HIGHWAY RESEARCH RECORD

Number 478

Management of Research

8 reports
prepared for the
52nd Annual Meeting

Subject Areas

11	Transportation Administration
12	Personnel Management
14	Transportation Finance
24	Roadside Development
25	Pavement Design
26	Pavement Performance
27	Bridge Design
40	Maintenance, General
84	Urban Transportation Systems

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Washington, D.C. 1973

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INTRODUCTION

Harold L. Michael, Purdue University

The Highway Research Board's Committee on Conduct of Research has as one of its purposes improvement in the quality and effectiveness of research through encouragement of better planning, management, and operational practices by organizations engaged in transportation research programs. The committee serves as a forum for the exchange of ideas and delineation of the problems associated with the various methods of organizing and administering research programs, the general consideration of project design and instrumentation, and the application of research findings in the transportation field.

The management system for research may be divided into five parts:

1. Selection of research projects,
2. Design of the experiments,
3. Supervision of the projects,
4. Implementing the results, and
5. Evaluating the benefits.

In carrying out its responsibilities the committee has sponsored several Annual Meeting Sessions in recent years directed to these parts of research management. At the 49th Annual Meeting in 1969, the committee sponsored a conference session concerned with the design of the experiment. Five papers presented at that session were later published in Highway Research Record 338. That same Record also contains a paper that discusses the organizational framework within which research projects are undertaken; it proposes a research organization structure based on the concept of a "mission-oriented systems approach".

At the 53rd Annual Meeting in January 1973, the committee held a two-session symposium on management of research. Three of the four remaining parts of the research management system were covered—selection of research projects, supervision of the the projects, and implementing the results. The eight papers included in this publication were among those presented. The first two are concerned with the selection process, two more with supervising (including one that discusses incorporating practical experience into research projects), and the last four with implementation.

The committee plans to cover the fifth part (the only one not yet formally covered), evaluating the benefits, in a session at the 1974 Annual Meeting.

RESEARCH AS A PROBLEM-SOLVING SERVICE

O. R. Dinsmore, Jr., Washington State Department of Highways

•MOST highway department research budgets consist primarily of highway planning and research (HP&R) funds. The allocation of federal funds for HP&R activities is based on a percentage of the total federal funds, mainly for construction, allocated to the state. Our feeling in the State of Washington is that these funds should be spent in the best way to improve the state's highway transportation services for our citizens.

Our research program developed from materials testing activities in such areas as portland cement concrete and asphalt pavements, subgrade materials and construction techniques, paints and delineation devices, and behavior of concrete and steel structures—that is, essentially in the basic and applied research fields. Today we have programs under way in such non-material areas as avalanche control; disposal of waste water from rest areas; social factors affecting highway transportation operations; development of toll-booth ventilation systems; noise levels adjacent to highways; environmental factors pertaining to highway operations; reduction in reflected waves from floating structures; and rainwater runoff from highway structures. However, we have not forgotten that we still have materials problems—development of a pavement management system, reduction in pavement surface wear from studded tires, development of skid-resistant pavement surfaces, and the like. Our philosophy regarding the national research programs (NCHRP and FCP—the Federally Coordinated Program of Research and Development in Highway Transportation) is that programs having regional or national implications should be carried out under the NCHRP or FCP and the states should pursue research in problem areas related to their own particular highway operations.

Each of the projects I have mentioned was stimulated or triggered by a problem arising in one of our highway functional areas: planning, design, construction, maintenance, and management. I will describe several of these problem areas and our efforts to provide solutions.

Let me start with avalanche control. "Control" may be a bad choice of words. Maybe I should call it development of a system to forecast avalanche conditions and to do something about it when an avalanche occurs.

The North Cascades Highway crosses some of the most scenic mountain country in the world, from Puget Sound on the west through the Cascade Mountains to a point about 75 miles north of Wenatchee on the east. The highway was opened in September 1972 and closed in November 1972—not permanently, but at least until May or June of 1973. The reason is that approximately 90 avalanche paths cross this highway in some 50 miles. In addition, we have two other major mountain pass highways that are kept open all winter, plus several others that are closed because it is too dangerous and uneconomical to keep them open. (We have more than 1,000 inches of snow per year in some Cascade Mountain areas.)

We needed some means of determining the conditions under which the avalanches would form, when it is best to trigger the avalanche, and what the best methods are for triggering or holding back a possible avalanche or controlling it when it does come.

Figure 1 shows a typical avalanche area along the North Cascades Highway. The starting zone and paths of previous avalanches are clearly indicated.

Speaking of winter, 4 years ago studded tires were legalized to assist drivers in crossing our mountain passes, getting to and from our excellent ski areas, and in and out of frozen driveways and side streets in a convenient and safe manner. Two years ago we noticed strange things happening to our road surfaces. Our delineation markers were losing their reflectivity, previously grooved areas were becoming smooth, coarse aggregate was being exposed and polished. Last spring transverse reinforcing began showing through the deck of the Evergreen Point Floating Bridge across Lake Washington in Seattle (Fig. 2).

To obtain better data on rates of wear, we established a research program using the test track at Washington State University to quantify whatever was happening on our highways. Figure 3 shows ruts resulting from studded tire wear on the test track. We are now testing studded-tire-equipped vehicles in cooperation with the Washington State Patrol to determine stopping distance and maneuvering characteristics on wet and dry pavements.

Reflected waves from the floating bridges across Lake Washington changed prevailing wave patterns in the lake. Various means of reducing reflected waves were studied and tested by the University of Washington using scale models. The university then built a test section of a wave attenuator to test the laboratory results against a full-size prototype to determine if scaling is realistic. Figure 4 shows the prototype installation on the Evergreen Point Bridge.

In Washington State we have some of the most beautiful safety rest areas in the country (Fig. 5). However, the conventional septic tank and drain field systems installed have not been suitable to meet the loading requirements. Several failed after a few weeks of operation. We tried to build larger conventional systems, but restrictions in area available and effluent disposal still cause problems. We use lagoons in eastern Washington, where rainfall is relatively low, and in some areas effluent is used for watering grass. We are presently experimenting with recycling and incinerator disposal systems in some rest areas.

We have recently been faced with the establishment of truck noise levels. What levels should we set? Should we use California standards? The truckers said, "We can't meet your proposed standards and still operate." We requested the Applied Physics Laboratory of the University of Washington to measure noise emissions and found to our surprise that some of the largest tractor-trailer rigs operating at maximum allowable freeway speeds were presently operating below the proposed levels. We obtained hard factual data to back up our legislative proposal.

Carbon monoxide concentrations during rush hours were a problem for toll-booth operators on the Evergreen Point Bridge across Lake Washington. The University of Washington's Air Resources Group studied the problem, installed CO monitoring equipment, and measured the gas concentrations in and adjacent to the toll plaza. Based on tests of a laboratory prototype, we installed a test ventilation system in one booth. Concentrations previously as high as 300 ppm were reduced to less than 5 ppm by the new system. We are now installing a complete system to handle all booths in the toll plaza.

In the development of our pavement management system, two devices were developed at Washington State University under a research project entitled "Pavement Deflection—Dynamic." One device, the size of a suitcase, is to be used to examine specific small sections of roadway; the second is intended to be towed down the highway at a speed of 30 mph. These devices work on the principle of shock waves traveling through the pavement. Figure 6 shows the suitcase model at the Washington State University test track.

