior patterns with determination of differences in social, economic, demographic, and geographic subgroups.

A first-phase report was published in 1968 as:

NCHRP Report 49, "National Survey of Transportation Attitudes and Behavior--Phase I Summary Report."

This report presents a preliminary analysis of the nationwide survey data. It includes a comparison of household and individual characteristics for both survey samples, and a question-by-question analysis of the total sample.

A second-phase report has been published as:

NCHRP Report 82, "National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report."

This report presents results of a more advanced statistical analysis of the data. This analysis is multi-variant in nature; that is, it considers many variables simultaneously to obtain a comprehensive view of transportation attitudes, their relation to behavior and demographic characteristics, and profiles of people holding these views.

The report includes 16 charts that indicate attitudes, according to eight demographic variables, toward spending for roadways and highways and public transportation. The report deals comprehensively with data by describing the methodology, statistical methods used, and the detailed findings.

**Project 20-5** FY '68 and continuing**Synthesis of Information Related to Highway Problems**

*Research Agency:* Transportation Research Board  
*Principal Invest.:* Dr. Paul E. Irick  
 T. L. Copas  
*Effective Date:* December 15, 1967  
*Completion Date:* Continuing  
*Funds:* \$100,000 annually, FY '68-71  
 \$200,000 annually, FY '72-'75  
 \$300,000 annually, FY '76-'77

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 un-evaluated. 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 39 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: "Durability of Drainage Pipe;" "Bridge Bearings;" "Staffing and Management Required for Social, Economic, and Environmental Impact Assessments."

The following reports are in the review stage: "Design of Pile Foundations;" "The Effect of Weather on Highway Construction;" "Recording and Reporting Methods for Highway Maintenance Expenditures;" "Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation;" "Safe Conduct of Traffic Through Highway Construction and Maintenance Zones."

The following topics are in the research stage: "Rapid-Setting Materials for Patching of Concrete;" "Consolidation of Concrete (Emphasis on Pavements and Bridge Decks);" "Rehabilitation of PCC Pavement Joints;" "Priority Programming and Project Selection;" "Effect of Bridge Painting Practices on Environment;" "Bus Transit Service Planning Guides (Route and Schedules);" "Recycling Materials for Highways;" "Construction Contract Staffing;" "Design and Use of Highway Shoulders;" "Pre-cast Concrete Elements for Transportation Facilities;" "State Highway and Transportation Data Storage and Retrieval Systems;" "Maintenance Equipment: Management and Selection Systems;" "Open-Graded Friction Courses;" "Photologging;" "Durability of Asphalts in Mixtures;" "Bituminous Patching Materials."

**Project 20-6** FY '69 and continuing

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

*Research Agency:* Transportation Research Board  
*Principal Invest.:* John C. Vance  
*Effective Date:* November 1, 1968

*Completion Date:* Continuing  
*Funds:* \$200,000 FY '69-'71  
 \$125,000 FY '72  
 \$50,000 FY '73  
 \$185,000 FY '74  
 \$125,000 FY '75  
 \$85,000 FY '76  
 \$75,000 FY '77

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 (Canceled)
- Study No. 11—Personal Liability of State Highway Department Officers and Employees (Research Results Digest No. 79)
- Study No. 12—Tort Liability of Highway Departments Arising Out of Skidding Accidents (Research Results Digest No. 83)
- Study No. 13—Appeal Bodies for Relocation Assistance (Research Results Digest No. 40)
- Study No. 14—Admissibility and Use of Severance Studies in Condemnation Litigation (Terminated due to insufficient data on which to base the study)
- Study No. 15—Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases (Research Results Digest No. 41)
- Study No. 16—Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation (Research Results Digest No. 42)
- Study No. 17—Liability of State Highway Departments for Design, Construction, and Maintenance Defects (Research Results Digest No. 80)
- Study No. 18—Compensability and Valuation of Noise, Pollution, and Other Environmental Factors (Abandoned)
- Study No. 19—Right of State to Secure Judicial Review of Federal Administrative Decisions (Study abandoned due to insufficient amount of case law)
- Study No. 20—Meaning of "Highway Purpose" (Canceled)
- Study No. 21—Duty to Warn Against Highway Defects (Study abandoned due to insufficient amount of case law)
- Study No. 22—Compensability for Consequential Damages Resulting from Partial Take or Taking Without Appropriation and Entry Upon the Land (Canceled)
- Study No. 23—Exclusion of Valuation Changes Resulting from Influence of Public Improvement: A Study of the Provisions of 42 U.S.C. 4651 (3) (Research Results Digest No. 45)
- Study No. 24—Eminent Domain: An Overview \*
- Study No. 25—Where Does Police Power End and Eminent Domain Begin? \*
- Study No. 26—Just Compensation and the Doctrine of Damnum Absque Injuria \*
- Study No. 27—The Meaning of Highway Purpose (Research Results Digest 68) \*
- Study No. 28—Valuation of Outdoor Advertising Rights \*
- Study No. 29—Valuation of Scenic Easements (Canceled)
- Study No. 30—Liability for Drainage Damage \*
- Study No. 31—Trial Strategy and Techniques Using the Income Approach to Valuation (Research Results Digest No. 54) \*
- Study No. 32—Trial Strategy and Techniques Using the Comparable Sales Approach to Valuation (Research Results Digest No. 47) \*
- Study No. 33—Trial Strategy and Techniques Using the Reproduction Cost Less Depreciation Approach to Valuation \*
- Study No. 34—Trial Aids in Highway Condemnation Cases \*
- Study No. 35—Model Airspace Act: A Vehicle for Joint Development \*
- Study No. 36—Formation of the Contract
- Study No. 37—Effect of Mistakes in Bids, Plans and Specifications
- Study No. 38—Legal Problems Arising from Changes, Change Clauses and Changed Conditions
- Study No. 39—Contract Completion Time: Damages for Delay; Liquidated Damages; Work Stoppage Under Court Order
- Study No. 40—Administrative Settlement and Disposition of Claims
- Study No. 41—Trial Strategy and Techniques in Contract Litigation
- Study No. 42—Environmental Litigation: Rights and Remedies
- Study No. 43—Trial Strategy and Techniques in Environmental Litigation
- Study No. 44—Legal Interrelationship of the Federal and State Governments
- Study No. 45—Review of the One-Offer System of Right-of-Way Acquisition
- Study No. 46—Liability of Governmental Agencies for Improper Traffic Control Devices, Signs, and Pavement Markings
- Study No. 47—Supplementation of Studies 15, 31, 32 and 33, and Project 11-1(2)
- Study No. 48—Supplementation of Studies, 3, 4, and 5.
- Study No. 49—Inverse Condemnation
- Study No. 50—Payment of Attorneys' Fees and Other Costs in Condemnation and Environmental Litigation
- Study No. 51—Appraisal of Property Damages Due to Highway Noise
- Study No. 52—The Use of Guarantee or Warranty Clauses in Highway Construction Contracts
- Study No. 53—Impact of Civil Rights Legislation and Regulations on State Highway and Transportation Department Activities
- Study No. 54—Outdoor Advertising Control and Acquisition
- Study No. 55—Legal Issues Arising out of Uniform Relocation Assistance and Real Property Acquisition Policy Act of 1970

\* Published in *Selected Studies in Highway Law*, Vols. 1 and 2.

- Study No. 56—Evaluation of the Adequacy and Equitability of Relocation Assistance Payments
- Study No. 57—Legal Aspects of Access Control on Unlimited-Access Highways
- Study No. 58—Zoning Changes Adjacent to Highways as a Result of the Highway Beautification Act
- Study No. 59—The Effect of Federal and State Public Information Acts on Highway and Transportation Department Activities

Studies No. 36 through No. 44 have been completed and will be published as Research Results Digests as well as in Volume III of *Selected Studies in Highway Law*. Volume III is in the editorial and publication process and will be published during 1977.

Research on Study No. 45 has been completed and copies of the final report have been distributed to NCHRP sponsors. Loan copies are available from the NCHRP Program Director.

Future work in this continuing project will include research on new topics of current interest in both the right-of-way and legal fields. Updating and supplementing the text book will also be continued.

Project Committee SP20-6 on August 4, 1976, authorized research on Studies No. 46 through No. 59. Through December 31, 1976, research on Studies No. 46 through No. 50 has begun.

#### **Project 20-7** FY '69 and continuing

#### **Research for AASHTO Standing Committee on Engineering and Operations**

<i>Research Agency:</i>	Open
<i>Principal Invest.:</i>	Open
<i>Effective Date:</i>	December 2, 1968
<i>Completion Date:</i>	Continuing
<i>Funds:</i>	\$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 of a continuing research capability at the Texas Transportation Institute (TTI) of Texas A&M University. In June 1973 the Committee stipulated that accomplishment of task research could be through any agency deemed by the NCHRP to possess the necessary expertise, provided the research could be initiated quickly.

The project includes a series of tasks specified by the Committee to obtain data required by the Committee to fulfill its responsibilities.

The tasks undertaken in this project and the status of each are as follows:

Task 1, "Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements" (TTI). Research has been completed and the task report published as NCHRP Report 148, "Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach." The report describes a hazard model that can be used to evaluate the effectiveness of a roadside safety improvement program.

Task 2, "The Relation of Side Slope Design to Highway Safety" (TTI). Research has been completed and the task report published as NCHRP Report 158, "Selection of Safe Roadside Cross Sections." Tentative criteria for the selection of safe side slopes and safe slope and ditch combinations are proposed.

Task 3, "Development of an Effective Earth-Berm Vehicle Deflector" (TTI). The final report has been completed and the results summarized in NCHRP Research Results Digest 77. The study was exploratory in nature and further research is recommended.

Task 4, "Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures (TTI). The final report has been completed and accepted by the AASHTO Standing Committee. NCHRP Research Results Digest 55 summarizes the results of the study. The study found that, although more needs to be known about the limitations of the existing AASHTO curve design policy, the present policy will in most instances provide safe, conservative designs for highway curves.

Task 5, "Effect of Curb Geometry and Location" (TTI). Research has been completed and the task report published as NCHRP Report 150, "Effect of Curb Geometry and Location on Vehicle Behavior." The study provides recommendations regarding curb configuration and placement.

Task 6, "Development of Impact Attenuators Utilizing Waste Materials" (TTI). Various used-tire configurations and a fiberized aluminum product were examined in the laboratory and analytically, and by full-scale field testing in some instances, to determine feasibility and to develop design information regarding the use of these materials for vehicle impact attenuation. Research has been completed, and the task report published as NCHRP Report 157, "Crash Cushions of Waste Materials." Designs are proposed for attenuators using two different configurations of scrap tires.

Task 7, "Safety at Narrow Bridge Sites" (TTI). Research has been completed, and the final report is in the NCHRP editorial and publication process. A bridge hazard index is proposed for assessing the degree of hazard of narrow bridges. Guidelines are offered for remedial treatments at narrow bridges.

Task 8, "Energy and Transportation Systems" (California Department of Transportation). This study is designed to establish "energy factors" for the various elements of energy use in constructing, maintaining, and operating transportation systems; to develop procedures for evaluating the energy use by such systems by applying the established energy factors; and to develop a rational method for reporting the results. Research is in progress.

Task 9, "Review of Highway Management Studies

Co-Sponsored by AASHTO and HUFSAAM" (Management and Transportation Associates, Inc.) This was an evaluation of the Highway and Transportation Management Institute and the National Highway and Transportation Management Conference that have been offered annually over the past several years to improve the management skills of highway department personnel. The study findings indicate that there is a continuing need within highway and transportation agencies for management training but it is becoming increasingly difficult to justify the travel, time, and expenses required by the courses currently being scheduled. As an alternative, the report recommends development of a two-week course to be presented once each year in each of the four AASHTO regions. Research has been completed and copies of the agency report distributed to the Program sponsors.

#### 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:* December 17, 1976  
*Funds:* \$214,279

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 has been 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 were (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.

Early in the project, a preliminary hypothesis was established which identified problems, variables and predictive techniques to be examined in case studies. Subsequently, compensation issues were identified. Home interview data were collected from displacees before and after moving at six sites geographically distributed throughout the United States.

Preliminary analyses of the data show that compensation inequities exist only for the elderly. The relocation process itself, rather than socioeconomic variables, was shown to be correlated to measures of happiness and satisfaction. In other words, socioeconomic characteristics were not found to be of importance in predicting the impact of residential dislocation on dislocatees. A report, carrying the project title, presents the results of a preliminary analysis and tentative recommendations for improving the relocation process. The report is available from the NCHRP Program Director on a loan basis.

Additional analytical work is under consideration to explore more thoroughly the justification for the findings described above.

#### Project 20-10 FY '73

##### The Benefits of Separating Pedestrians and Vehicles

*Research Agency:* Stanford Research Institute  
*Principal Invest.:* Ronald L. Braun  
 Marc Roddin  
*Effective Date:* August 26, 1974  
*Completion Date:* April 30, 1976  
*Funds:* \$100,000



In recent decades, the pedestrian has not been given adequate consideration in the decisions for person mobility. Increasing concern for the environment, safety, energy, community cohesion, and health have contributed to a social awareness of the pedestrian. In determining use of space, an inherent conflict exists between vehicles and pedestrians. There has been a need to identify and measure benefits of separating pedestrians and vehicular traffic.

The general objective of this research was to identify and quantify the benefits related to separation of pedestrians and vehicles and develop techniques for relating these benefits to the evaluation of proposals for separation.

Four categories of direct and indirect benefits of separating pedestrians from roadway traffic have been identified. These were (1) transportation; (2) safety, health, environment; (3) residential/business; and (4) environmental/institutional. The beneficiaries of these benefits have been defined. A methodology has been developed to weight the benefits identified according to values held by decision-makers and/or the community at large. The methodology has been tested at field sites in Seattle, Wash. (a highway overpass); Brooklyn, N. Y. (a mall); and Ottawa, Ont. (a mall).

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

#### 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 transporta-

tion facilities. These elements may be positive and/or negative, local and/or regional, long- and/or short-term.

2. Determine the significant elements and the relationships among these elements that may be altered by transportation facilities.

3. Develop quantitative scales for measuring quality levels of those environmental elements or categories, as appropriate, that have been identified as significant in Item 2.

4. Develop a method to identify threshold level(s) of adverse and beneficial effects on the quality scales defined in Item 3 for selected environmental elements and/or categories as appropriate.

The scope and direction of this project were modified to restrict the definition of "environment" to ecological and physical considerations. In addition, an energy concept was pursued by the research team and attempts were made to develop it for use. This concept is a numerical means of calculating the energy lost by an ecosystem when a facility destroys part or all of a given system. The energy approach also permits comparisons to be made on various levels—such as nationwide, regional, statewide, and local—between energy lost, energy used in building the facility, and energy to be used in operating the facility. The procedure allows for a comparison of the ecological impacts for transportation alternatives. The concept was applied to the Oyster Bay Bridge (New York) and U.S. Route 29 (Kansas).

The research has been completed. The final report will not be published, but the agency's unedited final draft may be borrowed from the Program Director, NCHRP, or purchased from Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Mich., 48106. The findings from this research will be summarized in two Research Results Digests entitled (1) "A Preliminary Energy Model" and (2) "Environmental Elements Impacting Factors and Threshold Levels."

#### Project 20-11A FY '74

##### Toward Environmental Benefit/Cost Analysis— Measurement Methodology

*Research Agency:* Cornell University  
*Principal Invest.:* Dr. Arnim H. Meyburg  
Mitchell J. Lavine  
*Effective Date:* September 1, 1975  
*Completion Date:* November 30, 1976  
*Funds:* \$26,575

Since the passage of the National Environmental Policy Act of 1969 and other similar legislation spurred by growing environmental concerns, there has been an increasing demand to develop practical and meaningful environmental impact assessment methodologies. The task has proved to be difficult, due to the diversity of disciplines involved. The aspect of diversity of impacts is accentuated with large projects such as most transportation facilities. Consequently there exists a need for a comprehensive approach to environmental impact assessment, a multidisciplinary ap-

proach embracing a wide array of physical, natural, and social science concerns, capable of dealing with the extensive networks of interactions that constitute the environment of any project.

A start has been made in developing a usable methodology in assessing environmental impacts of transportation facilities using the energy-flow concept. It was recognized that similar research may be under way in other fields. Further development of the concept for transportation facilities planning should reflect the state of the art in all relevant fields.

The general objective of this research was to identify and describe programs of research being undertaken or completed that use the energy-flow concept to measure impacts of man-made changes in ecosystems. Specifically, the following tasks were completed:

1. The identification and description of relevant research programs, including a literature search, a description of each of the research programs, and a description of supportive research information.
2. Evaluation of potential applications to transportation facilities planning.
3. The formulation of recommendations identifying particularly promising programs or findings and recommendations necessary for further development and implementation of an energy-flow analysis methodology for transportation-facilities planning.

Research on this project has been completed, resulting in initiation of Projects 20-11B and 20-11C. The agency's draft final report, "Toward Environmental Benefit/Cost Analysis: Measurement Methodology," Meyburg, A. H., Lavine, M. J., is available from NCHRP. Cost \$8.00. All orders should be directed to Mr. L. M. MacGregor, Administrative Engineer, NCHRP, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. Please make check or money order payable to *Transportation Research Board*.

#### **Project 20-11B    FY '74**

##### **Toward Environmental Benefit/Cost Analysis— Energy-Flow Analysis (Manual)**

*Research Agency:*

*Principal Invest.:*    Contract pending

*Effective Date:*

*Completion Date:*

*Funds:*

A start has been made in developing a usable methodology for assessing environmental impacts of transportation facilities using the energy-flow concept. However, there is no one source available now that succinctly describes the theories, tools, procedures, and data sources necessary to apply the energy-flow analysis methodology. An applications manual will help to assure that the methodology is thoroughly understood and readily usable. Such a reference will explicitly describe the procedures involved and identify their range of applicability in the transportation field.