The Seattle Highway District had 300 requests for possible joint use of areas within, adjacent to, or above or below highway rights-of-way in the greater Seattle area. Evaluation and selection criteria were needed to determine what joint use was possible and practicable. A Stanford Research Institute study developed guidelines that include the following major topics: (a) precedent for joint development, (b) description of joint development, (c) fundamental considerations and basic policy, (d) general criteria analysis, (e) air quality and noise, (f) identification of community and neighborhood goals, (g) comparative display procedure, (h) implementation, and (i) new concepts for joint development. Starting with the chapter on joint development description, work sheets are included in each chapter for use of the evaluator.

In summary, our philosophy for research is short- and long-range problem-solving for Washington State. The kinds of results I have described indicate our efforts to solve these problems. And this our management understands.

Figure 1.

Figure 2.

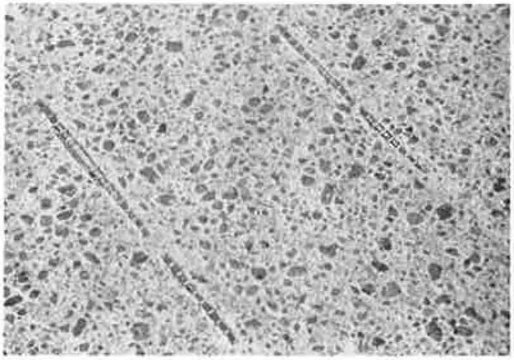


Figure 3.

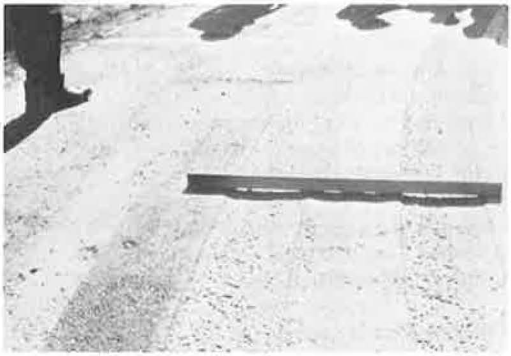


Figure 4.

Figure 5.

Figure 6.

DEVELOPMENT OF AN ANNUAL RESEARCH PROGRAM

William C. Burnett, Engineering Research and Development Bureau,
New York State Department of Transportation

•FOR many years, the New York State Department of Transportation used an informal approach toward developing an annual engineering research program. Research topics were submitted verbally or by memorandum to the Deputy Chief Engineer (Research), to the Director of Research, or to the research staff. These individuals also identified problems they believed needed investigation. All problems were reviewed, and the cost to solve them was estimated along with the probability of success and potential benefits.

About 3 years ago T. W. Parker, then Commissioner of Transportation, pointed out that, while this procedure was effective, it provided little documentation that could be used to follow a suggestion from its conception to implementation. As a result, a more formal system was evolved that is in use today. In our present system, an annual request for suggested research studies is sent throughout the department. This is supplemented by reminders 2 or 3 times a year in the monthly department newsletter that potential research subjects are not only welcome but needed. As a result, many suggestions are generated that are then evaluated for appropriateness for in-house research and are checked to be sure they are not a duplication of ongoing work or solvable from research already completed.

Because the program managers are the people whose problems we are striving to solve, we (the researchers) work with an individual in each program area. This man is selected by the program manager and designated as a Research Liaison Representative. In cooperation with the Research Liaison Representative we fill out a "research needs statement," which reads as follows:

> The information you supply on this form is your principal means of suggesting researchable subjects for the work program of the Engineering Research and Development Bureau. Subjects are selected for formal research on the basis of estimated benefits, urgency of solution, estimated costs, probability of successful completion, probability of implementation, staff capability, available facilities, current staff commitments, and general program balance.
> The information that you supply will provide a basis for review by the research staff and future consultation with your engineers. Thus, it is essential that your statements be as detailed and factual as possible. Please send your completed Research Needs Statement to the Director, Engineering Research and Development Bureau, Main Office, New York State Department of Transportation.
>
> 1. Short Title (try to limit proposed project title to 50 characters or spaces):
> 2. Submitted By:
>   DOT Agency:
>   Date:
> 3. Problem Definition (concisely describe the background of the problem or subject to be researched):
> 4. Specific Research Objectives (list specific technical objectives to be accomplished before the study can be considered completed):
> 5. Benefits (state as accurately, specifically, and quantitatively as possible how the study may increase usefulness or efficiency, decrease costs, enhance safety or beauty, or provide other benefits when anticipated results are implemented):
> 6. Implementation:
>   a. What DOT agency will be responsible for implementing results?
>   b. In what specific form will results be implemented? (Specifications, design practice, construction practice, etc.)
>   c. What is your estimate (state approximate percent) of the probability of implementing the anticipated results?

d. What problems do you anticipate in implementing results?

e. By what date must the project be completed in order for anticipated results to be useful?

7. Resources (include whatever published or unpublished reports, memoranda or other data you know of that may be useful in solving the problem, and what personnel, equipment, or facilities could you provide if required in the course of the study):
8. Who in your organization should be contacted to discuss questions that may arise regarding the content of this Research Needs Statement? At what phone number?
9. Other remarks:

As you can see, a complete and concise "needs statement" can be of great assistance in starting a project. However, background information necessary to define the scope of a proposed project is sometimes difficult to obtain, and Research Liaison Representatives often request research engineers to perform literature searches. This effort has paid off, however, and after a lot of work a booklet entitled "Proposed Engineering Research Program" is prepared and several copies are sent to each Research Liaison Representative.

To acquaint you with the actual results of this process in the New York State Department of Transportation, the introduction to the latest proposed engineering research program will be of interest. The fiscal year 1973 publication states:

> This publication outlines the proposed engineering research program which, upon approval, will be conducted by the Engineering Research and Development Bureau during Fiscal Year 1973-74. Its purpose is twofold: 1) to identify both on-going research projects that will continue into next fiscal year, and all new research topics suggested by the Department's staff to date; and 2) to serve as a basis for preparing this Bureau's budget requests for Fiscal Year 1973-74. Input for the proposed program consisted of ideas and suggestions submitted as "Research Needs Statements" by various Department units (Form PHR-73, copy appended at the end of this publication). To encourage widespread participation in identifying important problems warranting investigation, a "Call for Research Problems," dated January 19, 1972, was sent to all Main Office Program managers and to Regional Directors. All responses were forwarded to appropriate program managers for evaluation and assignment of priorities. This review included problems recommended in previous years but deferred because of low priority or for other considerations. Thus, the proposed program reflects an updated appraisal of all outstanding problems as well as new ones. The final selection of projects necessarily considered the current level of staffing within each of this Bureau's six research sections, present workloads, and the effects of existing expenditure ceilings on the progress of current research.
>
> In all, 42 suggestions for research were reviewed, of which 32 described new problems and 10 were resubmissions from previous years. A summary by categories is given in Table 1. Each suggestion is discussed in Chapter IV and the originator is acknowledged.

TABLE 1
SUMMARY OF SUGGESTED RESEARCH SUBJECTS

Subjects Reviewed	Category
15	Formulated into new research projects
2	Integrated into existing research projects
9	Research currently in progress
3	More appropriate for other agencies
11	Research not required; handled through Technical Assistance Program as needed
2	Backlog
42	Total

We in the New York State Department of Transportation are proud of our ability to formulate problems into topics suitable for engineering research. It is my personal belief that every hour spent in defining a problem before undertaking a research project will return the investment many times over in high-quality, implementable research results. Because research costs money, it is always necessary to concentrate our efforts on problems that are important and that have a high probability of being solved.

MONITORING CONTRACT RESEARCH

Krieger W. Henderson, Jr., National Cooperative Highway Research Program, Highway Research Board

•ALTHOUGH the title does not so state, these comments on monitoring contract research center on policies and procedures of the National Cooperative Highway Research Program (NCHRP), many of which apply equally well to any contract program. To provide complete perspective, a good bit of philosophy is included, because monitoring (or "surveillance" as we term it) is a function to both ensure and assure that research progresses as intended along technical and administrative lines. It must be remembered, however, that surveillance is only one function well along the way in a sequence of activities calculated to enhance the probability of achieving overall goals. Notwithstanding the desire for this function to be a major contributor to a high probability of success, there is a delicate balance to be maintained in the practical and realistic exercise of it. Surveillance must be penetrating enough to be effective, yet the requirements on the research agency must not be procedurally complex or burdensome to the point of distracting the researchers from their primary efforts or adding to an agency's cost of doing business. In this regard, a major NCHRP consideration in the establishment of requirements has been the hope that they will be tools useful to the agency's project management. Streamlined procedures are also important to the ability of the NCHRP to do its job, because the large number of projects to be monitored always results in too many projects per staff engineer.

The NCHRP is now in its eleventh year of operation under a three-way agreement among the American Association of State Highway Officials, the Federal Highway Administration, and the National Academy of Sciences. The Program's purpose is to be the central source of administrative control for AASHO's national program of cooperative research. As time passes, it is easy for others to lapse into the thinking that the Program is an autonomous entity. This is not so, and it bears repeating that primary responsibility for Program operation lies with the National Academy of Sciences and that this responsibility has, in turn, been delegated to the Highway Research Board. Inasmuch as the three-way agreement requires the Academy to sign contracts each year with AASHO's member state highway departments for the planning, organization, and administration of the Program, the Academy is placed in the role of a prime contractor. Agencies contracting with the Academy for NCHRP research then become subcontractors.

A contract is an agreement to accomplish certain things, and its acceptance automatically imposes responsibility. Consequently, the NCHRP framework embodies two levels of responsibility—that of the Academy to the sponsors and that of the research agency to the Academy. "Responsibility" is then the keystone of NCHRP's operational philosophy because it is synonymous with "accountability." Everything that we do, including the requirements that we impose on ourselves and others, is geared to respond to that issue and, although the Program maintains a firm stance in administering them, it is one in which every attempt is made to be fair and objective. This is the pervading theme to keep in mind in reading these remarks as well as any of the various publications addressed to Program organization and operation.

Because the Highway Research Board does have surveillance responsibility yet is not sponsoring the research, we, in turn, are monitored by our sponsors. Although this aspect of overall management of monitoring is not covered here, let it suffice to say that our sponsors do have procedures for monitoring our performance and that we do have to answer to them periodically concerning all aspects of Program management on their behalf.

Project surveillance is carried out by a staff of engineers assigned by the Highway Research Board to the NCHRP. Staff members have individual specialties and training in the broad areas of physical research, traffic planning, and special projects and are responsible for administrative and technical surveillance of research contracts. Besides reviewing various agency reports and maintaining telephone contacts, they visit their assigned projects at least once every 6 months for in-depth reviews of all administrative and technical matters. In addition to determining if research is in line with the plan approved by the advisory group, they help the researchers maintain a perspective of the relationships between research objectives and the needs of the practicing engineer and see that all project developments, from beginning to end, center around these needs. At the same time, they are responsible for maintaining liaison with an advisory group of experts that is constituted for each project to provide technical guidance and counsel. Finally, they and the advisory group review the completed research to determine the degree of technical compliance with the contract.

A first requirement of the research agency immediately after contracting is the development of the working plan, which is a comprehensively detailed amplification of the approved research plan, including a specific schedule of events (presented in chart form) for the major tasks. This document is used by the staff in the day-to-day surveillance of the project's progress. Should review of this document by staff and the project advisory group bring to light necessary changes not previously apparent, these can be accommodated readily by contract amendment without hindering prosecution of the work.

As you have seen emphasized elsewhere, the NCHRP is not a grant operation. It is a contract program employing contractual constraints in the conduct of applied research to solve operational problems. Understandably, cost and time have long been considered by the scientific community to be unnatural constraints; only technical performance mattered. Because all of these factors are important in our operation, it is obvious that the individual preferences of anyone wanting to do NCHRP research must be subjugated to contract commitments. At no time, however, is there any intent on the part of the NCHRP to work against a creative environment where creative people can make recognizable contributions. On the contrary, mutual understanding and cooperation must prevail in seeking a common goal. Meeting the sponsors' expectation that their resource allocation will be expended in the best possible way to acquire research results that are practical and directly amenable to practice is fundamental to the Program's accountability and is, therefore, the central focus of all operation. By and large, the resource allocation goes for brainpower, and brainpower is expensive. The fact that the allocation might be high does not guarantee efficient performance or ultimate success. Obtaining the right competence will usually result in getting our money's worth; however, this does not obviate the need for surveillance, because the agency's performance obligation entails both technical and administrative matters.

A peripheral issue that cannot be ignored in establishing policy that includes surveillance requirements is the influence that Program achievements have on the sponsors' desire to continue support of research. As is well known, there is a perennial argument whether sufficient return is received on the research dollar. Couple this with today's requirements for stretching available dollars, and there certainly is no apparent decrease in reluctance to commit resources where intangibles and risks are involved. Even though progress is evident through advanced technology, the question of cost-effectiveness persists because there is, unfortunately, no good way to measure it. The rising cost of doing business not only will result in even more critical scrutiny of resource allocations but also will certainly reinforce the imperativeness of NCHRP surveillance to protect the sponsor's investment. Seemingly overnight, for example, our estimates for labor have risen from $35,000 to $50,000 per man-year, including overhead rates that now range to 165 percent.

It was stated earlier that mutual understanding and cooperation between the NCHRP and the research agency are a must. This can be achieved only if there is effective communication. Without communication there will be misunderstanding and confusion. Consequently, establishing the base for dialogue is essentially the Program's first surveillance step and is actually carried out prior to contracting. Although this may sound strange, it is a procedure that has been received enthusiastically by the agencies. Suggested modifications to the proposed research plan are taken by the Program's staff to the agency, and a clear meeting of the minds is established regarding what is specifically expected technically and administratively from the research, the personnel carrying it out, and the agency's contracts administrators. By means of copies of a "Procedural Manual for Agencies Conducting Research in the National Cooperative Highway Research Program," further emphasis is placed on the requirement for practically oriented research and the proper means for reporting it. Experience has demonstrated that, once contracted, the practical fact of life is that the destiny of the research is pretty well committed no matter how extensive the staff surveillance or how many administrative procedures are available to accommodate changes.

Because project funding is fixed by the sponsors, the need for budget control is another matter that receives considerable emphasis in the initial dialogue. We recognize that there is nothing sacrosanct about the project budget, other than the upper bound, and that deviations from original calculations are to be expected. Nevertheless, it is made clear to the researchers and contract administrators that budget control is part and parcel of their contract commitment. This is emphasized as much as possible, because the coupling of this activity with preparation of monthly progress schedules constitutes one of the useful management tools referred to earlier. Compliance by the agency will help to prevent internal confusion. All too often, the NCHRP encounters administrative problems because communication between the agency's contract administrators and the technical staff performing the research is inadequate. Consequently, researchers have found themselves unexpectedly out of money and their work incomplete because they were not advised of increased overhead costs. Agency invoices are checked monthly by the NCHRP staff against budgets as some measure of backup to the agencies, but not as a substitute for their responsibility. Budget control is effective only if it gives early warning of deviations so that timely corrective measures can be taken.