The general objective of this research is to develop a user-oriented manual to assist any state or local transportation agency in conducting environmental analyses using the energy-flow concept. It is anticipated that this work will build on the findings of NCHRP Project 20-11A and other related research efforts. The manual will be designed for direct use in project development and system analysis for the movement of people and goods, and will emphasize simplified techniques not requiring computer application. It will include, as a minimum:

1. A step-by-step description of the procedure for energy-flow analyses.
2. A checklist and brief discussion of specific parameters (e.g., productivity rates) for which data are required.
3. Methods for obtaining needed data, including a list of sources for data that do not require direct field collection.
4. Examples that demonstrate the step-by-step methodology as it applies to transportation problems.
5. An explanation of the relationship between the step-by-step procedure contained in the manual and accepted theories of energy flow.
6. A discussion of the application and the limitations of the methodology to the planning, construction, operation, maintenance and regulation of transportation facilities and services.

Research is to be initiated in early 1977.

#### **Project 20-11C    FY '74**

##### **Toward Environmental Benefit/Cost Methodology— Energy-Flow Analysis (Study Design)**

*Research Agency:*

*Principal Invest.:*    Contract pending

*Effective Date:*

*Completion Date:*

*Funds:*

A start has been made in developing a usable methodology for assessing environmental impacts of transportation facilities using the energy-flow concept, including an evaluation of theoretical energy-flow concepts. It is now necessary to explore in some considerable detail the application of such concepts to transportation planning. The required exploration involves practical application in (a) measuring and interpreting transportation-related impacts and (b) assessing sensitivity to the variety of situations encountered in the planning of transportation facilities and services.

In view of the complex nature of these research requirements and the apparent broad application of energy-flow analysis to transportation systems and project planning, further specific research on the application of the methodology requires the careful preparation of a study design.

The objective of this project is to develop a study design for a program of research that will provide evaluations of the application of the energy-flow methodology to the planning of transportation facilities and services. Par-

ticular attention will be given to the social-cultural and esthetic considerations that have not been adequately accounted for in preceding studies.

This study design is intended to be the basis for execution of research necessary for application of the energy-flow methodology which will lead, in turn, to the development of guidelines. Presently, however, funding is available only for the study design. Execution of the research proposed in the study design will depend on obtaining future funding.

**Project 20-12**    FY '74

**Effects of Air Pollution Regulations on Highway Construction and Maintenance**

*Research Agency:*    Howard, Needles, Tammen and Bergendoff  
*Principal Invest.:*    Orrin Riley  
*Effective Date:*        April 1, 1974  
*Completion Date:*      July 31, 1975  
*Funds:*                    \$89,000

This research evaluated the effect of air pollution regulations for fugitive particulates and hydrocarbons on the highway construction and maintenance industry. Research was limited to the on-site construction process rather than off-site materials processing.

A survey of air pollution control officials and highway maintenance and construction officials was conducted. This survey determined the monitoring procedures used by the industry to identify possible violations, and tabulated those activities likely to produce illegal emissions. Mitigation methods favored by construction are also listed.

A testing program for fugitive particulates generated by highway construction was performed to measure ambient air quality concentrations. Also a hydrocarbon testing program evaluated the emissions from both the asphalt paving operation and cutback asphalt application during highway construction.

It was found that fugitive particulate regulations have had little effect on the industry because they are primarily concerned with persistent, permanent sources rather than sporadic, temporary sources such as construction. Conspicuous, costly, and lengthy test requirements make enforcement difficult. Open burning can be adequately controlled through present technology. Site watering reduces particulate levels for a short period of time and is often overused as a mitigant because it causes tracking of the soil from the construction site thereby increasing the dust potential. More efficient mitigants such as oil-based products and temporary pavements should be used more. Fugitive dust particles tend to settle out within right-of-way limits and the industry has long undertaken adequate mitigation procedures in response to neighbors' nuisance complaints.

The hydrocarbon tests revealed that the quantity of reactive hydrocarbons emitted from the more volatile cutbacks is small compared to that of vehicular exhaust, and that which is emitted dissipates within a short distance of its

source. Essentially no violations of the ambient air quality standards are attributable to highway paving and priming.

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

**Project 20-13**    FY '75

**Beneficial Environmental Effects Associated with Freeway Construction**

*Research Agency:*    The Pennsylvania State University  
*Principal Invest.:*    Hays B. Gamble  
                                   Dr. Thomas B. Davinroy  
*Effective Date:*        September 3, 1974  
*Completion Date:*      August 2, 1975  
*Funds:*                    \$49,965

It is necessary to discuss both positive and negative environmental aspects of a project during preparation of the Environmental Impact Statement. The positive aspects have not previously been documented to any degree. This study provides an evaluation of environmental improvements attributable to freeways in order to place present and future freeways in proper perspective.

The objective of this project was to determine the long- and short-range positive aspects of freeway construction. These were differentiated, where necessary, for urban and rural freeways. A literature search, analysis, and evaluation was accomplished. The investigators were concerned with studies such as, but not limited to:

1. Improved emergency ambulance, fire, and police services.
2. Movement of goods and services.
3. Influence on land-use planning.
4. Influence on economic growth.
5. Accessibility to recreational and other activities.
6. Pollution control.
7. Energy utilization.
8. Effects on plants and wildlife.

A matrix approach was used to catalogue and classify beneficial environmental effects. Literature reviews and surveys conducted by a multi-disciplinary team were carried out to develop the required information for the matrix. The project report is in the NCHRP editorial and publication process.

**Project 20-14**    FY '77

**Monitoring Carbon Monoxide Concentrations in Urban Areas**

*Research Agency:*    Technology Service Corporation  
*Principal Invest.:*    William S. Meisel  
                                   Yuji Horie  
*Effective Date:*        October 1, 1976  
*Completion Date:*      January 31, 1978  
*Funds:*                    \$99,973

Federal and state regulations currently require that air quality reports be included in environmental impact state-

ments in order that compliance with ambient air quality standards can be assessed. Many of these air quality reports need to include an analysis of on-site monitoring data of urban background carbon monoxide (CO) concentrations. It has been assumed that this monitoring must be performed for at least one year to be reliable. However, practical considerations dictate that the period of monitoring be as short as possible consistent with chosen accuracy. Therefore, an acceptable statistical method for evaluating CO data obtained over a relatively short period of time needs to be developed.

The general objective is to develop a methodology (1) to estimate urban background CO concentrations from incomplete monitoring data sets for three types of areas (a) where urban background monitoring stations already exist, (b) where source-affected monitoring stations exist, and (c) where there are no existing stations; and (2) to determine the precision of the estimates. This study will be accomplished by a statistical analysis of existing high-quality aerometric data. Development of the method will be accompanied by (a) clear statements of all necessary assumptions and (b) the theoretical rationale for statistical calculations. The method will be convenient, economical, and usable by both small and large agencies.

The specific objectives are to:

1. Identify existing sets of high-quality CO monitoring data representing diverse geographic regions in each of which exist several monitoring stations, including at least one urban background site.
2. Using historical data sets, formulate and develop a statistical and/or empirical method to extrapolate from an incomplete data set maximum 1-hr average, maximum 8-hr running average, and annual average CO concentrations. Incomplete data sets are defined as those having less than one year of data (e.g., 30 days of continuous data or randomly sampled data). Correlations among stations in a specific area will be considered; a diffusion modeling effort is not anticipated.
3. Quantify the precision (e.g., confidence intervals) of parameters estimated by the method in item 2 for use in sampling strategies to include, but not be limited to, (a) 30 days continuous, (b) 100 random samples over 30 days, (c) 100 random samples over one year, and (4) 3-day midweek, continuous (one per month and once per quarter). In addition, a sensitivity analysis will be conducted to quantify the effect on precision of (a) sample size for random sampling (e.g., between 10 and 600), (b) seasonal factors (selection of sampling months), (c) characteristics of monitoring sites (urban background versus source-affected), (d) number of monitoring sites, (e) stratification of the data with regard to meteorological parameters (e.g., wind speed, wind direction, and stability class), and (f) duration of continuous sampling time (15 to 180 days).
4. Investigate the feasibility of using a statistical and/or empirical methodology to extrapolate from an incomplete data set maximum 1-hr average, maximum 8-hr running average, and annual average CO concentrations in areas where no historical data sets exist.

Research has begun with the assembling of existing data and a thorough analysis of data deficiencies in data sets.

Appropriate procedures for handling missing data will be used prior to a search for explanatory variables to estimate the highest and second highest values of the 1-hr average and the 8-hr running average.

**Project 20-15** FY '77

### **Ecological Effects of Highway Fills on Wetlands**

*Research Agency:* University of Massachusetts  
*Principal Invest.:* Dr. Paul W. Shudiner  
 Prof. Carl A. Carozzi  
*Effective Date:* December 1, 1976  
*Completion Date:* November 30, 1978  
*Funds:* \$149,925

Many people and organizations are encouraging increased use of bridges rather than earth fills across wetlands to be traversed by highways. Earth fills produce various ecological effects, frequently reported to be detrimental, on wetlands. Reported effects include (a) inhibition of storm water and tidal distribution, (b) increased water turbidity, (c) alteration of water circulation patterns, (d) removal of natural filtration systems, (e) introduction of exotics, (f) inhibition of movement of animals, (g) alteration of biological productivity, and (h) alteration of nutrient flux.

Determination of the impact of a bridge or earth fill on the ecology of a specific wetland is a very complex problem. Nevertheless, transportation agencies are required to make environmental assessments for proposed wetlands facilities. Consequently, a need exists for a better understanding of the ecological effects of highways on wetlands as well as for guidance in making highway location and design decisions when wetlands and associated flood plains are involved.

The over-all objective of this project is to determine the ecological effects of placing highway fills on wetlands and associated flood plains and to develop initial guidelines as a management tool for the decision-making process regarding routes, fills, bridges, and other design alternatives.

It is anticipated that accomplishment of this objective will involve simultaneous activity and iteration among the following tasks:

**Task 1.** Review, examine, synthesize, and evaluate all available information relevant to the over-all objective and prepare a state-of-the-art report covering (a) the ecological effects of highway fills and bridges on wetlands and (b) techniques, procedures, and methodology—including sampling and equipment—for assessing the ecological effects.

**Task 2.** Identify wetlands case studies for which ecological data are available—either at the same or comparable sites—prior to, during, and following construction of a highway or similar fills and structures. These case study data will be evaluated and compared to determine the nature and extent of ecological impacts. Types of wetlands cases that will be considered include swamps, freshwater marshes, saltwater marshes, coastal and inland bays, and near-shore areas.

**Task 3.** Identify, adapt, or develop systematic guidelines,

presented in the form of a users' manual, for ecological assessment of wetlands and for guidance in selecting from among such design alternatives as fills, bridges, and related elements in wetlands and associated flood plains. Consideration will be given to such specific parameters as analytical methods, sampling, and modeling techniques. Where feasible, documentation of observed and suspected ecological impacts will be categorized by wetlands types. Existing and potential engineering remedies for adverse impacts and any observed beneficial ecological effects related to the location of highway fills and bridges in wetlands will be reported.

**Project 20-16**      FY '77

**State Laws and Regulations on Truck Size, Weight, and Speed**

*Research Agency:*      R. J. Hansen Associates, Inc.  
*Principal Invest.:*      Ralph D. Johnson  
                                     John C. Laughland  
*Effective Date:*        October 11, 1976  
*Completion Date:*      January 11, 1978  
*Funds:*                    \$149,977

There is evidence that the diverse requirements of current state laws, regulations, and interstate agreements controlling the interstate and interregional movement of trucks may add unnecessarily to the cost of trucking operations and state administration. A need exists for comparative analyses of the effects of the existing diversities, and for the establishment of alternatives to eliminate or minimize those effects by improving the uniformity of the laws, regulations, and agreements. Alternative systems should be designed to facilitate interstate and interregional truck operation, with due consideration given to economy, safety, and administrative efficiency.

The objectives of the research are to:

1. Identify and describe the effects of current state size, weight, and speed laws, regulations, and interstate agreements on trucks and the highway systems they use.
2. Investigate the potential benefits and disadvantages of increased uniformity in truck size, weight, and speed limits among states.
3. List and evaluate the available alternatives for eliminating or minimizing the differences in truck size, weight, and speed limits among states.

The research is divided into two phases, only the first of which is in progress at this time. This first phase is intended to synthesize the present system of state regulation of truck size, weight, and speed and to describe its effects.

Phase I will include the following tasks:

1. Compilation and comparative summarization of state laws, regulations, and interstate agreements relating to size, weight, and speed of trucks on all highway systems. The results of this task will be presented as a synthesis of present state legal requirements regarding (a) regulation of truck size, weight, and speed; (b) the extent of uniformity; (c) the major considerations that have prevented achieve-

ment of greater uniformity; and (d) the major measures of interstate cooperation that have been developed to facilitate compliance with the administration of diverse state requirements regarding truck size, weight, and speed.

2. Identification and description of the effects of differences in current size, weight, and speed laws, regulations, and interstate agreements on truck operations among states, including, but not limited to, equipment selection, route selection, equipment utilization, vehicle qualification (permits), and fuel and operating costs. In this task, (a) classifications will be developed based on the type of carriers and operations that are responsive to differences in vehicle size and weight, and (b) data will be developed to show the impacts of states' nonuniformities of size, weight, and speed laws, regulations, and interstate agreements on these classifications.

3. Identification and description of: (a) the influence of different maximum allowable truck sizes, weights, and speeds on the structural and geometric requirements of highways, with appropriate consideration of safety and operational characteristics; and (b) the special state problems and costs of administering the present system of differing truck size, weight, and speed laws, including, but not limited to, record keeping, processing of permits, participation in interstate agreements, revenue accounting, and manpower.

Dependent on the findings of Phase I, a second phase may be undertaken to identify and evaluate alternatives to eliminate or minimize the adverse effects of states' nonuniformities of truck size, weight, and speed limits.

Through December 31, 1976, progress continued on all three tasks. A preliminary draft of the final report on Phase I is due for submittal in October 1977.

**AREA 21:      TESTING AND INSTRUMENTATION**

**Project 21-1**      FY '70

**Instrumentation for Measurement of Moisture**

*Research Agency:*      Research Triangle Institute  
*Principal Invest.:*      Dr. L. F. Ballard  
*Effective Date:*        August 25, 1969  
*Completion Date:*      February 24, 1971  
*Funds:*                    \$35,027

Water in its various states, when insufficient or in excess in the components of a highway system, adversely affects the service behavior. Despite recognition of the importance of the relationship between the presence of water and service behavior, the engineer has been hampered in his effort to provide predictable performance by the lack of instrumentation and techniques for adequate water or moisture measurement. The economic significance of the problem in highway construction and maintenance is particularly evidenced by the large financial investment aimed at removal

of excess water which causes loss of supporting capacity of subgrade soils and aggregate bases, embankment instability, and deterioration of pavements.

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

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

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

#### Project 21-2 FY '71

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

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

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

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

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

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

The technology on which the prototype sensor is based is described in a paper by Gardner & Matzkanin, published in TRB Record 532. The essential findings of the study have been published in NCHRP Research Results Digest 75. Information contained in the project report is expected to be published ultimately in the Project 21-2(3) report.

#### Project 21-2(2) FY '72

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

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

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

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

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

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

The technology on which the prototype sensor is based is described in a paper by Selig, Wobschall, Mansukhani, and Motiwala, published in TRB Record 532. The essential findings of the study have been published in NCHRP Research Results Digest 75. Information contained in the project report is expected to be published ultimately in the Project 21-2(3) report.

#### Project 21-2(3) FY '75

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

*Research Agency:* Southwest Research Institute  
*Principal Invest.:* George A. Matzkanin  
 E. T. Selig (SUNY)  
*Effective Date:* September 3, 1974  
*Completion Date:* March 1, 1977  
*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 elec-

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

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

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

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

3. Simulated field installation and evaluation of the fabricated sensors in parallel under a wider range of soil, compaction, moisture, and contamination conditions than can be encountered in actual field installations.

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

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

The final report is being prepared.

## 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:* May 30, 1975  
*Funds:* \$40,000

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

application. Emphasis should be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

The objectives of NCHRP Project 22-1, "Concepts for Improved Traffic Barrier Systems," were accomplished by the development of a traffic barrier system that was analyzed using the Barrier IV computer program. The results of this analysis indicate that the proposed system meets the desired criteria.

The objective of Project 22-1A was to evaluate the prototype of the proposed barrier by full-scale impact tests.

The accomplishment of this objective included the following tasks:

1. Fabrication and construction of the barrier system shown in Figure 6 of the final report on Project 22-1 (Pages 148 to 173, *NCHRP Summary of Progress Through 1972*).
2. Testing and evaluation of the system under the following impact conditions:
  - (a) A passenger vehicle impacting the bridge rail at 60 mph and 25°.
  - (b) A passenger vehicle impacting the bridge rail at 60 mph and 7°.
  - (c) A passenger vehicle impacting the approach railing-bridge rail transition at 60 mph and 25°.

Research has been completed, and the final report is in the NCHRP editorial and publication process. The essential findings have been summarized in NCHRP Research Results Digest 81, "Crash Testing and Evaluation of Attenuating Bridge Railing System."