As another safeguard in this respect, the agency is required to notify the Academy when the total of past expenditures plus those expected in the forthcoming 60-day period will exceed 75 percent of the contract amount. Upon receiving such notification, the NCHRP staff explores with the researchers the prospects of work completion within the contract period.

Two types of progress reports are required from the agencies while work is under way. On a monthly basis, 1-page progress schedules are submitted that graphically depict (a) actual progress through the major tasks outlined in the working plan schedule of events; (b) actual gross expenditures versus those planned on a month-by-month basis; and (c) estimated percentage of overall completion versus that planned on a month-by-month basis. On a calendar quarter basis, narratives are required that fully describe accomplishments to date and outline future activities dictated by the accomplishments. Based on these reports and information gained through surveillance visits, the Program's staff prepares its own progress reports, which are sent to the sponsors to provide a current awareness of ongoing work.

Research agencies are required to report their final research results in language that is understandable and in a format that succinctly summarizes the findings for the highway administrator and highway engineer and clearly informs them of the practical application of the findings. Available to the researchers during report preparation are guidelines that have been developed with the objective of providing a report of maximum utility to the sponsors. Because our report format is quite different from others', the guidelines are discussed with the researchers during the first surveillance visit so that the agency can plan ahead. Repeated references to the format are made in subsequent surveillance contacts.

In conclusion, it is hoped that this summarization has revealed that the Program's surveillance requirements and procedures have been designed from a practical and realistic standpoint. It is further hoped that, when viewed objectively, the requirements will be seen to be minimal in extent yet sufficient to enable both parties to the contract to fulfill their respective responsibilities.

INCORPORATING PRACTICAL EXPERIENCE IN THE CONDUCT AND MANAGEMENT OF RESEARCH

Keshavan Nair and Fred N. Finn, Woodward-Lundgren and Associates, Oakland, California; and
Haresh C. Shah, Stanford University

•THE purpose of this paper is to discuss the incorporation of practical experience in the conduct and management of research. The paper is general in tone in order to include in the audience research managers who function at the policy-making level in the formulation of research programs. The discussion on formally including practical experience in research programs is divided into the following parts: (a) its necessity (why); (b) a methodology for doing it (how); and (c) the benefits (advantages) in terms of (b).

Before proceeding further, it is appropriate to establish the general framework for the discussion. First, only applied research, which is defined as research for the purpose of solving current or foreseeable practical problems, is considered. Second, the discussion is oriented toward pavement problems, although the concepts expressed are of wider applicability.

The solution to practical problems is obtained from relevant information that is or can be made available. The development of solutions depends on the investigator's ability to formulate hypotheses that can be tested with available information and can be further verified through the conduct of well-developed experiments. The information for doing this comes from two sources: (a) research and (b) practical field experience. Except where one is directly involved, this information is acquired primarily through the study of published materials. Discussion with experienced individuals does result in practical field experience being included into the system, but this is done in an unstructured fashion and the effect is minimal. Consequently, it is the published information that plays the dominant role in shaping research programs and in developing solutions. Because of this, research is often conducted in areas where there is a considerable body of existing knowledge. It is easier to formulate a problem on which there is considerable information than to develop research questions on problems on which there is little information. This research might not be the most appropriate from the standpoint of solving practical problems and hence from the research manager's viewpoint cannot be considered the best investment of funds.

It is safe to conclude that, compared to the information generated by observation and field experience, the great majority of the information generated in research is published. When one realizes the extent of the highway system and the number of man-years of experience that has been built up by knowledgeable and experienced individuals, it becomes obvious that a most valuable storehouse of knowledge has been inadequately utilized by researchers and research managers. This information is certainly complementary to that generated by research and, it may be argued, is more valuable because it represents field conditions. Because of these considerations, it is necessary that a methodology be developed that can utilize this information in the development of a strategy for obtaining solutions to practical problems.

METHODOLOGY

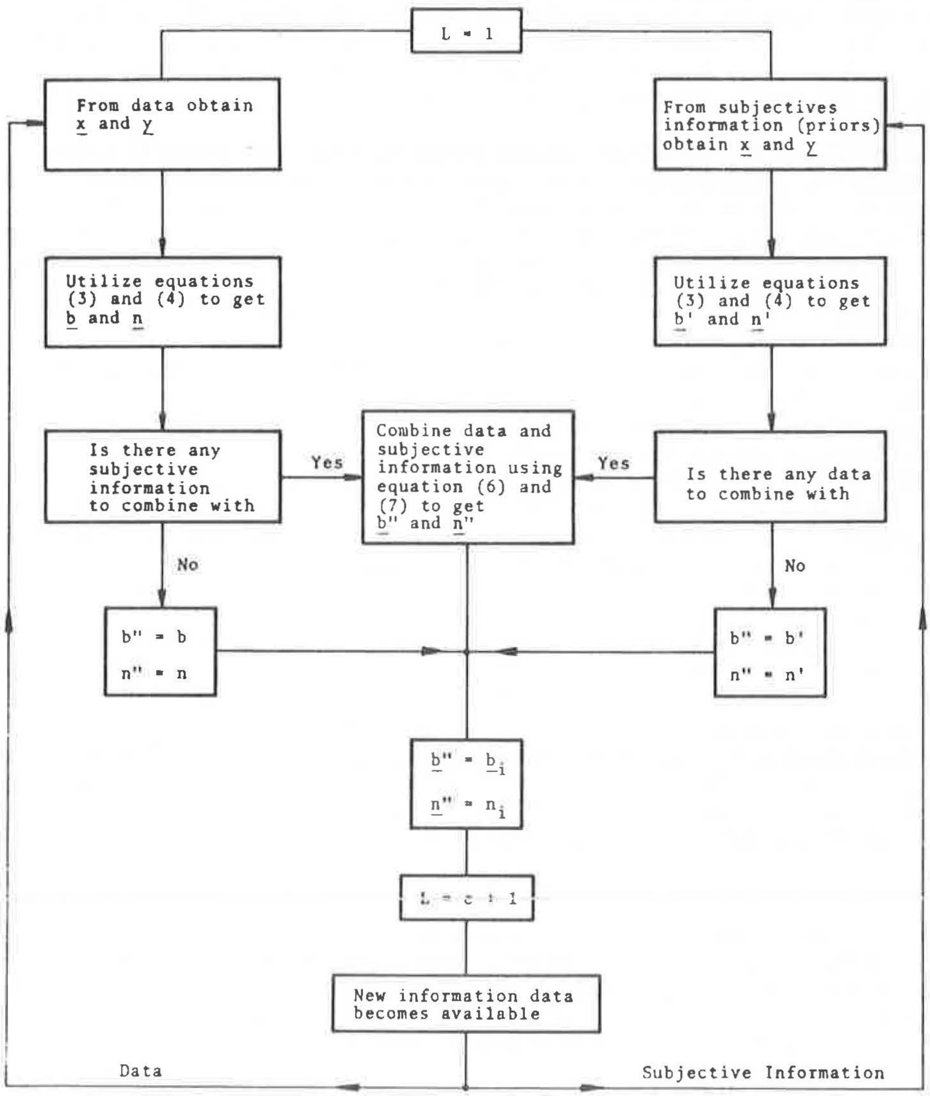
The methodology presented will utilize the cumulative experience of engineers working in the area of design, evaluation, construction, and maintenance of pavements, together with laboratory data, data from special test sections, and analytical studies. The most important feature of this approach is that it can utilize information from all these sources and place them in a consistent and compatible format for use by the practicing highway engineer. Research and field experience can be brought together to assist in solving the problem.

The methodology for such an approach is based on Bayesian decision statistics. Using this approach, it is possible to extract the past experience of engineers in a meaningful statistical format similar to data obtained from experiments. New experience gained from observation of field performance or test data can be combined with previous experience using Bayes' formula to arrive at posterior information. Such an approach, while new in the highway field, is well established for decision-making in other fields and areas of transportation engineering (1).

The general methodology is presented in simplified form in Figure 1. The key concepts are as follows:

1. Interim solutions and research programs developed on the basis of published information are based on "partial" state of knowledge. Such strategies for solving prob-

Figure 1. General methodology for combining subjective and objective information to represent current state of knowledge.



lems are formulated without the inclusion of a great deal of the experience that has been gained in the performance of the highway system because this experience resides in the subjective evaluation of experienced engineers. It is believed that only a small percentage of this information has been published.

2. To develop solutions, including the formulation and conduct of research programs, a "more complete" state of knowledge should be developed. This can be done by extracting the subjective information from experienced engineers and combining it with the available published information.

3. The state of knowledge developed in item 2 can be updated periodically as new information becomes available. This new information will come from laboratory and analytical research and from observations of performance. In this context, the existing highway system can be considered as a large-scale experiment. The methodology will provide a rational method for designing feedback systems and, more significantly, will provide a means for including this information (experience) into the design process.

The methodology is described in a series of steps that generally follow the approach in Figure 1. Theoretical aspects are omitted in this discussion but are given in the Appendix.

Step 1. Identify and Rank Factors That Have Significant Influence for a Particular Problem

Based on the available information, a list of those factors that are considered to have a significant influence on the problem should be prepared. This list should be circulated to experienced engineers, who should be asked to rank the factors in order of importance and add any that had been omitted from the list. In selecting the engineers, emphasis should be placed on design and materials engineers from state highway departments with suitable geographic distribution, since the opinions of researchers will, in general, have been considered in the context of published information.

Step 2. Obtain Subjective Information of Experienced Individuals on Influence of the Significant Variables

To obtain the desired information from the appropriate individuals on a systematic basis requires designing a suitable questionnaire, implementing the questionnaire, and arranging the data in suitable statistical format.

Designing the Questionnaire—The questionnaire is prepared to extract (a) range, mean, and coefficient of variation of each variable and (b) information regarding the influence of the independent variables on the dependent variable that defines the problem (e.g., fatigue cracking). In formulating the questionnaire, attention must be paid to the background and training of the individuals who will be asked to respond to the questionnaire. In some cases it will be necessary to go through a number of iterations before a satisfactory questionnaire is designed.

Implementing the Questionnaire—Individuals with experience in the field under study should be located. As in Step 1, emphasis should be placed on materials and design engineers from state highway departments and the major climatic subdivisions of the United States should be covered. It is suggested that the questionnaire be implemented on a personal basis (interview). Utilizing the interview process has three significant advantages: It permits an explanation of the basic philosophy of the method; it provides an opportunity to explain statistical concepts to individuals when necessary; and it provides an opportunity to explain questions that may be stated in terms that are outside the usual thought process of the individuals interviewed. It is also important to recognize that the personal explanation and individual participation will greatly increase the acceptability of the results of such research into practice.

Arranging the Data—Based on an examination of the data and discussions with experienced engineers, a relationship (equation) between the dependent variables and the independent variables can be postulated. Based on techniques of information theory, the subjective information can be equated to experimental data. This requires equating the experience of the engineers to a certain number of experiments.

Step 3. Assemble Objective Information

Objective information, in the form of both laboratory and field data, should be assembled. The relationship developed between the dependent and independent variables in Step 2 is utilized to analyze the data. The results are placed in the same form as the information obtained from implementing the questionnaire. In some cases, if substantial published data are available, Step 3 may be conducted prior to Step 2, and the relationship between dependent and independent variables is postulated on the basis of objective data.

Step 4. Combine Information to Develop State of Knowledge

The information obtained in Steps 2 and 3 can be combined to develop the state of knowledge. This is done utilizing Bayes' formula. The theoretical basis for doing this is presented in the Appendix.

Step 5. Recommend Solutions and Formulate Research Programs

Utilizing the updated relationship developed in Step 4, sensitivity studies can be conducted to evaluate the relative influence of various factors on the problem. Solutions and research programs can now be developed utilizing these sensitivity studies, which are conducted on the basis of a more complete state of knowledge as developed in Step 4.

Step 6. Continue Evaluation and Modification of Programs and Solutions

In the classical approach, evaluation and modification would require a factorial design of experiments. In the approach outlined above, a single set of experiments is unlikely to have any significant effect on the cumulative experience of engineers as determined in Step 4. Therefore, continuing evaluation will be based on incorporating the results of continuing research and the experience being gained by engineers on the basis of the performance of the highway system to update the existing state of knowledge. In this context, this step will consist of designing feedback and information-gathering systems and detailing the procedure for combining information as it becomes available with the previously available information to obtain a new state of knowledge.

It is envisioned at this time that the total data-gathering process will include three sources of information: subjective priors, feedback, and special test sections, as follows:

1. Subjective priors—The fastest way to expand on the existing information is through the quantification of engineering experience. By this procedure, a great amount of data can be generated over a relatively short time. There are limitations regarding this procedure. Probably the most significant one is that engineers who are interviewed can best speak with confidence only about their personal experience, which itself is limited to "what is" and not so much about "what might be". For example, if one is interested in exploring recommendations regarding the use of thick asphalt layers, it may develop that field engineers have very little experience with this type of design. Nevertheless, experienced engineers can be asked to extrapolate on their experience if the weighting assigned to such experience is modified and the confidence is reduced.

2. Feedback system—To supplement, reinforce, or negate existing information, a field feedback system can be developed. Three aspects are required for this system: (a) the development of a model for statistical analysis, (b) the field quantification of the input variables required by the model, and (c) the field evaluation of performance. Such a feedback system would require time to develop and implement. However, such a system is feasible and does not require special construction, since the existing highway system would be utilized. It does require special measurements of both the dependent and independent variables.

3. Test sections—If the information from subjective priors and the feedback system is sufficiently definitive, implementation can be initiated without further delay. However, in the event that further documentation is considered necessary, a series of field test sections can be programmed.

Step 7. Research Special Problems

As has been pointed out, there is the case when, because of new materials, new methods of construction, or other factors, there is very limited prior experience. In such cases, people may be asked to extrapolate data, based on their previous experience. However, to rely on this extrapolation alone can be very misleading. Therefore, in some cases, it will be necessary to conduct laboratory research, carry out analytical studies, and implement special field experiments.

MAJOR ADVANTAGES

The major advantages accruing to the methodology described are as follows:

1. Information from both laboratory and field research and field experience can be combined in a rational and consistent manner for the development of research programs and the conduct of research for the solution of practical problems.
2. The experience of practicing engineers, which is the greatest collection of valuable information on the performance of pavements under a variety of conditions, can be utilized in the development of design recommendations. This will increase the likelihood of acceptance of the results obtained through the proposed methodology by the practicing engineer.
3. The methodology provides a means for updating information as new information becomes available.
4. It provides a basis for designing performance monitoring and information feedback systems.