#### **Project 22-2** FY '69, FY '72 and FY '73

##### **Traffic Barrier Performance and Design**

<i>Research Agency:</i>	Southwest Research Institute	
<i>Principal Invest.:</i>	M. E. Bronstad J. D. Michie	
<i>Effective Date:</i>	Jan. 1, 1972	Oct. 1, 1973
<i>Completion Date:</i>	Sept. 30, 1973	Mar. 31, 1975
<i>Funds:</i>	\$125,000	\$80,000

Conventional traffic barrier systems are presently being widely applied by highway and bridge engineers. All of the existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails.

Among the most important of current needs in the area of vehicle barrier systems is a safer terminal design. The work of Project 22-2 was structured to emphasize the systematic experimental development of terminal treatments to fulfill this need. Terminal treatments for a number of selected guardrail systems were investigated. This study built on earlier preliminary NCHRP efforts that are described in NCHRP Reports 118 (1971) and 129 (1972).

The initial task in Phase I included a review of terminal concepts previously developed under Project 15-1(2), the

development of several new concepts, and an examination of concepts developed outside the NCHRP. More than 20 of these concepts have come under consideration. This work was covered in an interim report that was submitted to the advisory panel in April 1972, and was subsequently accepted. Although the report will not be published, it is available on a loan basis.

Based on the interim report, the advisory panel selected designs and established priorities for full-scale testing of several terminal systems. The experimental program consisted of some 26 full-scale crash tests. Interest in this testing was concentrated on a breakaway cable terminal (BCT) in combination with the W-beam guardrail and median barrier systems most often used.

Ten crash tests were carried out on the BCT with the flared W-beam guardrail. A summary of the tests results and other information on this terminal are contained in NCHRP Research Results Digest 43 (October 1972). The second part of the experimental program, comprising some 16 tests, was concentrated on the development of a crash-cushioning terminal for use with median barriers. The results of this effort are reported in NCHRP Research Results Digest 53 (December 1973).

Phase II research has been completed. It led to the refinement of BCT designs to provide more safety to smaller cars and to improve economy relative to the first cost, maintenance, and repair. Findings from the Phase II research were reported in NCHRP Research Results Digest 84 (March 1976).

In late 1976, the Federal Highway Administration sponsored additional tests on the median barrier BCT. An NCHRP Research Results Digest will be published early in 1977 summarizing the findings of these and previous tests and clarifying recommended details for both guardrail and median barrier terminals with either steel or timber posts. Meanwhile, copies of the uncorrected drafts of the agency's final reports may be obtained on a loan basis by request to the NCHRP Program Director.

A separate task of Phase II, funded at \$20,000, was intended to develop uniform barrier testing criteria and procedures. Research has been completed on this task and the final report has been published as:

NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances."

#### **Project 22-2(2)** FY '73

##### **Multiple Service Level Highway Bridge Railings—Performance and Design Criteria**

<i>Research Agency:</i>	Southwest Research Institute
<i>Principal Invest.:</i>	M. E. Bronstad
<i>Effective Date:</i>	August 1, 1976
<i>Completion Date:</i>	July 31, 1978
<i>Funds:</i>	\$195,000

Current design specifications for bridge railing systems are predicated on a general performance requirement of assured containment. Decelerations and trajectories experienced by "average" vehicles impacting bridge railings



at speeds and angles normally associated with primary and Interstate highways must be tolerable. The "average" vehicle referred to in AASHTO specifications is not defined, but is generally considered to be a full-size domestic passenger car. Impacts by 4,000- to 4,500-lb (1,820 to 2,040 kg) vehicles at speeds in the 50- to 70-mph (80.5 to 112.6 kph) range with impact angles of up to 25° have been considered to be appropriate full-scale crash test conditions. Excessive vehicle decelerations or penetration of the bridge railing under these test conditions have been considered to constitute unacceptable performance.

Bridge railing systems used on primary and Interstate highways can be categorized as "normal service level" railings and must meet the above performance requirements. These are generally designed through application of static-elastic design criteria expressed in the AASHTO Standard Specifications for Highway Bridges. The resulting designs may have substantial structural integrity, and a concomitant substantial cost. Routine verification of these designs through full-scale impact testing is not required by AASHTO specifications.

Many secondary or local roads are designed for and subjected to operating speeds, traffic volumes, vehicle weights, and possibly vehicle-barrier impact angles that are somewhat less than the "normal service level." These roadways can be considered to serve a "lower service" need and, in the view of some, the application of "normal service level" bridge railing design criteria may not be cost-effective in these instances.

There are also situations where circumstances call for a higher level of performance than usual on primary or on Interstate highways. This may be due to heavy traffic volume, a preponderance of truck traffic, severe geometric conditions, or vulnerable land use beneath the bridge. In these cases designers may consider using a high-performance railing such as the collapsing steel ring system recently developed by the Federal Highway Administration.

Accordingly, development of an array of service levels, performance criteria, and design criteria would prove useful to those desiring to use more appropriate and cost-effective bridge railings.

The initial objective of this project is to identify and document realistic performance criteria and correlated design criteria for bridge railing systems on roadways providing various (at least three—normal, higher, and lower) levels of service. The major objective is to develop at least one design based on criteria for the lower service level, and to validate this system using analytical and full-scale testing methods.

The research includes the following tasks:

1. Identify traffic and other parameters for use in defining appropriate categories of roadway service levels.
2. Establish reasonable performance criteria for bridge railings to be employed in each category.
3. Propose bridge railing design criteria for each category.
4. Develop and validate, through analytical simulation and full-scale testing (in accordance with the relevant provisions in NCHRP Report 153), at least one lower service level bridge railing design with first cost and maintenance advantages over normal service level systems. The railing

will be designed according to the criteria proposed in Task 3, to give performance consistent with the criteria developed in Task 2. Bridge railing designs considered in this task may include some already in use.

5. Through analytical simulation, evaluate the performance of this railing when struck by a 25,000-lb (11,340 kg) school-type bus under various impact conditions.

6. Compare the developed bridge railing design with the present AASHTO static-elastic bridge railing design requirements.

7. Recommend appropriate modifications to current bridge railing design practice based on this study.

Through December 31, 1976, the first three tasks have been completed, and an interim report on the findings has been submitted for Project Panel review.

### Project 22-3 FY '73

#### Field Evaluation of Vehicle Barrier Systems

*Research Agency:* Calspan Corporation  
*Principal Invest.:* J. W. Garrett  
 N. J. DeLeys  
*Effective Date:* January 1, 1974  
*Completion Date:* February 15, 1975  
*Funds:* \$25,000

The relative in-service performance of most guardrail systems is unknown. Although over-all performance of guardrail installations, in general, might be determined from state and national efforts in accident investigations, limitations in the data preclude the analysis of specific guardrail systems in terms of safety and cost. Accordingly, the relative merits of two or more systems must be evaluated on the basis of idealized laboratory experiments (including full-scale crash tests) and gross accounting procedures. The use of accident data to evaluate the field performance of barrier systems would be very desirable.

The objective of this project was to determine the degree to which accident data currently being accumulated by various agencies meet the needs of those concerned with the effectiveness of vehicle barrier systems and, to the extent warranted, to recommend new approaches that may better serve those needs.

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

1. Enumerate the specific items of information that are of interest in evaluation of the field performance of vehicle barriers, including angle and speed of impact, location of impact, frequency of occurrence, cost of damage to barrier system, permanent deformation of system, vehicle damage, occupant injury, and post-impact behavior of both barrier and system.
2. Identify the primary existing sources of accident data.
3. Classify the information available from each of these sources as to its suitability to the needs identified in Task 1.
4. Recommend several alternative processes for using available data and for collecting new types of data that would be more appropriate than those available. This task also considered potential sources of funding.

5. Outline subsequent research to systematically collect and evaluate accident data.

6. To the extent possible within the funding and time constraints, analyze and discuss in the final report such useful data as were discovered during this study.

Research has been completed, and the essential findings from the final report have been summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Copies of the uncorrected draft of the agency's report may be obtained on a loan basis by request to the NCHRP Program Director.

**Project 22-3A**      FY '73

**Field Evaluation of Vehicle Barrier Systems**

*Research Agency:*     Arthur L. Elliott  
*Principal Invest.:*    Arthur L. Elliott  
*Effective Date:*       July 1, 1974  
*Completion Date:*     December 31, 1974  
*Funds:*                    \$10,000

The relative in-service performance of most guardrail systems is unknown. Although over-all performance of

guardrail installations, in general, might be determined from state and national efforts in accident investigations, limitations in the data preclude the analysis of specific guardrail systems in terms of safety and cost. Accordingly, the relative merits of two or more systems must be evaluated on the basis of idealized laboratory experiments (including full-scale crash tests) and gross accounting procedures. The use of accident data to evaluate the field performance of barrier systems would be very desirable. The use of formal accident reports has been investigated under NCHRP Project 22-3.

At the same time, Project 22-3A was concerned with an investigation of a less formal approach to barrier evaluation. This approach consisted of personal interviews with highway agency maintenance, safety, and traffic operations personnel to obtain any data they may have and to solicit their subjective opinions on the performance of various barriers. Five representative states were visited for this purpose.

Research has been completed, and the essential findings from the final report have been summarized in NCHRP Research Results Digest 76, "Field Evaluation of Vehicle Barrier Systems." Copies of the uncorrected draft of the agency's report may be obtained on a loan basis by request to the NCHRP Program Director.

## SUMMARIES OF UNPUBLISHED REPORTS

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

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

Persons having deeper interest in the subject matter of any of these projects can obtain information on securing copies of the agencies' reports by writing to Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48106.

**Project 3-7**    FY '73

### **Establishment of Standards for Highway Noise Levels\***

*By:*                    Karl S. Pearsons  
                             Ricarda L. Bennett  
                             Sanford A. Fidell

*Research Agency:*    Bolt Beranek and Newman

#### **Introduction and Research Approach**

##### *Problem Statement and Background*

The predominant noise source in contemporary urban areas is automotive traffic; in many areas, it is noise from highways that controls local noise levels. Traffic noise interferes with numerous activities and creates annoyance, necessitating measures to bring noise levels into conformity with criteria for habitability. Research to improve existing criteria for time-varying highway noise was undertaken in this part of NCHRP Project 3-7. The research included investigations of the effects of time-varying noise on speech communication, annoyance, and sleep.

Most investigations, including those conducted previously under NCHRP Project 3-7, have utilized steady-state noise or single-event noise in connection with speech interference studies. Some current measures, such as Traffic Noise Index (TNI) and Noise Pollution Level (NPL), purport to account for the variability of sounds in the environment by adding to the measure an extra factor that increases with

increased variability. The validity of these measures is still in question. Therefore, research was also necessary to study the annoyance of time-varying highway noise.

The effect of time-varying noise on sleep is even less well understood than annoyance and speech interference. This report summarizes the results of studies carried out in the three areas.

##### *Research Approach*

*Speech Intelligibility.*—Speech intelligibility tests were conducted in the presence of recorded traffic noise to assess the effect of the variability of that noise on verbal communication. Samples of traffic noise were selected to provide a wide range of variations. These were supplemented by steady-state sounds and individual truck passbys to simulate extreme cases of noise variability. Conventional intelligibility tests were also conducted to permit comparison with the results of other investigations.

Assessment of speech intelligibility in the presence of a background of recorded traffic noise was undertaken by panels of observers. Panel members were required to indicate which of six words in ten groups of spondee (two syllable) words was articulated at any given time. Speech levels were varied systematically to determine percentage intelligibility at various signal-to-noise ratios.

*Annoyance.*—The annoyance of time-varying traffic noise was studied using a five-point adjective category scale and noise samples from the speech intelligibility tests. Tests were conducted both in the presence and absence of speech. The speech employed was either phonetically balanced (PB) word lists or continuous discourse. A four-point (1-4) scale of acceptability was included in some cases for comparison.

\* This summary deals only with "A Study of Time-Varying Highway Noise Criteria," one task of the concluding phase of NCHRP Project 3-7. Other task results are reported in *NCHRP Report 173*, "Highway Noise—Generation and Control," and *NCHRP Report 174*, "Highway Noise—A Design Guide for Prediction and Control."

*Sleep Interference.*—The great expense of conducting meaningful sleep studies dictated that the investigation of sleep interference be restricted to a literature review supplemented by results of BBN sleep studies conducted near the airport in Los Angeles.

#### Test Description

*Stimuli.*—The word lists for the first portion of the intelligibility tests are exemplified by the excerpts from Table 1. For the steady sounds employed in the test, phonetically balanced words were also used. Levels of the spondee words were initially determined by observing the peak deflection of a standard VU meter. Absolute calibration of the speech levels was accomplished by measurement of a 250-Hz tone at the observer's ear position in the anechoic chamber, without the subjects present. Daily calibration of the speech level was performed by measurement of the voltage level of a 1,000-Hz tone across the loudspeaker terminals.

Within each set of six words the peak levels varied by about  $\pm 3$  dB, with standard deviations on the order of 2 dB. The arithmetic mean of the levels for each of the ten sets that were used varied by about  $\pm 1$  dB. This small variation among mean levels of the word sets permitted pooling of data from the ten sets in determining the intelligibility of the words. The slight variation in peak speech levels further allowed reduction of the number of word sets tested for certain traffic noise situations, although all ten sets of words were employed for most determinations. However, speech levels of the sets were varied over a 30-dB range to allow determination of various intelligibility scores.

Long-term RMS (root-mean square) measurements were made of the word lists utilizing over-all, A-weighted, and one-third-octave band analysis. The final levels reported for the word lists were the over-all long-term RMS values with an averaging time equivalent to the "fast" scale on a standard sound level meter. These over-all levels averaged 3.5 dB higher than A-levels for the same speech samples. One-third-octave band spectra of long-term RMS values for the spondee words were also plotted and compared with the speech spectrum taken from an American Standard. Speech levels were similarly determined for the phonetically

balanced (PB) words. A sample of two of the lists is given in Table 2.

Continuous discourse, in 5-min samples, was employed in the comprehension tests involving annoyance and acceptability judgments. The speech samples were magazine and newspaper articles read by a radio announcer. In addition, old radio dramas were used to provide a variety of talkers and listening material. The radio shows demonstrated two-way communications in contrast to the monologues of the news articles. Care was taken to maintain the same presentation level for both types of speech material. The difference in level between the articles and old radio programs was less than 1 dB; the materials were therefore used interchangeably in the test presentation.

The excerpt in Table 3 lists several of the 23 5-min samples of traffic noise that served as background noises. The first 10 samples of traffic noise were obtained from direct recordings made at locations of 100 to 800 ft from the roadside. Vehicle volumes for these samples ranged from 252 to 8,030 vph, with the volume of trucks varying from 40 to 345 per hour. Samples 11 and 12 were simulated traffic noise produced by shaping broadband noise to conform in spectrum to recordings of relatively steady traffic noise. Samples 13 through 16, consisted of the steady-state noise sample 11 combined with an increasing number of 44-sec truck passbys. Samples 17 through 23 used the same truck recording and background noise as samples 13-16; however, the level of the background noise was recorded approximately 20 dB lower. Samples 17 through 19 differed only in the location of the truck passby in the 5-min sample period. The truck was presented at the beginning of sample 17, in the middle of sample 18, and at the end of sample 19. Four trucks were equally spaced 1 min apart throughout the 5-min duration of sample 20. Four trucks were also used for samples 21, 22, and 23. They were spaced 15 sec apart, resulting in overlap in the noise levels of individual trucks. The group of four trucks was presented in the same time sequence within the 5-min sample as stimuli 17, 18, and 19.

Measurements of the traffic noise stimuli (see Table 3) were made by sampling the noise at 0.5-sec intervals using a microphone placed at ear position in the anechoic chamber. The presentation levels for both the field-recorded traffic stimuli (No. 1 through 10) and the simulated traffic stimuli (No. 11 through 23) were comparable. Samples 1

TABLE 1  
EXCERPTS FROM SPONDEE WORD LISTS

LIST 1	LIST 2	LIST 3
Cowboy	Baseball	Birthday
Headlight	Grandson	Hothouse
Bonbon	Railroad	Padlock
Whitewash	Sunset	Beehive
Eggplant	Nutmeg	Pinball
Shipwreck	Whizzbang	Vampire

TABLE 2  
EXCERPTS FROM THE PHONETICALLY  
BALANCED WORD LISTS

LIST 1	LIST 2
1. cane	26. pest
2. there	27. slip
3. dish	28. rub
4. hid	29. feast
5. heap	30. deed
6. pants	31. cleanse
1. tang	26. blush
2. fate	27. nab
3. such	28. bait
4. else	29. bud
5. pit	30. rap
6. gill	31. moose

TABLE 3  
SELECTED TRAFFIC NOISE STIMULI (5-minute samples)

STIMULUS NO.	VOLUME (VEH/HR)	VOLUME (TRUCKS/HR)	PERCENT TRUCKS	$L_{eq}$	$L_{10} - L_{50}$	DESCRIPTION
1	487	40	8.3	64.6	4.9	Recorded traffic noise
2	8030	345	4.3	73.2	1.6	Recorded traffic noise
7	1940	161	8.3	72.6	3.8	Recorded traffic noise
9	3510	193	5.5	59.2	1.7	Recorded traffic noise
11	—	—	—	63.5	0.4	Broadband noise shaped like traffic noise
13	—	12	—	64.8	1.9	One truck with sample of No. 11
16	—	96	—	69.1	6.9	Eight trucks with sample of No. 11
22	—	48	—	65.0	24.3	Four trucks spaced 15 sec apart placed in middle of No. 11

through 16 were presented with the spondee words for the intelligibility tests. The intelligibility tests with the phonetically balanced words used only the shaped steady-state noise stimuli (No. 11). The annoyance tests used 12 different noise stimuli, with and without continuous discourse. The stimuli for these tests were presented at the same noise levels as the intelligibility tests, also at 10 dB higher and 15 dB lower than this original level. Cumulative distributions were plotted of all samples relative to their individual Equivalent Noise Level ( $L_{eq}$ ) values, which consist of the noise level integrated on an energy basis over the duration of the stimuli.