FINAL REMARKS

In the formulation of research programs and in the development of solutions for practical problems, there is a significant deficiency in that we do not formally consider the knowledge that is present in the subjective opinions of practicing engineers. Considering the cost of research programs in terms of money and talent and the cost of applying solutions that are not suitable or acceptable to the practicing engineer, it is imperative that the experience of the practicing engineer be utilized.

The theoretical concepts for utilizing subjective opinions in the decision-making process are well developed. It remains for research managers and researchers to utilize these concepts in their work. The methodology for doing this is briefly outlined in this paper. It is hoped that this paper will stimulate enough interest for the ideas expressed to be implemented in practice.

ACKNOWLEDGMENTS

Many of the ideas contained in this paper were developed during the conduct of research associated with NCHRP Project 9-4.

REFERENCE

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APPENDIX

THEORETICAL BASIS FOR COMBINING DATA AND SUBJECTIVE INFORMATION

As indicated in previous discussions, it is the objective of this procedure to combine the subjective evaluation of experts in the field with actual experimental data to obtain the total available state of knowledge. Therefore, the basic question is how to combine the data and the subjective information (prior) in a meaningful way. The formulation not only should be able to handle the analysis of this subjective information but should also be able to combine future experimental data with subjective information. The theoretical basis for combining the data and prior is discussed in the following paragraphs.

The theoretical basis of the method depends on Bayesian statistical theory. Basically, the methodology combines the experimental data (called sample likelihoods) with subjective or experience-based data (called prior) to get combined information (called posterior information). In general, for any kind of prior and sample information, one could come up with posterior information by means of Bayes' formula. This approach is neither analytically nor numerically tractable for most situations. However, if the sample and the prior information belong to a special family of distributions, called conjugate distributions, then the posterior distribution can be obtained by simple numerical calculations. Thus, for example, if the sample data have normal distribution with a specified precision and the subjective data have normal distribution, then the posterior distribution is also normal. We utilize these conjugate distributions in our further development.

It is assumed that the data-based information is in the form of a regression equation where it is assumed that errors have Gaussian distribution. If we wish to use a conjugate distribution for priors, then it should be in the form of a normal regression process. Consider, for example, a generalized normal regression process. Let Y_1, $Y_2, \ldots, Y_i, \ldots, Y_k$ be dependent variables generated by independent variables X_{ij} according to the model

$$Y_i = \sum_{j=1}^{r} X_{ij}\beta_j + \epsilon_i \qquad (1)$$

The number of independent variables is denoted by r. Now, the values of β_j s can be calculated either from data or from priors. Let the data matrix $\underline{X}$ be

$$\underline{X} = \begin{bmatrix} X_{11} & X_{12} \ldots & X_{1r} \\ X_{21} & X_{22} \ldots & X_{2r} \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ X_{k1} & X_{k2} & X_{kr} \end{bmatrix} \qquad (2)$$

where $X_{11} = X_{21} = \ldots X_{k1} = 1$.

Each row in the above matrix represents one set of data points. Thus, if we have 150 data points, then k = 150. Then, using data, the regression coefficient vector $\underline{b}$ can be found as

$$\underline{b} = (\underline{X}^t\underline{X})^{-1}\underline{X}^t\underline{Y} \qquad (3)$$

where $\underline{X}^t$ is the transpose of matrix $\underline{X}$, and $\underline{Y}$ is the dependent vector. Let

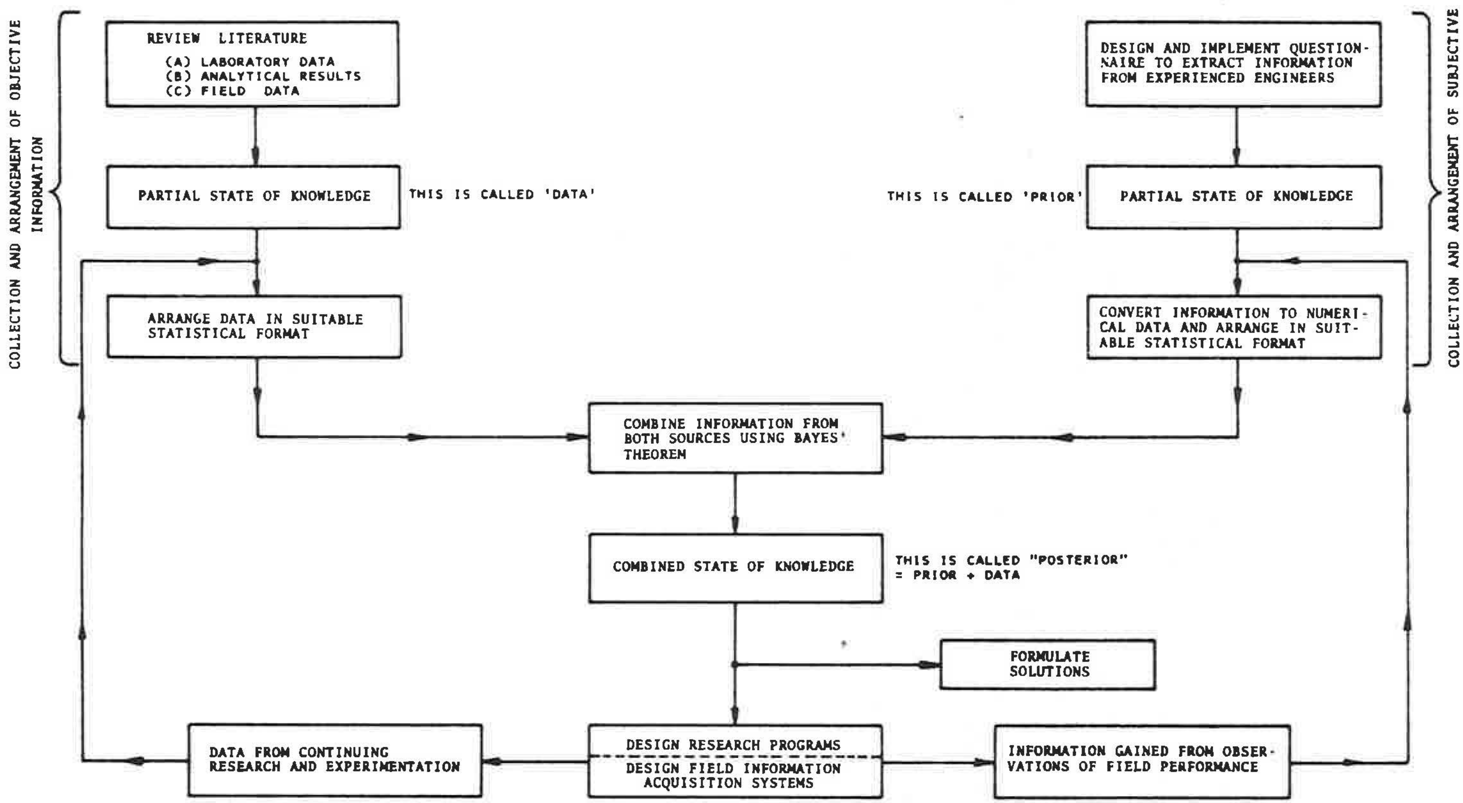
$$\underline{n} = \underline{X}^t\underline{X} \qquad (4)$$

Then,

$$\underline{b} = (\underline{n})^{-1}\, \underline{X}^t\underline{Y} \qquad (5)$$

We can also obtain the values of $\underline{b}$ and $\underline{n}$ from subjective information. Let us call these prior matrices as $\underline{b}'$ and $\underline{n}'$. The procedure for doing this is explained in the example.