**Equipment.**—Two equipment systems were used to administer the subjective tests. Computer-controlled equipment was used for one system to aid in the automatic presentation of the spondee words in the intelligibility tests. A laboratory computer initiated a trial by selecting one of a set of six spondee words to be played by a cartridge tape machine. The background traffic noise was reproduced on a reel-to-reel tape recorder. The word was mixed with traffic noise at preset levels and heard over a loudspeaker by a panel of observers in an anechoic chamber. The computer also controlled an electronic switch whose gradual rise time suppressed tape starting transient noises. Observers were notified of the presence of a test word by the illumination of all of the switches on their response boxes. As soon as the word was pronounced, the lighted switches were extinguished and the observers pressed the switch corresponding to the word they thought they had heard. Their respective responses were automatically recorded and printed out at the completion of each test.

The second system allowed manual control for presentation of stimuli for annoyance and intelligibility tests with phonetically balanced words. The manually controlled equipment operated in a similar manner to the computer-controlled equipment except that all stimuli were presented from reel-to-reel tape recorders. The observers responded by writing their answers on prepared forms.

The computer was used in each case to determine  $L_{eq}$  values as well as cumulative distributions of the samples. A response time equivalent to the "slow" scale of a sound

level meter was employed for measuring the traffic noise. A response time equivalent to the "fast" scale on the sound level meter was used for one-third-octave band and over-all sound level analysis of speech material.

**Observers.**—The observers were selected from a pool of about 30 university students. Each met an audiometric screening criterion for hearing acuity within 15 dB of a standard threshold. The observers ranged in age from 18 to 28 years. The number of male and female observers was approximately equal in each test. Not all observers participated in each testing phase because of the long duration of the test program. Many of the observers did participate, however, in more than one test. Twenty observers were in the test involving intelligibility of spondee words. The study involving intelligibility of PB words used 30 observers. Twenty observers participated in the annoyance evaluation tests with and without continuous discourse. In this final test an average of approximately 12 people evaluated each traffic noise stimulus.

**Procedure.**—Observers were seated in an anechoic chamber throughout all testing. Usually, four observers were tested as a panel over a 2-hr period with rest breaks approximately every 30 min.

The task of the observer in the computer-controlled spondee word intelligibility study was word recognition in a traffic noise environment. Observers were asked to depress a button corresponding to the word they thought they heard. Observers were cautioned that failure to push a button, or pushing more than one button at a time, would be recorded as an incorrect response. They were encouraged by a competitive incentive to respond within a 2-sec period even if uncertain of their response.

When the preset number of words had been presented (i.e., 4 sets of 36 words — 144 "signals"), the computer calculated the number of responses per observer and the percentage of correct responses for each. The average across observers was also computed for the mean percent correct.

At the completion of some tests the observers were instructed to rate the background on the following annoyance response scale:

Not at all annoyed	0
Slightly annoyed	1
Moderately annoyed	2
Very annoyed	3
Extremely annoyed	4

The speech intelligibility tests for phonetically balanced words were conducted in accordance with the American Standard method for measurement of monosyllabic word intelligibility. Listeners were presented the words in quiet until 90 percent correct response was achieved. Then, using a re-randomization of the words, eight lists of 50 words were presented to the observers in the presence of steady-state noise. The observers were asked to write the words they thought they heard. At the completion of each test session, the percent of correct responses was tabulated for the particular noise level employed during the test session.

Panels of observers were also used to rate 5-min samples of traffic noise on an annoyance scale and an acceptability scale. In addition, for some of the samples, speech material was presented in the form of old radio dramas or news articles. At the conclusion of each of the traffic noise samples, the observers were instructed to rate the noise on both scales, and, if speech was present, to answer three questions concerning the contents. These questions served as a measure of listening comprehension and as a means of ensuring the observers' attention.

## Findings

### Speech Interference

Speech intelligibility, defined as the percent of correctly identified spondee words, was determined for each of the 16 traffic noise distributions. Figure 1 shows typical data collected in response to sample 3 of the traffic noise distribution. The curve represents an interpolated psychometric function through the data points, which are aggregate percent correct scores for a panel of four observers listening to six spondee words in traffic noise. The percent correct spondee words can be determined for various speech levels for each traffic noise sample from such psychometric functions.

Table 4 gives a summary of the speech levels required for 50, 70, and 90 percent correct response rates. Plots were made of noise level (using  $L_1$ ,  $L_{10}$ ,  $L_{50}$ , and  $L_{90}$  measures) versus speech level for the speech levels associated with the 90 percent correct response rate. Figure 2 shows results using the  $L_{90}$  noise measure. Correlation between the various noise measures and the 90 percent speech level are all significantly different from chance correlations. Although  $L_{90}$  has the highest correlation ( $r = 0.96$ ), the fact that all of the measures correlate highly with one another precludes establishment of the definite superiority of one measure over the others.

The results of the PB word intelligibility tests were also plotted. A comparison between the results for both word types suggests that a higher speech-to-noise ratio is necessary for the PB words than for the spondee words to obtain 90 percent correct identification.

### Annoyance

Annoyance ratings were elicited for each of the traffic noise samples in the speech intelligibility tests. It became clear while scoring the data that the annoyance ratings were a function of the speech level in a constant background traffic noise sample. Figure 3 shows for sample 9 how the mean annoyance rating varied over level. As speech level increased (thereby increasing the intelligibility), the mean annoyance rating of the traffic noise decreased. Regression equations were calculated for all traffic noise samples.

*Annoyance of Traffic Noise Samples Without Speech.*—Figure 4 shows the results of average annoyance ratings over  $L_{90}$  values when no speech was present during the traffic noise sample. Each point represents a mean annoyance rating of about 12 observers. Regression line analysis was not reported due to the nonlinear relationship of the data for the annoyance versus noise levels of the traffic noise samples.

*Annoyance of Traffic Noise Samples With Speech.*—Tests were also conducted in which observers were asked to rate the annoyance of traffic noise samples containing continuous discourse. An effort was made to vary the speech-to-noise ratio to provide high (+7.5 dB), moderate (-9.0 dB), and low (-16.0 dB) comprehension of the speech material.

The results were grouped in terms of low, moderate, and high comprehension based on a corresponding percentage

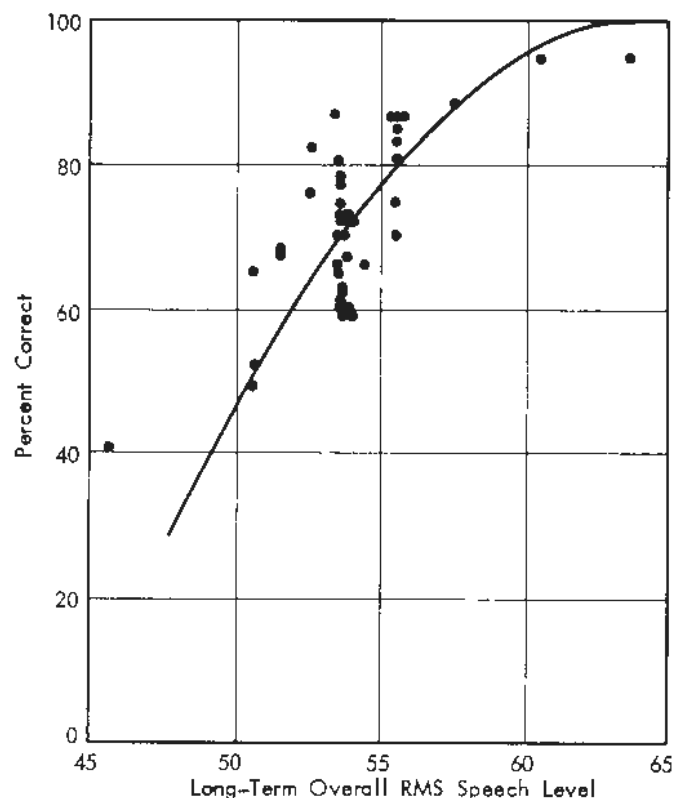


Figure 1. Percentage of spondee words correct for stimulus No. 3 with  $L_{90} = 65.5$  dB.

correct for spondee words (i.e., 50 percent correct = low; 70 percent correct = moderate; etc.). Plots of annoyance ratings for moderate and high comprehension versus  $L_{eq}$  are shown in Figure 5. The noise stimuli were coded to identify the samples with different speech-to-noise ratios. A high speech-to-noise ratio is comparable with high speech comprehension. For all the points, the speech-to-noise ratios were held constant while the presentation level of the samples was varied by +10 dB and -15 dB.

*Annoyance Versus Acceptability.*—Acceptability ratings were determined along with annoyance ratings for each of the traffic noise samples. The relationship between annoyance and acceptability was plotted for tests with and without speech presence. The close agreement between the data points and the regression line confirmed that annoyance and acceptability judgments are highly correlated (without speech,  $r = 0.98$ ; with speech,  $r = 0.94$ ).

*Variability Effect.*—Individual regression lines for noise samples 3, 7, 9, and 11 for speech presence conditions are shown in Figure 6. These samples were chosen because they represented a broad range of typical traffic noise variations. This variability is defined as  $L_{10} - L_{50}$ ; for these samples the values varied from 0.4 to 7.9 dB. The difference of  $L_{10} - L_{50}$  (i.e., those levels which are exceeded for 10 percent and 50 percent of the time) is used to describe the variability of traffic flow and is seen in the "Highway Design Guide" (*1*) as it related to  $VD/s$ .

The results show that each sample is associated with a different slope in the plot of annoyance versus noise level. In general, the more steady sounds do not have as steep a slope as the more variable sounds. However, an increase in the noise level which corresponds to a higher annoyance

rating reduces the difference between annoyance judgments for all stimuli. That is, for high noise levels (70 dBA and above) the variability seems to have little effect on the high annoyance rating. Yet, for low levels (less than 55 dBA), more variable sounds are judged to be less annoying than the steady sounds. This is generally true whether or not speech material is present.

#### Comprehension

After listening to a prerecorded oral presentation combined with a traffic noise sample, the observers were instructed to answer questions on the speech contents. The comprehension of the recorded speech material was defined as the number of correctly answered questions. All observers averaged less than 1 out of a possible 3 correct responses when performing their task for low speech-to-noise stimuli ( $\bar{X} = -16$  dBA). Figure 7 shows the number of correctly answered questions versus the  $L_{10} - L_{50}$  measure of variability for four of the samples. It is noted that in the moderate comprehension condition (speech-to-noise ratios of about -9 dBA) there is a definite effect of variability. Figure 7 clearly indicates minimal comprehension for steady sounds, whereas for the widely variable sounds the number of correctly answered questions ranged from two to three.

Observers were asked to judge the annoyance of a noise versus comprehension or number of questions correctly answered. The results show an inverse relationship between annoyance and the number of questions correctly answered. The observers rated the noise very or extremely

TABLE 4  
SPEECH AND NOISE LEVELS FROM INTELLIGIBILITY TESTS

STIMULUS NO.	$L_1$	$L_{10}$	$L_{50}$	$L_{90}$	$L_{eq}$	$L_{10} - L_{50}$	STANDARD DEVIATION	SPEECH LEVEL (LONG-TERM RMS) TO OBTAIN PERCENT CORRECT		
								50%	70%	90%
1	71.7	67.9	63.0	58.4	64.6	4.9	3.7	50.0	53.0	58.5
2	75.2	74.7	73.1	71.4	73.2	1.6	2.1	62.0	65.0	69.5
3	74.9	70.3	62.4	55.9	65.5	7.9	4.9	50.5	53.5	58.0
4	72.7	70.4	62.6	55.5	65.5	7.8	5.1	50.0	53.5	58.5
5	74.7	68.9	61.6	57.6	65.0	7.3	4.4	48.5	52.0	57.5
6	76.4	72.7	68.3	64.5	69.7	4.4	3.1	54.5	57.5	61.5
7	78.6	75.4	71.6	68.9	72.6	3.8	2.4	57.0	60.5	66.0
8	63.2	61.2	59.2	57.7	59.7	2.0	1.5	45.0	48.5	54.0
9	65.8	60.8	59.1	56.8	59.2	1.7	5.4	45.5	49.0	53.5
10	63.0	61.9	58.2	55.8	59.2	3.7	2.3	45.5	48.5	52.5
11	63.8	63.9	63.5	63.1	63.5	0.4	0.2	50.0	51.5	54.0
12	63.8	63.9	63.5	63.1	63.5	0.4	0.3	48.0	51.0	55.5
13	72.8	65.6	63.7	63.1	64.8	1.9	1.8	50.5	53.0	57.0
14	73.0	67.6	63.4	63.2	65.5	4.2	2.2	50.5	53.5	58.5
15	73.6	69.9	64.3	63.2	66.6	5.6	2.7	50.5	54.0	59.0
16	75.7	73.3	66.4	64.4	69.1	6.9	3.3	53.5	57.0	62.0

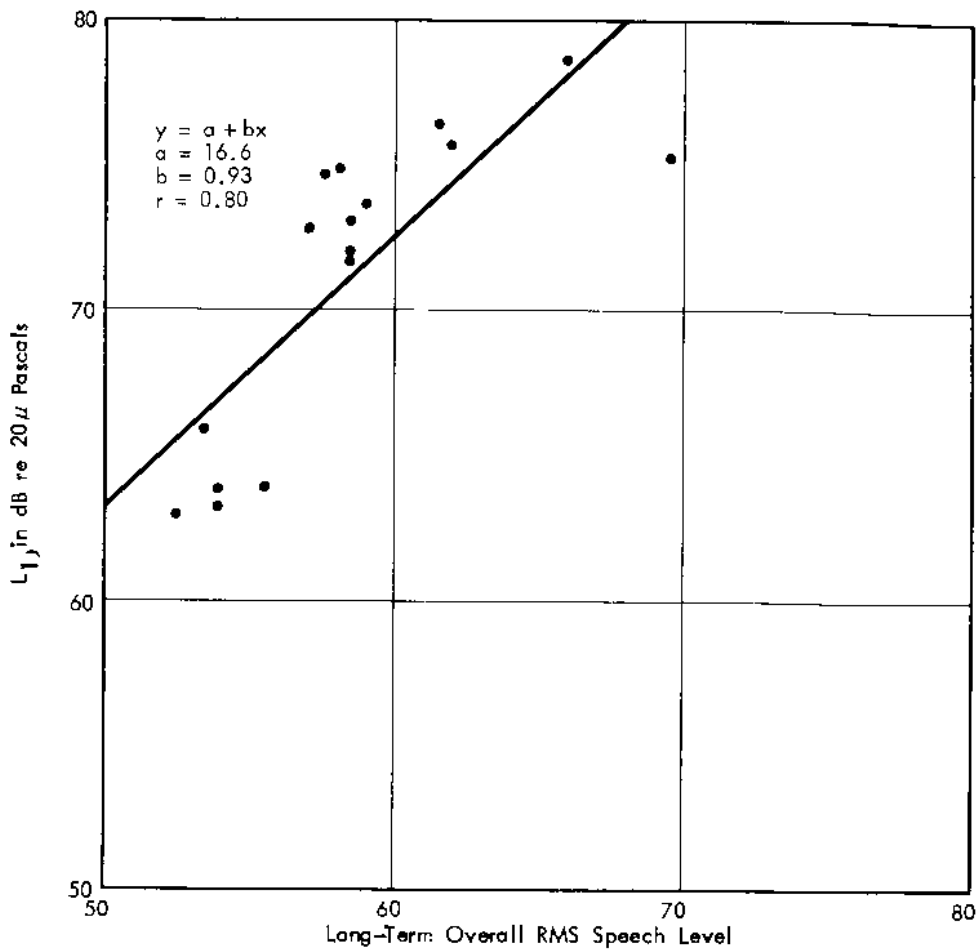


Figure 2. Noise level ( $L_i$ ) that permits 90 percent correct spondee words.

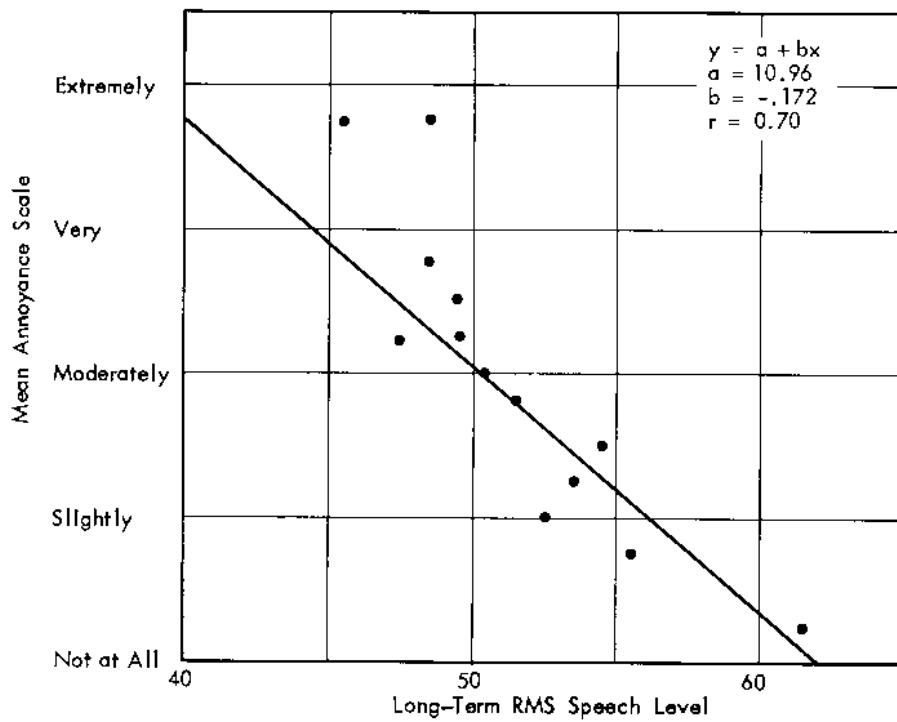


Figure 3. Annoyance ratings for traffic noise for stimulus No. 9 at various speech levels.



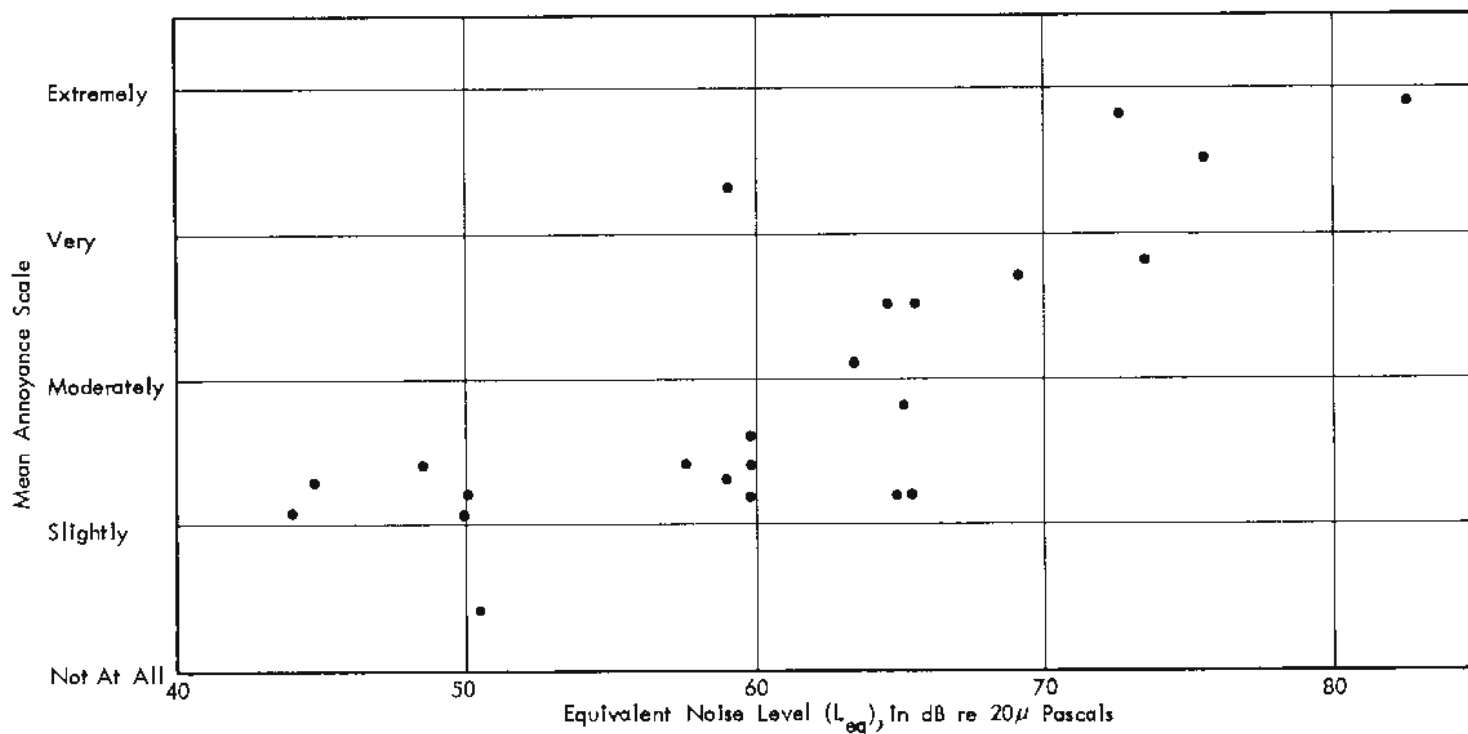


Figure 4. Annoyance rating versus  $L_{eq}$  of traffic noise; without speech.

annoying when they were able to answer only one question correctly. The number of correctly answered questions for the highest speech-to-noise samples (average +7.5 dBA) was almost always three out of three. It follows that in such cases the annoyance ratings were quite low.

#### Findings of Literature Review on Sleep

The scientific literature on the effects of noise on sleep was reviewed, concentrating on recent studies reporting quantitative results. In general, it was found that current

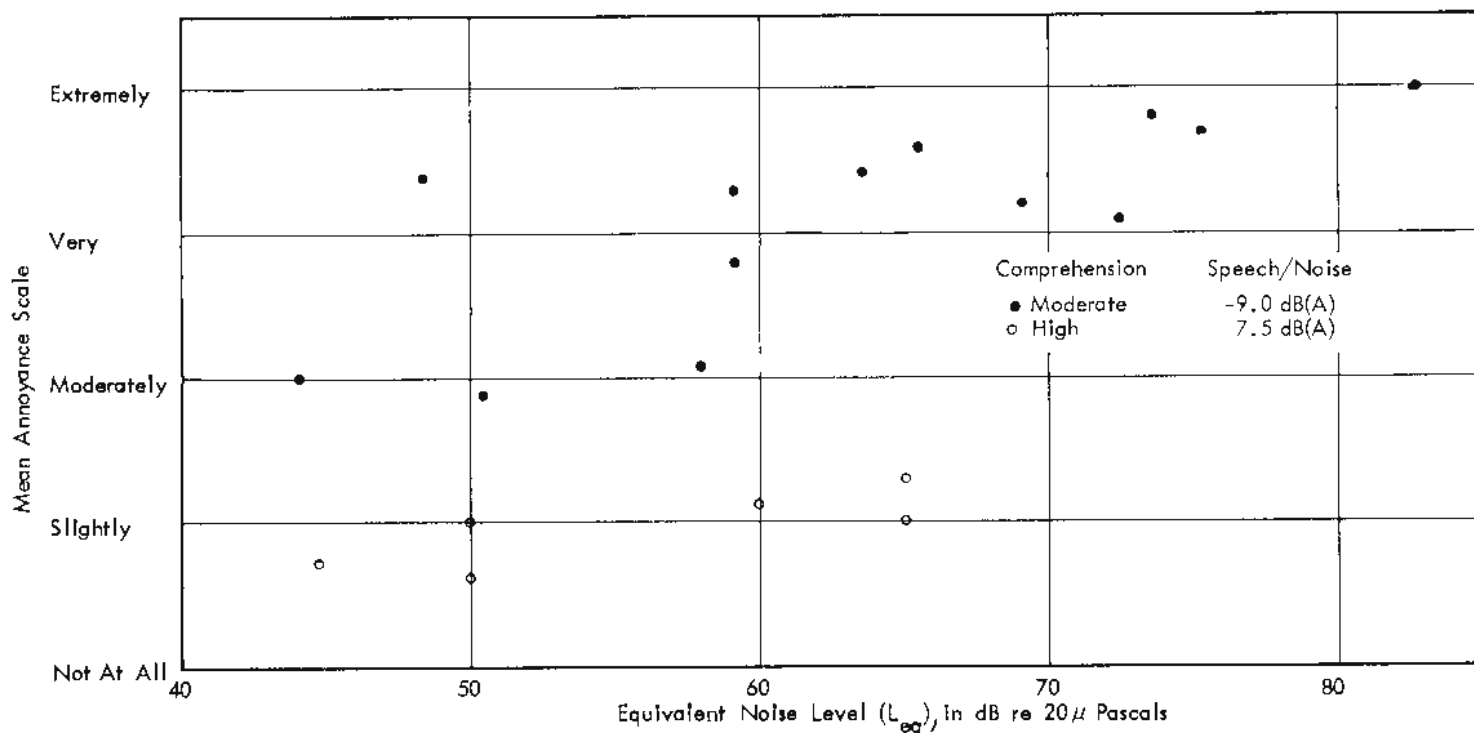


Figure 5. Annoyance ratings versus  $L_{eq}$  of traffic noise; with speech for moderate and high comprehension.

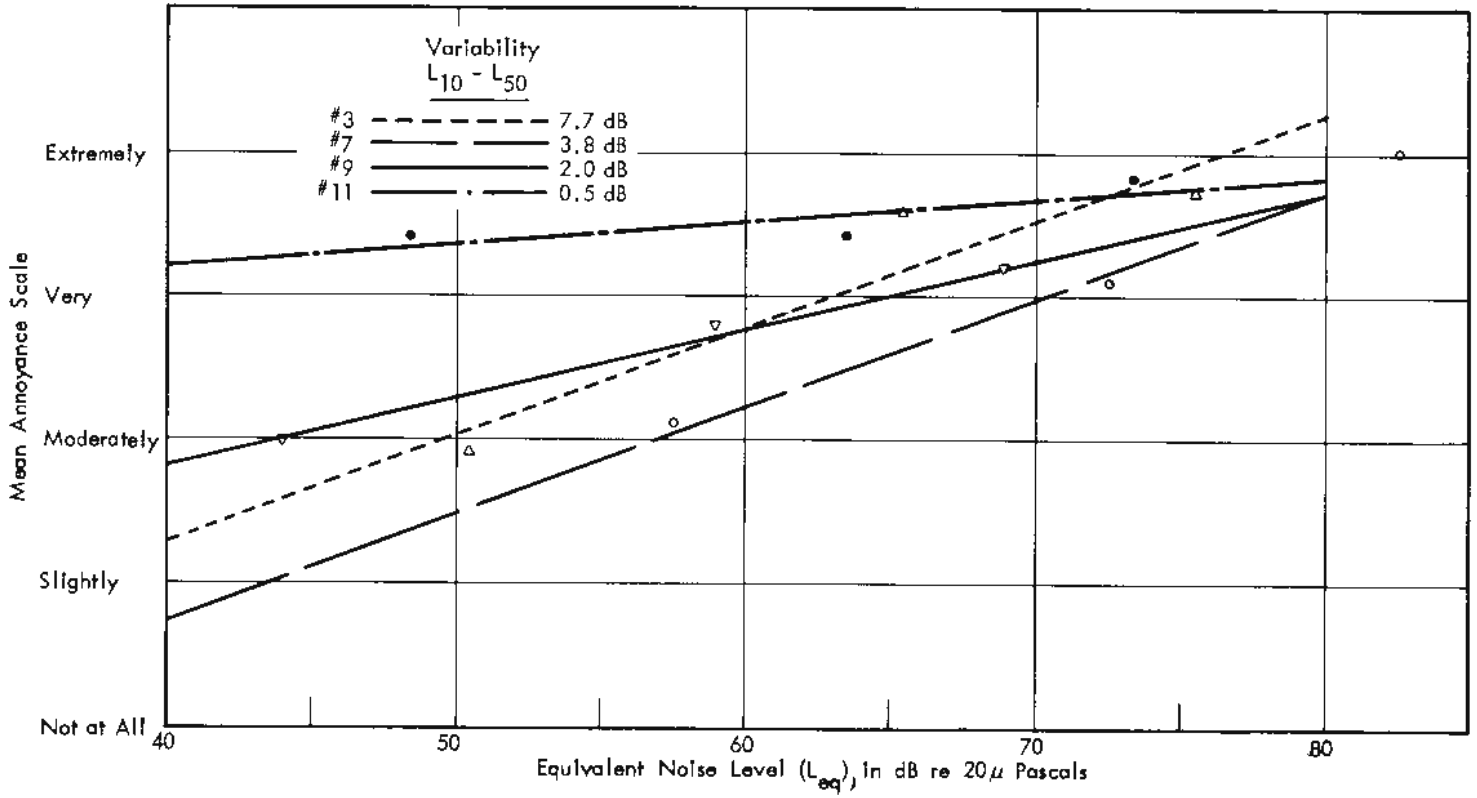


Figure 6. Annoyance rating of traffic noise with speech for Nos. 3, 7, 9, 11 at  $-9$  dBA speech/noise ratio.

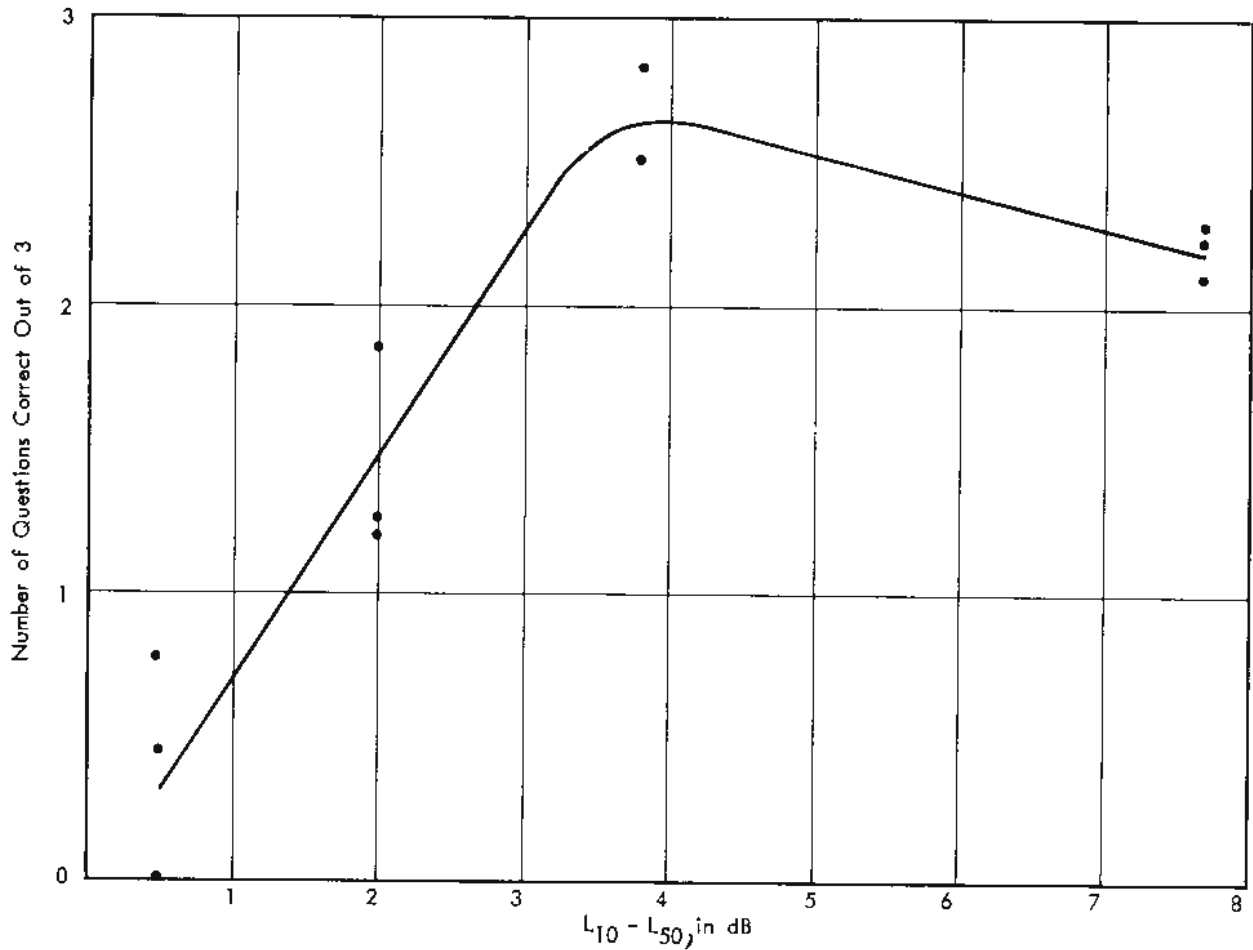


Figure 7. Speech comprehension in traffic noise for an average speech/noise ratio of  $-9$  dBA.

knowledge about the effects of noise on sleep is not adequate to support the sort of criteria that would be of greatest use to highway designers. In fact, the question highway design engineers would like answered (What effect will a new highway have on the sleep of people nearby?) is, strictly speaking, unanswerable. So many factors - acoustic and otherwise - influence sleep quality that this question may not yet be reasonable to pose.

Instead, two types of generalizations about noise effects on sleep are justified. These include broad statements that are basically quantifications of common sense (e.g., Noise exposure in excess of 85 dBA will disturb the sleep of a large proportion of the population.) and heavily qualified statements of experimental findings (e.g., Control participants in a laboratory investigation took 10 percent less time to fall asleep than participants exposed to a synthetic noise environment for six hours per night.) Of these two types of generalization the former seems preferable for highway design purposes, even though the latter is more defensible scientifically. A little background in sleep research will illustrate this point.

Adaptation to noise exposure is one example of the complexity of sleep phenomena that makes it difficult to establish simple criteria. The phenomenon of adaptation to noise intrusions (diminution of response intensity to repeated stimulation) is known to be quite strong, but little is known of its time course. Field studies have shown very little disturbance of sleep in long-term residents of extremely noisy environments. Pearsons et al. (2), for example, found little degradation of sleep quality in groups of people living directly under the approach path to a busy airport.

It seems, therefore, that noise exposure initially capable of degrading sleep quality may eventually (within weeks, or months at most) be tolerated with no apparent ill effect. Both scientific and anecdotal evidence supports this observation. Consider, for example, popular stories about city dwellers who have difficulty falling asleep in the country without the din of street traffic; or stories of people who cannot sleep without the noise of elevated railroads; or stories about a lighthouse keeper awakened by silence when the foghorn fails; or of sailors sleeping in the boiler rooms of ships, etc.