Figure 2. Schematic representation of procedure for combining data and priors.



Then, if one wishes to combine data-based information with the prior information to obtain posterior information, the following simple manipulation yields the desired results:

$$\underline{n}'' = \underline{n}' + \underline{n} \tag{6}$$

and

$$\underline{b}'' = (\underline{n}'')^{-1} (\underline{n}\underline{b} + \underline{n}'\underline{b}') \tag{7}$$

For the derivation of these two results, see Raiffa and Schlaiffer (2). The variance matrix of the posterior regression coefficients ($\underline{b}''$s) is given by $(h\underline{n}'')^{-1}$, where $h = 1/\sigma^2$ is defined as the precision of the process.

Thus, if we wish to combine priors of two experienced engineers, the only thing we have to do is to obtain the $\underline{n}$ matrix and the $\underline{b}$ matrix for these two. Then, the combined information is obtained by means of the above relationships. Such a formulation allows us to keep track of our information at any given time, and the updating or combining of future information is systematic and rational. In all of this description, we have kept the basic notion that the process by which one accumulates experience or one accumulates data-based information has the same type of statistical variability. The procedure for combining priors and data is shown schematically in Figure 2.

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IMPLEMENTATION—A PART OF THE RESEARCH PROJECT

Charles J. Keese, Texas Transportation Institute, Texas A&M University

•IMPLEMENTATION—putting research results to work—is also research and should be considered a part of the research project. There is a great waste of good research results because of the widely held opinion that research ends before implementation begins.

A review of the history of highway research suggests at least one reason for the separation of research and implementation. During the years prior to World War II, most research emphasis was on materials, pavement design, and the like—basically experiments and experience. A review of the Highway Research Board Proceedings even up to the early 1960s reflects a predominance of reporting on experiments.

Many criteria in use today were based on the results of successful experiments and on experience and practice. Call it what you want to, there was a great amount of work that would now be called implementation. Most of the criteria that have stood the test of time were based on field experience (implementation). On the other hand, most of the experimental research not proved in the real world of field experience never found its way into practice.

Research results are implemented through specifications, criteria, procedures, and practices. The results of research do not reach one of these stages until they have been proved in the real world of practice.

During the early "get the farmer out of the mud" years, it was natural that research on pavements and structures would predominate. During the past couple of decades, and particularly during the last decade, research has become more and more complex. Even the pavement and structures research is more complex and requires more than the experimental approach. Research in planning, traffic, and economics as well as in social and environmental problems involves highly complex research techniques. The advent of the electronic computer changed research completely.

Several years ago it was possible for practicing engineers to understand and apply the results of research in the rather limited scope of highway technology. Today it is unlikely that anyone can keep up with all new highway technology. The man in the field with a full-time job to do simply does not have the time and the opportunity to keep up with new technology. Let's be honest. When we separate research and implementation we are expecting the practitioner to read and study a myriad of research reports, separate the good from the bad, translate the results into practice, and sell the administration, FHWA, and others on the use of this new technology. This is not a realistic approach.

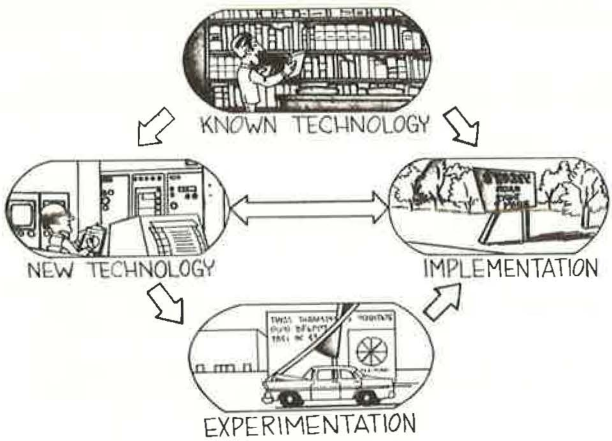
Experience has shown that there are two effective ways to bridge this gap. One is to bring the practitioner into the research project; the other is to make implementation a part of the research and charge the researcher to invade the field of practice. It generally makes him a better researcher.

Both of these methods are used by the Texas Highway Department and the Texas Transportation Institute. The success and acceptance of our research is proportional to the involvement of field personnel in the conduct of the research. However, making implementation a part of research is generally difficult because there are strong prohibitions on the use of "research" funds for implementation. Funding procedures isolate research from practice.

Let's look at the full research cycle (Fig. 1) and I will explain why I feel so strongly that implementation is a definite part of research.

New technology should be based on the foundation of all available known technology, lest we keep inventing the wheel. New technology is validated experimentally through

Figure 1. Cycle of research.



controlled tests, experiments, or studies in which the variables can be isolated, controlled, or varied. This generally is a false environment in comparison with the real world in which the research results will finally be used. Therefore, after experimental validation, the research results should be validated in the real world, with real-world variables and interactions, and the loop should be completed to permit the findings from real-world implementation to be fed back for refinement of the new technology. And it is no mystery that one learns something when he tries to put research to work.

Important factors in implementation are the review and appraisal of research findings that are put into practice. In the application of findings to real-world conditions, adverse side effects often occur that were not anticipated in the research phase. As we all know, experimental work must necessarily be done in a controlled environment. These adverse side effects become apparent to the man in the field in the form of accidents, maintenance, and delay to travelers. These are costly results of unanticipated conditions that occur in application of new technology. The public has the problem, the man in the field has the problem, the administrator has the problem, but the researcher never knows the problem exists. He is isolated from aiding the review and appraisal of the adverse side effects and the measures required to correct these adverse side effects.

This isolation of the researcher can and must be eliminated by providing for his continued services during the time the findings of research are put into practice. A mechanism must be provided for ensuring that the researcher's expertise be available to the practitioner during the review and appraisal period of implementation.

We have reached the point where the researcher must translate the result of research into practice (in cooperation with the practitioner who has been involved in research). He must invade the area of practice.

For best results, the cycle of research should be completed: Implementation should be considered as part of the research effort.

EFFECTIVE IMPLEMENTATION: A SYSTEM OR PERSUASIVE LANGUAGE?

Jack H. Dillard, Virginia Highway Research Council

•THE Committee on Conduct of Research is one of the Highway Research Board's newest, having been formed only 5 years ago, but is proving to be one of the most significant in the transportation field. It is lamentable, I feel, that thousands of papers and reports have been written on technology and research and so very few on how highway agencies can organize internally to take advantage of the plethora of research findings. The Committee on Conduct of Research is making great strides in filling the gap, but we need many more programs of this type. To my knowledge this committee is the only one in any national highway organization or association that provides a forum for discussion of the management of innovations. So it is we in the HRB who must foster an exchange of ideas on the management of innovations and thus, it is hoped, promote a dialogue among the state highway agencies.

The thoughts that follow have been shaped by my association with the Virginia Highway Research Council, which, in effect, is an in-house, applied research organization. However, I feel that the remarks are not parochial and that the concepts are relevant to many highway agencies.

My purpose here is to offer a few thoughts on the question of implementation or, more broadly, on innovations. Some are specific and descriptive; others are general, perhaps even vague, but I hope they provide an impetus for others to give their views. A few of my comments may seem negative, but all are offered in a constructive sense. Specifically, I would like to comment on (a) the relationship of innovations to research, (b) the organizing of an innovation effort, (c) problems besetting the establishment of a positive innovation effort, and (d) experience in Virginia.