Another source of difficulty in establishing simple criteria is the nearly complete lack of understanding of the consequences of sleep disturbance. Acute studies of prolonged sleep deprivation (on the order of several days) have demonstrated that severe effects may occur. Chronic studies of mild sleep disturbance (such as loss of a few minutes of sleep several nights a week, occasional awakening during a night, or prolongation of time required to fall asleep) have yet to be performed.

Thus, there is no firm scientific basis for predicting the consequences of the sorts of sleep disturbance most likely to result from highway noise exposure. In the absence of such knowledge, the seriousness of sleep disturbance cannot be evaluated other than in vague terms. Everyone knows that it is unpleasant to be awakened by nocturnal traffic noise and that it is annoying to be unable to fall asleep because of traffic noise intrusions. Nobody knows any more precisely, however, whether there are consequences

other than transient annoyance associated with such sleep disturbance.

Worse yet, the results of the little research that is directly relevant to highway noise criteria are contradictory and confusing. Recent EPA attempts to summarize the literature have emphasized these problems. Consider the following quotation from a report prepared for the Environmental Protection Agency (3):

Two principal ways in which noise exposure can interfere with sleep are to delay the onset of sleep and to shift sleep "stages." Although there is frequently broad agreement among sleep studies, detailed agreement is lacking. Discrepancies among outcomes of similar studies are attributable to incomparable control conditions, differences in experimental design, and the host of individual differences which beset sleep research.

For example, it is universally observed that the initial time required for subject to fall asleep increases monotonically with exposure to increasing noise levels. Unfortunately, different studies produce estimates of the sleep-delaying effects of noise that are more than 35 dB apart. Thus, two studies report delay in onset of sleep from 20 to 90 minutes . . . , corresponding to exposure to continuous noise at levels of 35 dBA and 50 dBA, respectively. Other studies . . . , however, report that subjects can fall asleep in as little as 12 minutes despite exposure to noise levels of 70 dBA.

The following factors that impede criterion development have also been noted: methodological difficulties in interpretation of electrophysiological records of sleep; interactions between people's attitudes toward noise sources and their likelihood of awakening; potential differences in sleep disturbance from steady-state and time-varying noises; effects of age, sex, and health on sleep quality; meaningfulness of noise intrusions; and a host of other factors, including drug use and general stress.

In short, the literature review found no substantive or quantitative body of scientific knowledge about the effects of noise on sleep that would justify establishment of criteria for the present purposes.

## Interpretation and Applications

### *Speech Interference*

Figure 8 shows that normal voice communication is possible in an  $L_{101}$  environment of 56 dBA. For a relaxed voice one would be able to communicate with 98 percent sentence intelligibility in an  $L_{101}$  environment of 47 dBA. This agrees with the recommended inside residential level of 45 dBA.

The 95 percent confidence intervals for the regression lines are also shown in Figure 8. The graph of  $L_{101}$  versus speech level in the upper half of Figure 8 has the smallest confidence interval. However, the high correlation among  $L_{101}$ ,  $L_{50}$ , and  $L_{1,1}$  for the noise samples precludes absolute statements about the superiority of one of these measures.

### *Annoyance*

It was not feasible to select the best noise measure for these stimuli on the basis of linear regression analyses between noise measures and annoyance. A linear correlation was not appropriate because the annoyance rating scale limits the possible responses at the high noise levels.

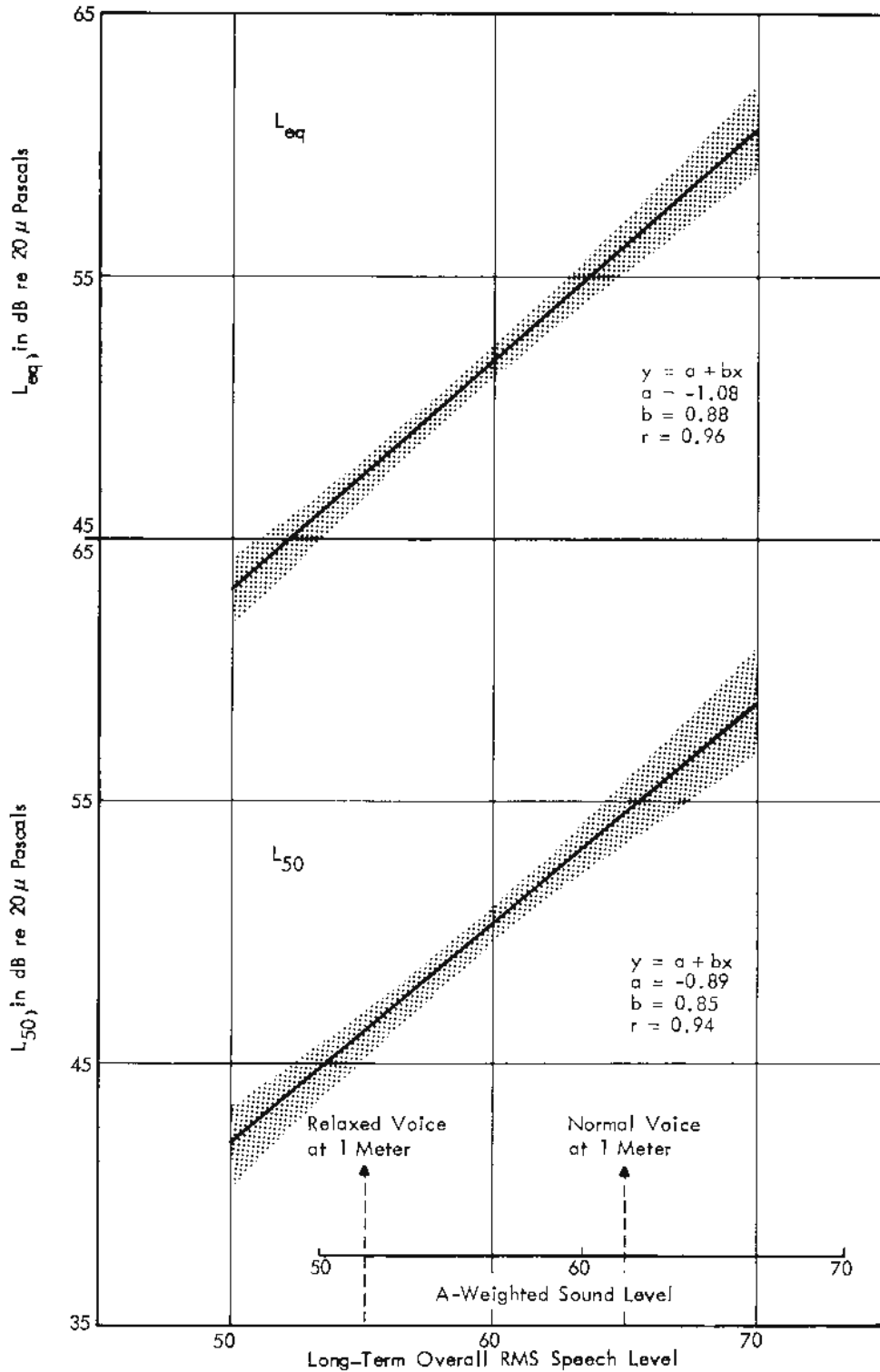


Figure 8. Noise level ( $L_{eq}$  and  $L_{50}$ ) required to attain 98 percent intelligibility ( $AI=0.6$ ).

One approach to determine the most effective measure calculates the average noise levels associated with each of the five annoyance categories for the noise distributions judged without speech. Figure 9 shows a comparison of the average noise levels for several of the measures. In general, for each of the noise measures annoyance increases

with level. However, the shapes of the interpolated psychometric functions begin to differ below the point on the annoyance scale designated "very annoying." For the highly correlated measures ( $L_{eq}$  and  $L_{10}$ ) there is virtually no difference between the annoyance categories of "moderately" and "slightly" for a given noise level. The stan-

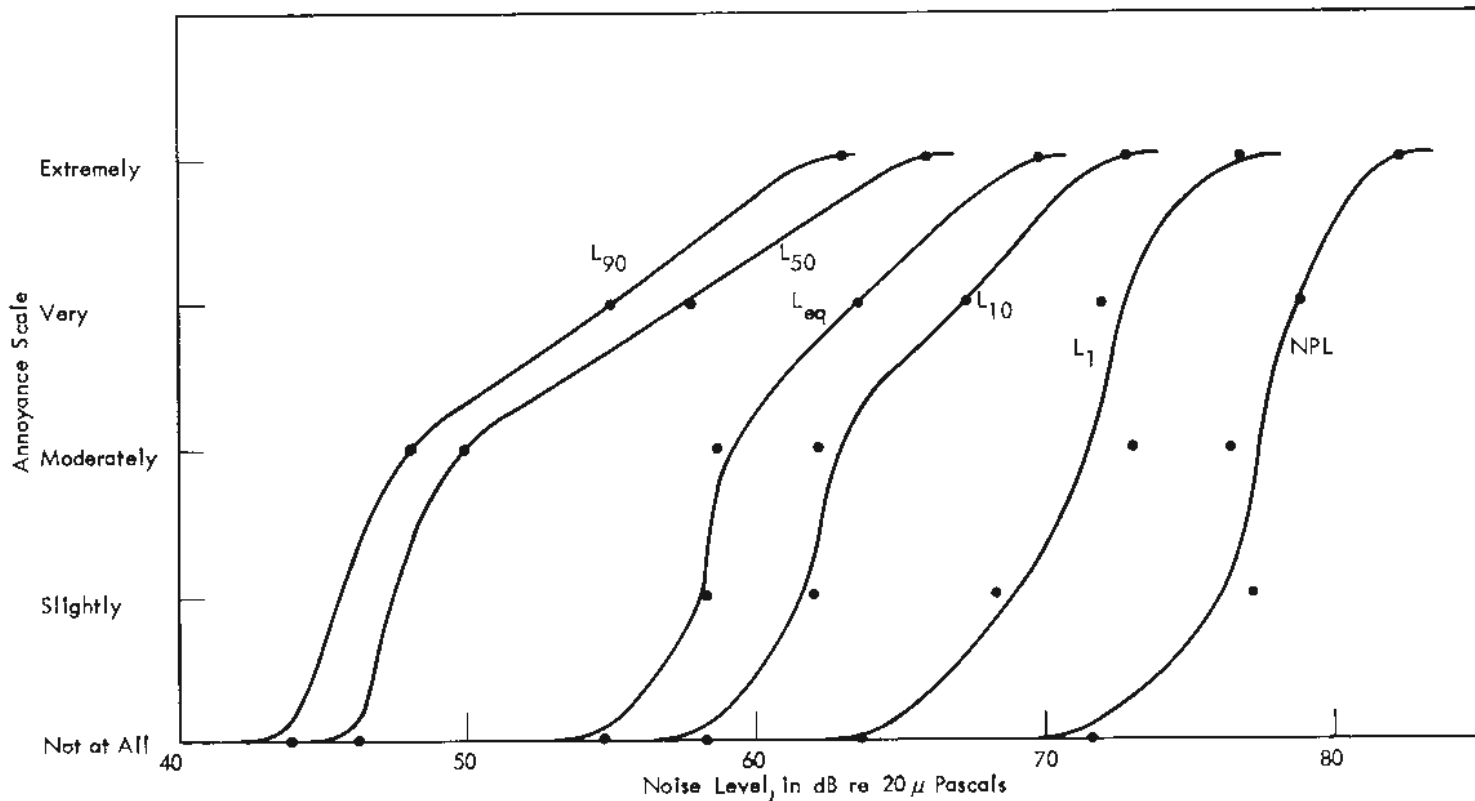


Figure 9. Mean noise level for various annoyance ratings.

standard deviation of  $L_{eq}$  for a specified response category was, in all cases but one, less than or equal to the other noise measures. The exception was the Noise Pollution Level (NPL) measure, which had a smaller standard deviation than  $L_{eq}$  for the "extremely annoying" category.

#### Annoyance Versus Acceptability

The information gathered for all samples on annoyance versus acceptability produced a high correlation ( $r = 0.96$ ) of acceptability and annoyance judgments for stimuli with and without speech. The close relationship between the scales suggests that a given rating on the acceptability scale may be accurately predicted (within the 95 percent confidence intervals for the regression line) from the annoyance scale.

#### Comprehension Versus Intelligibility

Intelligibility as measured by the percent correct of spondee words was not seemingly affected by the dispersions of the traffic noise samples employed in those tests. But comprehension, defined as the number of correctly answered questions for continuous discourse presented in a background noise, increased with the variability of traffic noise distributions for a fixed value of  $L_{eq}$ . This finding is probably due to word-context dependency and the temporal length of noise intrusions.

#### Variability

As discussed earlier, speech comprehension in time-varying traffic noise increased for the traffic stimuli with more variation, but equal values of  $L_{eq}$ . At the same time it was concluded that annoyance decreased as speech comprehension rose. In establishing the effectiveness of  $L_{eq}$ , the question remains whether the annoyance of sounds for a specified  $L_{eq}$  is affected by noise dispersions. Analysis showed that when speech was combined with traffic noise, there was a clear reduction in annoyance as the noise variation increased. For stimuli judged without speech, the evidence is not as definite. There is a general trend toward less annoyance as the noise distribution rises, yet there is a reversal where the traffic noise variability ( $L_{10} - L_{10}$ ) is 2 dB.

#### Interpretation of Literature Review Findings on Sleep Interference

The consequence for highway designers of the confusion, uncertainty, and disagreement found in the sleep literature is that no meaningful criterion for the effects of noise on sleep is yet justifiable. This does not imply that there are no effects of traffic noise on sleep. Fortunately, noise levels specified by other criteria for effects of noise on people probably afford a good first approximation to noise levels that may be appropriate for minimizing sleep interference.

### Conclusions and Recommendations

The research conducted for this test program supports the following conclusions and recommendations:

1. A comparison of noise measures  $L_1$ ,  $L_{10}$ ,  $L_{50}$ ,  $L_{90}$ , NPL, TNI, and  $L_{in}$  indicates that  $L_{in}$  is the most stable measure for predicting annoyance.  $L_{in}$  proved the most consistent and least variable of the measures for all annoyance categories used in rating the traffic noise distributions whose  $L_{10}$  -  $L_{90}$  values ranged from 0.4 dB to 24.6 dB. This is comparable to traffic conditions, which might vary from high-density freeway traffic flow to one truck passby every 5 min.

2.  $L_{in}$  is an adequate predictor of speech interference for traffic noise distributions whose  $L_{10}$  -  $L_{90}$  values range from 0.4 dB to 7.8 dB.

3. For a constant  $L_{in}$ , an increase in the traffic noise variation increases the comprehension of contextual material. That is, for periods when the traffic flow fluctuates the speech-to-noise ratio is high for a larger portion of time than for steady flows, thus allowing an increase in communication.

4. For a constant  $L_{in}$ , an increase in the traffic noise variation tends to decrease annoyance. Thus, a highway with truck and automobile noise would be less annoying than the same highway with constant automobile traffic if the  $L_{in}$  were the same for each situation. This proved to be true for tests conducted without speech and for the moderate (-9 dBA) speech-to-traffic noise condition. These results closely follow the second conclusion because, as might be expected, traffic noise would be judged less annoying if communication were reasonably possible.

5. Annoyance judgments are sensitive to changes in both noise level and speech interference. For low levels (less than 60 dBA) of traffic noise, the annoyance ratings are related to speech interference, but at high levels annoyance is rated on the basis of traffic noise intensity.

6. On the basis of their high correlation, the annoyance scale may be used to predict acceptability ratings for the traffic noise distributions found in this study. A judgment of "moderately" annoying corresponds to a "barely acceptable" rating for traffic noise with or without speech at a constant  $L_{in}$ .

7. If people are able to communicate at a "relaxed" voice level, they will rate the traffic noise of  $L_{in} = 47$  dBA as "not at all" annoying. However, if people must raise their speech level to communicate at a "normal" voice level, they will rate the traffic noise of  $L_{in} = 56$  dBA as "slightly" or "moderately" annoying (or "acceptable," which is in close agreement with the recommended residential level of 45 dBA).

8. Levels of noise exposure that minimize speech interference are probably adequate to minimize sleep interference as well.

On the basis of these conclusions it is recommended that criteria for the effects of traffic noise on people be expressed in terms of Equivalent Noise Level ( $L_{in}$ ). It is further recommended that the  $L_{in}$  measure of traffic noise be used to evaluate: (1) the more extreme cases of traffic noise variations that occur in typical spaces occupied by

people in everyday life, and (2) the order and grouping effects of vehicles on subjective assessment of traffic noise.

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Project 5-5A FY 71

### Development of Optimum Specifications for Glass Beads in Pavement Marking

By: Luke M. Shuler  
Research Agency: The Pennsylvania State University

### Introduction and Research Approach

For many years, the combination of glass beads with paint binders for pavement marking has been one of the most important elements in providing nighttime guidance for motorists. The important role of glass beads is indicated by estimates that approximately 150 million pounds are used annually, representing an investment approaching \$20 million per year. However, there has been some doubt as to whether this quantity of material has been employed most effectively and has performed to greatest advantage.

Effective use of glass beads in reflectorizing pavement marking materials depends on variables that are neither fully defined nor understood. This may explain why various bead gradations and compositions, bead surface treatments, and rates of application in varying thicknesses and compositions of binder are currently employed by highway organizations. Better understanding of the principles surrounding performance of glass beads in traffic paint markings is necessary if delineation techniques are to be improved, and if maximum benefits are to be derived from their use.

The research reported here was directed to achieving such a better understanding through the following five specific objectives:

- To review and analyze worldwide research and practices involving the use and manufacture of traffic marking beads.
- To identify those variables that markedly influence the effective utilization of glass beads in pavement markings and evaluate these variables by laboratory and field tests in order to rate them in terms of their influence on the effectiveness and serviceability of delineation under actual traffic conditions. Field tests were specified to include measurements of wet-nighttime reflectivity.

3. To determine the capability and economics of producing glass beads of specified gradation, composition, shape, flow properties, color, etc.

4. To develop practical specifications and criteria for the selection and use of beads for reflectorizing traffic paint markings.

5. To evaluate for one or more States the probable benefits that would accrue should the proposed specifications be adopted in place of current specifications.

#### *Research Approach*

The research approach to these goals included (a) a review of former work, (b) development of an experimental program of field tests and laboratory work and the development of measuring instruments, (c) calculation of glass-bead retroreflection from physical principles, and (d) a survey of both State highway users of glass beads and bead manufacturers. The two-year program included two seasons of pavement-marking activity, allowing conclusions and lessons learned in the first season to be applied in the second-season test. In addition, the survey, after being conducted for the 1971-72 period, had a follow-up to update the information close to the end of the project.

The research was successful in part. Current practices were reviewed and reported on, a number of factors affecting performance were identified, recommended sets of specifications and laboratory practices were drawn up, and the potential benefit of changes in practice on one State's budget was explored. The extent of savings that can be achieved by making the recommended changes in bead specifications was found to be mainly a function of changes in binder application practices. For the case studied, paint quantity reductions accounted for nearly three-quarters and bead material changes for one-quarter of the total dollars saved. More extensive testing would be necessary to confirm the validity of these estimates.

#### *Contents of the Project Report*

The final report submitted by the agency presents the findings arising from investigations and also the recommended specifications for glass-bead users. An annotated bibliography is also provided, as are suggestions for further research. An analytical assessment of the physics of retroreflection from spherical glass beads is also included as one appendix to the report.

#### **A Summary of Selected Findings**

In the 36 years since the first experimental road tests used small glass beads to reflectorize pavement markings, the amount of glass beads used has grown to an estimated 150 million pounds per year in the United States.

Major examples of various uses and practices are:

1. Drop-on bead application versus use of beads premixed in the paint binder, with or without additional top-dressing beads.

2. Use of wet-film binder 10 mils thick versus 15 mils or thicker.

3. In combination with a 10-mil binder, use of 4 lb of

beads per gallon of binder versus 6 lb per gallon.

4. For the 4-lb-per-gallon application, use of more uniform bead size (40 to 80 mesh) versus well-graded (about 30 to 100 mesh) beads.

5. Use of an oleophobic surface coating (flotation treatment) to improve embedment of the 40- to 80-mesh beads versus silicone treatment (moistureproofing) or other means of preventing the caking of beads. Continuing efforts to improve the performance of beads for retroreflection include tests of beads with higher than usual refractive index, with higher clarity and strength, and of other compositions, such as various transparent plastics.

Performance of retroreflecting glass spheres in pavement markings is strongly influenced by the binder (paint) in which the beads are embedded, so that bead properties alone only partly determine marking effectiveness. Field test conditions, in which deterioration resulted from abrasive wear under high traffic volumes, favored the test lines with greatest reflective durability compared to standard Pennsylvania specification beads (moistureproofed, wide gradation, low index) applied at 6 lb per gallon of standard binder at 15-mil wet-film thickness. Test lines included (a) beads like the standard glass but uncoated, (b) flotation-treated beads with wider gradation than the usual 40 to 80 mesh, (c) regular flotation beads (40 to 80 mesh) in some applications heavier than the usual 4 lb per gallon in 10-mil binder. The usual flotation-bead (4 lb per gallon, 10 mil) application was not much worse than the reference lines, and was definitely better than standard glass applied at the same rates.

A general pattern of contrast between performance on portland cement concrete pavement and bituminous concrete pavement was found in both series of field tests: higher brightness on concrete, but more rapid wear; less bright, but longer-lasting performance, on bituminous pavement. Bead macrophotographs indicated that the explanation lay in immediate loss of beads on top of aggregate particles but prolonged protection of beads in depressions of the pavement surface texture.

No useful wet reflection of test lines appeared after exposure to traffic wear. The lines that were brightest when dry were still brighter than others when wet, but were still very dim.

Recommendations for improved bead application procedures in Pennsylvania included as alternatives: (1) use of uncoated glass as a substitute for present moistureproof glass, with a possible saving of \$605,000; (2) use of flotation-coated beads of modified (wider) gradation for edge lines only, with a possible saving of \$238,000; and (3) use of flotation-coated beads of modified (wider) gradation for all markings, with a possible saving of \$1,064,000. Alternate 2 would involve use of thin (4 lb per gallon, 10 mil) applications for edge lines, with heavier (6 lb per gallon, 15 mil) applications between traffic lanes. Alternate 3 would involve the thin applications for all markings. Large-scale verification trials with regular application equipment and personnel would be necessary before adopting the changes generally.

Some other kinds of beads showed promise: for example, two types are plastic beads having only moderate

brightness but, at least in one case, extreme durability, and others having higher refractive index in some applications. Optical calculations and tests on laboratory panels showed the higher brightness to be expected from a higher refractive index, other things being equal. Large random errors encountered in measurements of reflection on laboratory test panels at high ( $88^\circ$ ) incidence angles suggest other approaches for determining reflective head performance. Visual ratings of test line performance at night, by vehicle headlights, can be supplemented satisfactorily and perhaps replaced by use of a portable photometer with realistic optical geometry ( $88^\circ$  incidence,  $1^\circ$  divergence). Some laboratory test procedures can be improved (e.g., wet flow tests) or omitted (e.g., acid tests); others have doubtful significance and need further evaluation.

The survey of users and manufacturers of glass beads indicates that states paid average prices of \$0.11045 to \$0.13625 per pound for drop-on and flotation beads, respectively, in 1971-72, with part of the price difference caused by the tighter gradation specification for flotation beads. This study indicates that wider gradation (including more small beads as well as large) would reduce production costs as well as improve performance.

#### Specification Recommendations

Based on experimental marking performance in this study, the following recommendations were made for the use of glass beads:

- *Binder Thickness.* (Though not a bead property, line thickness was of major importance in the durability of test markings in this study.)

20 mils: for conditions of abrasive traffic wear, especially in wheel tracks, when long wet-paint protection is possible.

15 mils: for conditions of abrasive traffic wear, when protection of wet lines must be brief.

10 mils: with flotation-coated beads, under conditions of light wear and of line failure by chipping, to minimize total paint build-up and economize on the amounts of materials used.

- *Gradation.* Wide gradation, approximate size range from No. 20 or No. 30 sieve to No. 100 or No. 200, for use with 15-mil or thicker binder.

Broadened gradation, to range from about No. 30 sieve to No. 100, for flotation-coated beads in thin (10-mil) binder.

- *Bead-to-Binder Ratio.* 4 lb per gallon: for flotation-coated beads. 6 lb per gallon: for uncoated or moisture-proofed beads, or for increased reflection by flotation-coated beads.

- *Surface Treatment.* Uncoated: for increased durability, when performance in storage and handling permits. Moistureproofed (silicone-treated): when necessary to prevent caking or clumping from moisture. Flotation-treated (coated with an oleophobic material): for satisfactory performance in thin (10-mil) binder and increased reflection per pound of smaller beads.

- *Refractive Index.* Low index (about 1.50 to 1.55 soda-lime glass): for economical durability and adequate

reflection, at the present state of the art. Medium or high index (1.60 and higher): for increased reflection, especially at long distances by new markings.

#### Laboratory Test Recommendations

Although not proved to be preferable in this project, the following tests are recommended as a result of the reviews of current practices:

- *Microscopic Examination.* Preferred for testing roundness, clarity, and color, and absence of rough, broken, and foreign particles.

- *Color.* Examination of individual beads microscopically, by usual present practice.

- *Transparency (Clarity).* Tested in the same microscopic examination of individual beads, rejecting beads that are unclear for any reason, including surface roughness, excessive bubble content, or fractures.

- *Roundness.* Acceptable beads to include not only true spheres able to roll down a vibrating inclined plane by ASTM Method D1155-53, but also double-fused spheres (dumbbells) and nearly spherical beads that are clear and smooth, by microscopic examination. By this criterion, about 90 percent by count should be acceptable. Eventually this test and the preceding one should be replaced by an acceptable test for retroreflection.

- *Refractive Index.* Not needed for soda-lime glass beads except as an identity check. (A simpler identity check is measurement of the density by liquid displacement.) Both refractive index and density are important for other glass compositions.

- *Gradation.* According to present practice, by ASTM D1214-58, with clear agreement between supplier and user on details of the actual procedure, such as manual or mechanical shaking, loading of screens, and calibration against unworn reference sieves.

- *Surface Properties.* Flotation treatment: present test. Test for flow in presence of moisture: replacement of the bag test or beaker test by a desiccator test or similar test for flow of beads exposed to controlled humidity or mixed with a small measured amount of water.

- *Chemical Resistance.* Resistance to sulfide and to deicing chemicals (sodium chloride and calcium chloride): not needed for soda-lime glass except as an identity check; necessary for other glass compositions. Resistance to acid and alkali: not necessary. Resistance to attack by hot water (simulated weathering test): examination of bead appearance and titration of water with acid after boiling glass beads in water for a fixed time, in preference to extraction of glass beads in a Soxhlet apparatus. Probably not needed for soda-lime glass beads.

- *Crushing Strength.* Probably not needed for soda-lime glass beads that show no visible flaws microscopically. Of some value for other bead compositions.

#### Suggested Research

The research following most directly and logically from the work in the present study is the testing of the recommended specifications by large-scale applications with regular equipment and crews.



Additional areas needing research include the laboratory tests for specified glass-bead properties. Suggestions for such research are provided in the project's final report.

### Applications

Evidence of the potential values of this research was cited earlier in the mention of savings to Pennsylvania that might accrue from a change in specifications. The benefits were derived as described in the following.

To make an estimate of possible savings that might result if uncoated glass heads were to be substituted for moistureproofed beads in use on Pennsylvania highways, the following assumptions are made:

1. The cost per pound for uncoated beads is unchanged from that for moistureproofed beads.
2. All lines require a first painting in the year; the saving is a reduction in requirement for second painting in the same season.
3. Although the 1973 bead price and quantity are used, data on line applications are from 1972 and 1971.

From the test sites, it was determined that with both types of beads applied at 6 lb per gallon and 15-mil wet-film thickness the standard lines with moistureproof beads on bituminous and portland cement concrete pavements had lives of 156 and 148 days, respectively, whereas those with uncoated glass beads had lives of 260 and 284 days, respectively.

According to data from the PennDOT Bureau of Traffic Engineering, 543,000 lb of beads had been used between January and the end of August 1972 in repainting lines already painted earlier the same season, equal to 10 percent of the 5,425,000 lb used in first painting of lines in the season. For 1971, however, by the end of the year 1,645,000 lb of beads had been applied in repainting lines, or 27 percent of the 6,113,000 lb used in first painting. Because the additional repainting was mostly done in September and October, whereas the first lines of the season are mostly applied in April and May, the 5-month interval corresponds (roughly) to the figures found for the reference lines in this study, applied at the same rates using the same moistureproofed glass and the same conventional binder.

For the purpose of estimating savings with uncoated glass, the same 10 percent repainting ratio is assumed to apply for the entire season for uncoated glass as it did at the end of August for moistureproofed glass, inasmuch as the 8½- and 9½-month values found from the data for uncoated glass would represent durability past the end of the calendar year after first painting dates in April or later. Then, of the estimated 1973 glass requirements for Pennsylvania (9,902,000 lb), a fraction would not be needed, amounting to a reduction of the ratio of repainting/first-painting glass requirements from 27 percent to 10 percent for the year. The reduced bead requirement, therefore, is 1.10/1.27 of 9,902,000 lb, or 8,577,000 lb, a decrease of 1,325,000 lb of beads, worth \$154,000 at \$0.11596 per pound. Bigger savings result from the reduction of other associated costs. Based on 1972 figures through August of

\$2,037,000 in paint, equipment, and labor costs to apply lines with 5,968,000 lb of glass beads, these costs are \$0.341 per pound in addition to the glass bead cost. If a proportional reduction of these costs is assumed, these savings amount to \$452,000. Adding the two estimated figures and rounding off gives \$605,000 as the total saving.

Calculated in a similar manner and based again on field test performance comparisons, savings were estimated for a change to flotation-treated beads with a modified gradation. The following assumptions and calculations were made:

1. The bead cost per pound is increased only \$0.02, instead of the average \$0.026, because of the less restrictive requirements for gradation. The 1973 cost per pound of regular glass (\$0.11596) is used as a base.
2. Edge lines are applied at 4 lb per gallon and 10-mil binder, and center lines at 6 lb per gallon and 15-mil binder wet-film thickness.
3. Equal service life is obtained as with regular glass in present use, so labor and equipment cost changes are not involved.
4. The estimate is on the basis of 2-lane road marking only, which in 1971 totaled 31,800 yellow and 22,900 white line-miles. Paint costs are based on 1971 figures.

Substituting the flotation beads in the white edge line means that the amount of paint required is reduced to ⅔, saving ⅓ of the white paint costs (2-lane marking), or \$175,000. The amount of glass used in the edge lines is ⅓ of the previous edge-line use of 2,278,000 lb, or 1,012,000 lb. Adding this amount to the unchanged amount used in yellow center lines (3,163,000 lb) gives 4,175,000 lb as the total used. At \$0.13596 per lb, the cost is \$568,000, to be compared with a cost of \$631,000 for the original 5,441,000-lb total at \$0.11596 per lb, giving a saving of \$63,000 on beads. When this is added to the paint saving, the total saving is \$238,000.

Similar calculations were made with the assumption that the flotation-treated beads could be applied for both white and yellow markings.

To summarize, estimated possible savings in Pennsylvania from changes in specifications were as follows:

CHANGE IN SPECIFICATION	ESTIMATED ANNUAL SAVINGS
Alternate A (uncoated beads)	\$ 605,000
Alternate B (flotation-coated, modified gradation)	
Conservative application (thin edge lines, 15-mil center lines)	\$ 238,000
Full use of thin application	\$1,064,000

The report cautions that large-scale trials should be conducted before making such major changes in specifications. This would be especially important for making a choice between the application of flotation glass in thin films only on edge lines and a full substitution of thin film applications for present practice in pavement marking.

Project 7-9 FY '73

## Development of Models for Predicting Weekend Recreational Traffic

*By:* Edward L. Perkins  
 Andrew D. St. John  
 William D. Glauz  
 Walter R. Benson

*Research Agency:* Midwest Research Institute

### Introduction and Research Approach

#### *Description of the Problem*

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 rather than during more familiar weekday morning and evening rush hours. Although the weekend traffic problems are of increasing concern to highway officials, the emphasis in previous studies of traffic demand, capacity, etc., has been placed on weekday travel patterns, with most attention directed to urban areas. Techniques are needed by transportation planners and traffic engineers to predict weekend recreational traffic in those areas and on those highways where such traffic may be a significant problem.

#### *Objective and Scope*

The objective of this research was to develop techniques for the prediction of weekend recreational traffic. The techniques were to be capable of responding to changes in recreational demand, recreational supply, and transportation supply. The development of techniques having application to corridors at the fringes of urban areas and to highway networks in the vicinity of selected recreational complexes was desired.

Three products resulted from the research:

1. A narrative report (dated July 21, 1976) containing a description of the basic concept of a recreational traffic prediction model (RTPM), its methodology, significant input data, findings, shortcomings, and recommended future work.
2. A users' manual containing specific instructions for use of the computer-based program by highway planners and others interested in predicting weekend recreational traffic (dated February 12, 1974).
3. Model data and computer program.

The report and user manual are available from Xerox University Microfilms\*; the computer program is available from NCHRP.

#### *Previous Research*

A review of prior research indicated that two aspects of recreational traffic have been addressed. First, the demand

for and supply of recreation have been studied in both the public and private sectors, to provide inputs for recreation management and planning. Second, the traffic generated by recreation has been analyzed using essentially the same traffic assignment and related models employed for other traffic generators.

Numerous surveys and analyses have been conducted on recreational behavior, demands, and resources. Although these efforts were designed to serve the recreational industry they have been valuable in model development for this project.

Three types of models have been used previously to estimate the recreational traffic attracted to competing recreational areas. They are: gravity models, the intervening opportunities model, and the systems model.

The generalized and nonlinear gravity models used to allot the demand in a region to the competing recreational resources require calibration by iterative processes and provide good correlation with field data when the model uses real origin-destination (O-D) input data. The intervening opportunities model has also been used to allot recreational traffic; however, it has been found to be less efficient and less accurate than the generalized gravity model.

The systems model, which also uses O-D input data, appears to be superior to the gravity model. However, its computations are more expensive and, like the gravity models, it requires iterative calibration. However, unlike the gravity models, the systems model utilizes individual highway links so that localized traffic demands are available from the output.

The examination of prior work indicated that an existing model, COMPATRAX, previously developed by MRI, provided the best base for model development in this project. COMPATRAX analyzes the recreational performance, potentials, and economics of geographic regions. There were several major advantages in using COMPATRAX as a base. First, the model solves for recreational travel by simultaneously employing recreational demands, recreational resources, and highway transportation: there is no need to depend on O-D survey data. Second, the influence of transportation is incorporated through analytical descriptions of the way transportation is used in recreational travel. Consequently, the model did not need to be calibrated for each application. Finally, the quantifications of recreational demand and resources are logically organized, have been tested, and employ data that have been routinely collected and will probably continue to be collected in the future. The following section describes COMPATRAX, the starting point for the model developed in this project.

*The COMPATRAX Model.*—COMPATRAX is a contraction of the phrase COMPETING ATTRACTIONS; it was developed to analyze the recreational performance, potentials, and economics of geographic regions. The inputs to the model are the recreational demands and the recreational resources; the model allots the demands to the resources.

COMPATRAX treats individual recreational activities. The demand for these activities varies between age groups in the population and between regions in the country. By treating individual activities the recreational resources of

\* Xerox University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, MI 48106.

a region can be quantified with regard to the individual activities or groups of activities requiring similar resources. The seasonality of demand and patronage are also conveniently incorporated by the treatment of individual recreational activities.

COMPATRAX recognizes and incorporates recreational trips that occur under different time constraints. The occurrence categories are: few available hours, all-day outings, overnight outings or trips, and vacations. Obviously, the distances traveled and the times enroute are likely to be different for each of these categories.

The COMPATRAX model recognizes the importance of distance between the points of recreational demand and the locations of recreational resources. However, unlike the gravity models, which use analytical expressions, COMPATRAX employs trip distance data collected in surveys of recreational behavior. These data are employed when recreational demands from one zone are allotted to the surrounding resource zones. Fixed fractions of the demands indicated by the survey data are allotted to each of several concentric rings around the recreational demand zone. Within a ring, allotment is made to individual recreational zones on the basis of their quantified resources. As would be expected, the rings and the fractions allotted within rings depend on the occurrence category—few available hours, all-day outing, overnight, and vacation. Because the fractions are based on survey results, this procedure requires no further calibration.

The COMPATRAX model has been employed to estimate the future attendance and related economic effects at recreational areas. Where they could be checked, the attendance estimates for a season from COMPATRAX have been within 10 percent of the estimates derived from field data.

COMPATRAX is a usable model employing input data that are available and periodically updated. The model disaggregates the problem of recreational traffic demands. However, the COMPATRAX model was developed as a tool for economic and regional analysis. It required modifications and additions to meet the goals of NCHRP Project 7-9. The new model, developed for this project, was named the Recreational Traffic Prediction Model (RTPM).

*Development of RTPM.*—In developing RTPM the major extensions and modifications to the COMPATRAX model included: incorporation of logic to assign traffic to highway segments, addition of other recreational activities, and the addition of logic and distributions to estimate recreational traffic demands hour by hour during weekends.

The logic to assign traffic to highway segments employs the Urban Planning Battery (UPB), a computer program already in existence and extensively documented. Use of the UPB requires that the highway network be specified in detail for the region of primary interest. The UPB selects origin-to-destination paths in the highway network by minimizing trip attributes such as travel time, distance, or a combination supplied by the user. Highway travel time is used in RTPM.

Additional recreational activities, not included in COMPATRAX, that generate travel were added to the model. They were: visiting friends and relatives, driving around,

and visiting second homes. The frequencies of the added activities were quantified from data collected in a survey of 1,430 households located in the metropolitan areas of Kansas City, Missouri; Kansas City, Kansas; and Des Moines, Iowa. Additional data were collected in this survey on the activity "attending spectator events."

The survey of 1,430 households also collected data on the items when outbound recreational trips were started, the destinations, times of outbound arrival, times of inbound (return) departures, and times of inbound arrival.

*Tests of RTPM.*—The computer program for RTPM was compiled and run on the Florida Department of Transportation IBM 360/50 computer system and later on that Department's IBM 370. The results were compared with samples of recreational traffic identified from two weekend field data collections.

The test field data were collected during parts of two summer weekends on two highway segments close to the Lake of the Ozarks, a recreational area in central Missouri. During data collection a one-direction traffic count was made and the license plate of every third vehicle was photographed. At each site, data were collected on both Fridays between 6:00 PM and 9:00 PM for traffic flowing from the major cities toward the lake. Data were also collected on each of the two Sunday afternoons between 3:00 PM and 6:00 PM for traffic in the opposite direction of flow. Thus, data were obtained during a total of four time periods. The fraction of recreational trips was estimated from the results of telephone interviews directed to the owners of register derived from the license plate data.

## Findings

### *Development of the RTPM Model*

Recreation planners and analysts have developed data bases and knowledge enabling projections, at least in the near term, of demand for recreational resources. Likewise, highway engineers have developed sophisticated techniques for assigning well-defined traffic demands to a highway network. This contract focused on merging these two disciplines through development of the Recreational Traffic Planning Model (RTPM). This computer-based model uses the data and concepts of recreation analysts and traffic engineers to calculate recreational traffic by merging recreational demand, recreational supply, and traffic assignment logic. Then, using components of the Urban Planning Battery, the traffic demands on specified highway segments can be determined.

*Basic Concepts of RTPM.*—A major contribution of RTPM 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 recreational time available.

RTPM is 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, sea-

sons, 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.

*Geographical Coverage.*—RTPM is designed to provide weekend recreational traffic estimates on any highway link within an area selected for study. This so-called "primary" area is user-specified; within the primary area, demand-generating population centers, resource centers, and the highway network must be specified in detail.

RTPM also requires documentation of a less extensive nature of a secondary area, surrounding the primary area, so that demands and resources within the secondary area which result in traffic in the primary area are accounted for. The areas, primary and secondary, are divided into zones and trips are allotted with equations of the form

$$V_{ij} = D_i \frac{T_{ij} A_j}{\sum_{k \neq i} T_{ik} A_k}$$

in which

- $V_{ij}$  = recreational weekend trips from zone  $i$  to zone  $j$ ;
- $D_i$  = total weekend demand from zone  $i$ ;
- $T_{ij}$  = travel time factor from zone  $i$  to zone  $j$ ; and
- $A_j$  = recreational resource or supply at zone  $j$ .

*Output.*—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 and time parameters.

By using the trip file generated by RTPM, Urban Planning Battery programs provide estimates of weekend recreational traffic in either or both directions, for any pair of origin-destination points, or for any individual link, any group of links, or all links of a highway network within the primary area. Similarly, RTPM can provide estimates of total traffic through any zone or group of zones on the network.

RTPM can provide estimates of weekend recreational traffic by hour or other user-selected interval for any year for which recreational demand data are available. As presently configured, RTPM can provide separate estimates of weekend recreational traffic, for both two-day weekends and three-day weekends, during the summer quarter. This restriction to summer-quarter traffic is purely data limited; the analytical and computational techniques incorporated in RTPM can be applied by individual users to other periods of the year, provided adequate demand data are available.

*Input Data Requirements.*—RTPM is heavily dependent on extensive input data. Three major sets of data are required to describe recreational demand, recreational resource supply, and transportation supply.

RTPM derives estimates of total weekend recreational traffic by aggregating the five major components of this demand: participating in outdoor recreation; visiting friends and relatives; attending spectator events; visiting second homes; and driving around without a specific destination. These separate demand components are derived by applica-

tion of a series of demand generators to population; these demand generators, in turn, consist of participation rates and other recreational behavior functions.

The basic units of recreation supply incorporated into RTPM are usable recreational land, usable recreational water, and population. Such resource data are generally available throughout the United States from the State Comprehensive Outdoor Recreation Plans (SCORP) that have already been prepared for all 50 states. Provision in RTPM is also made for qualitative judgment-based ratings of supply attributes to account for those recreational resources that attract disproportionate numbers of visitors.

Within the primary study area, users must describe the essential elements of the highway network of interest. The network consists of links and zones. The zones are comprised of major intersections, points of linkage to major metropolitan areas, and boundary zones at the perimeter of the primary study area. The network linkage characteristics are described by the travel time on the links that connect the zones. Beyond the primary study area, transportation supply is treated in a more general way, reflecting driving time between geographic regions rather than a detailed simulated highway network.

*Demonstration and Testing.*—RTPM was demonstrated on an IBM 360/50 computer in the State of Florida Department of Transportation. The allocator portion of RTPM requires a rather large amount of computer time. This is the part of the computer program that calculates and writes a file of all weekend recreational trips. The file, once generated, should be usable for an extended time period and can be searched as desired for needed details of recreational traffic by link and weekend hour.

The basic product from the model and associated computer programs, the file of weekend recreational trips, can be searched in computer operations to obtain directional-link-hour counts. In the current form, the computerized search employs utility programs to assemble specified trip counts.

Test data were collected for comparison with the results from RTPM applied to the State of Missouri. A critical examination of the model and the data has located defects in the numerics used to define travel time functions in the RTPM tests. The defects appear to account for certain unsatisfactory comparisons with field data. However, the test runs have not been repeated with corrected values. Details of the corrections are included in the report, together with the reasons why their implementation should lead to improved validity of the model.

#### *Characteristics of Recreational Traffic*

Data collected expressly for this project, plus analysis of preexisting data using the logic contained in the model, provide valuable insights about recreational traffic. These insights are preliminary and based on limited data, and should be confirmed through use of the improved model and with additional data from other regions. The insights are organized into four categories: general recreational travel patterns on summer weekends; traffic demands near urban areas; traffic demands near recreational areas; and implications for the rural highway system.

*General Travel Patterns.*—On a two-day summer weekend (60 hr beginning at noon Friday and ending at midnight Sunday) one recreational trip (one vehicle) is made in the north central census region for every five persons in the population; in the southern region, one trip is made for every six persons. On two-day summer weekends 83 percent of recreational trips do not involve an overnight stay. Overnight trips are 16 percent of the total; vacations account for about 1 percent.

On three-day summer weekends, only 55 percent of the recreational trips involve only one day. Overnight trips account for 42 percent of the total; vacation trips account for about 3 percent. It is important to recognize that on three-day weekends the overnight trips increase not only in percentage but also in absolute numbers. There are 30 percent more overnight trips than on a two-day weekend. Trips made to visit friends and relatives contribute heavily to the increase in the overnight category on three-day weekends.

A survey of summer recreation behavior conducted for this project collected data on the times of the weekend when recreational trips were made. The results showed strong model peaks for the times when outbound trips (from the residence) departed and when the return (to the residence) trips arrived. On the other hand, the arrival times at, and departure times from, the recreation destination showed no strong peaks.

*Demand Near Urban Areas.*—On a two-day weekend only about 16 percent of recreational trips are of the overnight variety. However, it is these trips that contribute to the Friday afternoon peak. Forty-three percent of the weekend overnight trips depart from the residence between 4:00 and 7:00 PM. From a population center of one million, about 13,700 trips are indicated in the 3-hr period. Commuter and other demands normally peak during these hours of any weekday, when it is typical to count about 22 percent of the weekday ADT. On a three-day weekend, the Friday afternoon demand is enlarged because there are 30 percent more overnight trips, and 46 percent of them begin between 4:00 and 7:00 PM. More than 19,000 overnight trips depart during these hours from an area with a population of one million.

On a two-day weekend, most trips of one-day or less duration are made on Sunday. The most serious outbound concentrations come on Sunday afternoon and may create problems on highways to nearby water recreation areas. However, the short recreational trips help create the greatest problem on a two-day weekend when they return Sunday evening during the same time period as inbound arrivals from overnight trips. As a result, 49 percent of all recreational trips on a two-day weekend return (arrive at normal residence) between 5:00 and 8:00 PM. Another large fraction of overnight trips arrives between 8:00 and 10:00 PM. Consequently, an urban area with major through or bypass highways must handle its own arrivals in the 5:00 to 8:00 PM interval plus sizeable numbers of recreational through-trips that are still 1 to 2 hr from their destinations.

Except for the Friday peak, available data indicate that a three-day weekend should generate smaller peak demands than a two-day weekend.

*Demand Near Recreational Areas.*—The most serious peaking of traffic demands should occur near recreational areas that receive most of their patronage from one population center or from several population centers from which travel times are equal. The peaks will correspond to but be offset from the outbound (from residence) departure peaks and inbound arrival times.

Particularly large demands will occur on Sunday afternoons near and in areas with water recreation facilities that are less than 4 hr travel from large population centers. The demands will be even more extreme when travel times are less than 1 hr.

*Implications for the Rural Highway System.*—Part of the recreational traffic in the Friday peak will use major highway elements to other population centers or to links connecting to recreational areas. This demand should not constitute a serious problem beyond the typical commuting range, although the peak may be detectable at a large distance.

A more serious problem is likely on low-capacity links that provide the most direct or timely access to recreational areas from large urban centers. These same links, especially those to water facilities, are likely to have peak demands on Sunday afternoons and evenings of two-day weekends. In the rural areas special problems may occur on common links to a recreation area from several large population centers that have equal travel times from the area.

## Conclusions

The data assembled and the model concepts developed in this project combine to provide a more systematic picture of weekend recreational traffic than was previously available. The RTPM (Recreational Traffic Prediction Model) merges in a working computer program the essential features of recreation analyses and traffic assignment models to provide estimates of recreational traffic on highway links by direction and hour of the weekend.

Attempts to verify RTPM were only partly successful due to defects in numerically defined functions employed in the model. The defects have been identified, but tests with corrected values have not been run.

Like any prediction model that attempts to estimate fine details, the percent error from RTPM for separate directional-link-hour estimates tends to be increased by partition. A comparable problem in urban traffic predictions would be the estimation of the directional flow on a link during a specified hour of one day, as opposed to the total flow across a screen line.

It is feasible to test RTPM against samples of data such as those collected for this project. However, it is not feasible to test all sensitivities of the model because of the enormous amounts of field data required. Tests that employ samples of data are handicapped by the lack of information on weekend-to-weekend variances. As a result, rigorous analyses cannot be used in conjunction with data samples to determine how well the model duplicates weekend recreational traffic. Subjective comparisons must be used.

**Project 10-9** FY '70**Criteria for Need of Seal Coats for Bituminous Pavements**

**By:** Eugene L. Skok, Jr.  
Miles S. Kersten  
**Research Agency:** University of Minnesota

**Introduction and Research Approach**

Seal coats (surface treatments) have generally been accepted as the most economical method of maintaining bituminous-surfaced pavements in serviceable condition. As a result, decisions must be made by highway agencies with regard to the programming of seal coats. Maintenance personnel are frequently responsible for determining what roads should be sealed during a given season. A decision to prematurely seal a road will result in needless expenditure of funds. A decision to defer sealing of a road that is in need of a seal coat may result in excessive deterioration or unsafe conditions and greater eventual expenditures. Currently used methods for determining the need for a seal coat rely on the judgment of experienced personnel and thus are quite inadequate for general use. A need exists for practical methods and criteria to assist in seal coat programming for bituminous pavements.

The University of Minnesota researchers reviewed methods for seal coat programming used by various highway agencies, developed a Surface Condition Rating System to aid highway agencies in seal coat programming, and field tested the procedure in several states. The developed procedure is practical in that it is based on standardized visual observations and, except for measurement of pavement skid resistance where applicable, no special equipment or highly skilled personnel are required. It contains photographic examples of various rating levels and is thus adequately documented for immediate implementation. Field testing of the system in five states provides substantial assurance that it can be used effectively by maintenance personnel.

**Findings**

The essential product of this study is a Surface Condition Rating System consisting of a surface rating form that is to be completed for each section of road being considered for seal coat and complete instructions for use of the form. To aid in its use, photographs and descriptions of each rating level for each item to be rated are included, as well as a completed sample form. The Surface Condition Rating System has been published as *NCHRP Research Results Digest 48* and is available at a cost of \$1.50, payable in advance, from the NCHRP Program Director, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. (Checks should be made payable to *Transportation Research Board*.)

A philosophy of maintenance can be established using the Surface Condition Rating System. If it is desired to follow a preventive maintenance philosophy, pavements with high traffic volume should receive seal coats when the surface rating drops to a level of 3.0. If a less conservative philosophy is practiced, the rating might be allowed to drop to between 1.5 and 2.0 before seal coats are applied. In many cases the philosophy of maintenance may be dictated by the availability of funds. Generally, a lower rating will be allowed if sufficient funds are not available to seal coat all sections desired. Priorities should be based on level of rating, traffic, and type of surface; the most critical pavements should be seal coated first and then the next critical, in order, until funds have been depleted.

By putting numerical ratings on the various levels of surface condition it is possible to establish trends of ratings with time and traffic. There are advantages to establishing these trends, as follows:

1. The rate of deterioration of various types of surfaces under particular traffic and climatic conditions can be estimated. This information could be used to help predict when a given pavement will need seal coating in the future.
2. The trend of ratings could also be used to evaluate the effectiveness of various types of seal coats or other resurfacings.
3. It can be used to help set up and evaluate guidelines for seal coat programming.

**Applications**

It is recommended that the rating system and guidelines developed during this project be incorporated into an overall maintenance management system similar to those being developed by several highway departments, including Utah, Oklahoma, California, Washington, and Minnesota. In various ways, maintenance management systems consider the rideability, structural condition, strength, and sufficiency of the pavement section. These parameters are used to estimate when and what type of maintenance or rehabilitation is needed on various sections of road. The surface condition rating system developed during this project can be used within maintenance management systems to determine when and what type of seal coats would be most appropriate.

Training materials, including a set of 40 slides to help illustrate the Surface Condition Rating System, have been prepared. These materials can be used by highway maintenance organizations to introduce and assist in implementing the surface condition rating system. The materials have been used in training sessions presented to engineers in five states. Sections of road in each of the states (South Dakota, Utah, Georgia, Virginia, and Minnesota) have been rated to evaluate repeatability. It was found that the ratings could be made to a standard deviation of about 0.3, which indicates that it could be used to determine quantitatively the surface condition of a pavement.