RELATIONSHIP OF INNOVATIONS TO RESEARCH

An "innovation" in the sense in which I use the word means a manifest change in materials or processes. Research therefore must be subsumed to innovation, since it is merely one aspect of bringing about change. That is, change can be brought about in a number of ways—by an idea that has never been researched in a formal sense, by mimesis, or by evolutionary forces. This statement may seem to be a semantic nicety without any practical impact, but I think it is at the root of an apparent implementation gap. The significance, I feel, is that many agencies have organized well for conducting research but few have organized well for achieving persistent innovations at a rapid pace. (Eventually all innovations seep into practice, so it is the rapid pace that is at stake.) Would many disagree that the utilization of research findings within the organization conducting the research is generally no special problem, but that it is the adoption of the research findings of others that presents a problem?

I would suggest philosophically that highway agencies need a well-understood innovation effort rather than merely a program for financing research projects. A positive, clearly delineated innovation effort or system would assure a rapid acceptance of technology as it emerges from the various sources. Too often, especially with contract research, the research report is the final step of the effort to bring about change. If top management in a highway agency feels that the job is done when the report is expressed in simple language and sent to the relevant personnel, there very likely is an implementation gap. If, however, it is recognized that the research work is merely a segment of the innovative process, then a system can be devised to assure a rapid acceptance of new technology and ideas.

What, then, are some of the essential considerations in an innovative process as it might apply to any large, complicated activity or agency? I offer the following observations:

1. Change can be hastened deliberately by properly organizing for it. Conducting research is not identical with change.
2. Conversely, the casual "diffusion" approach will take many, many years longer and waste money and perhaps lives as well.
3. Operational people have too many daily crises, problems, and aggravations to be solely responsible for adopting changes.
4. Change can be resented if urged upon personnel abruptly.
5. Change can be an interesting feature of daily operational work that can make the work "fun."
6. A positive innovation effort must include all sources of change, of which internal research is only one.
7. Top management must be a part of the implementation loop.

These points are not altogether self-explanatory, but the next section will perhaps reduce the vagueness. The major point that should be stressed here is that innovations are the goal and research is but a part of the innovative process and, further, that an effective and positive innovation effort or system will involve nearly all the personnel of an agency.

ORGANIZING AN INNOVATION EFFORT

An essential ingredient of any management effort is a clarification of responsibility. This is perhaps the greatest flaw in highway agencies—the responsibility for innovations is often ill-defined, scattered, or not recognized as a responsibility that needs to be placed anywhere. The responsibility for supervising the research effort, however, is generally well delineated. Too often it seems that an agency is content to sponsor research and depend on reports to achieve implementation. I think that the Federal Highway Administration can probably verify the nebulousness of the total innovation process in some of the states. The FHWA has been actively encouraging implementation for several years and has specific groups organized for this purpose. I suppose that in dealing with the various states they often find it extremely difficult to determine the right person or group within a state to approach with an implementation idea. I would further speculate that the FHWA is often quite wary of approaching the research group in some of the states, feeling that the research group is not organized to shepherd innovations through the highway agency and might merely conclude that further research is necessary. This speculation about the FHWA is made because it seems to reinforce the thesis that highway agencies are fairly well organized to conduct research but most are not specifically organized to accommodate innovations at a rapid pace. Also, some groups that conduct research feel that their job is accomplished once the report is completed; the utilization of the results is left to others, and very often the report is filed and never utilized.

Let's consider what an idealized innovation group or suborganization might entail in a highway agency. I would like to point out that the innovation group need not be an entity that includes only full-time personnel but can and should combine the work of full-time personnel and the part-time participation of persons in operations, research, etc. It seems to me that an ideal innovations group should have the following characteristics:

1. Responsibility for innovations should be vested in an individual who manages the innovation process on a full-time basis.
2. The innovations group must include people with backgrounds that permit evaluation of all of the sources of innovations, including (a) in-house research, (b) external source research, (c) innovative practices of other agencies, and (d) creative ideas for development projects.
3. Recommendations for change should be submitted to top management so management will be a formal and in-line part of the innovative process.

4. The innovations group must include full-time personnel who can encourage and assist operating groups in adopting innovations.

5. The innovations group must recognize that the selling of change is best accomplished by involving at the outset those who must eventually implement change. The assistance (or pressure) of top management in making certain that change is not overlooked is needed occasionally, but only as a last resort. Top management, however, can provide the proper climate for persistent change.

6. The innovations group should include an applied research effort that finds practical solutions for its sponsoring agency.

7. The innovations group must be able to delineate (a) problems that have been solved elsewhere and need no research; (b) problems that need applied research to be implementable; (c) problems that need long-range research and high funding support; and (d) the differences among these three types of problems.

8. The innovations group must realize that operating personnel are constantly upgrading their procedures and that the innovations group is not the sole source of change. The ideal attitude is that everyone must be alert to beneficial change but that the innovations group has the responsibility for bringing beneficial change opportunities to the attention of the operating groups.

PROBLEMS BESETTING ESTABLISHMENT OF A POSITIVE INNOVATIONS EFFORT

No inference should be drawn that the problems discussed below exist in all highway agencies, but in my opinion they are widespread enough to warrant their inclusion.

Attitude of Top Management

Several means come to mind through which top management can present an unintentional obstacle to an ongoing innovations effort:

1. Belief that if clear and simple language is used in a research report the operating personnel will adopt it.
2. Insistence that only Highway Planning and Research funds be used on research and also on funding of an innovations group.
3. Relegation of the innovations group to a position where it is a subunit of an operating group.

Contract Research

Contract research is a problem only if both the highway agency management and the contract research group feel that the job is fulfilled when research is conducted and the results are reported. If there is no follow-up or implementation assistance, then the research is often not utilized. This implementation gap can easily develop or be perpetuated if HPR funds are the sole source of research funding, because the HPR program is project-oriented and does not easily accommodate the daily bits and pieces that an ongoing innovations effort demands. Also, an effective innovations effort must entail the implementation of ideas of others. If an agency has only a research coordinator who has no professional staff and all research is done by contract with an outside agency, the opporutnity for an implementation gap is great. Again, the total innovation package should include new ideas from many sources.

The implementation gap should be considerably less if applied research is conducted by in-house research personnel. Because of their continuing daily relationship with operational personnel, the in-house research personnel are more apt to be a "perpetual advocate" than contract research personnel, who may conclude their contract with the report.

In both contract research and the in-house type there is often a tendency to neglect the research done by others, but an effective innovation program demands that beneficial changes from all sources be advanced within the agency. It seems clear that, if research is done by contract, then there must be a group of in-house personnel, working full time, who are assigned the responsibility of assisting in bringing about the innovations from the many sources.

Lack of Closed Loop

The recommendations of the innovations group (normally made through collaboration with operating personnel) should in my opinion be submitted to top management, who sees that they are either adopted or rejected for good cause. If the innovations group is a part of an operating group, it may be difficult to avoid the antagonisms generated by one group trying to bring about change in another peer group. I feel strongly that the innovations group should report directly to top management.

EXPERIENCE IN VIRGINIA

The Virginia Highway Research Council is located on the grounds of the University of Virginia in Charlottesville. The Council is sponsored by the Virginia Department of Highways and the University of Virginia; however, all funding is from the Virginia Department of Highways. The employees hold job titles in the Virginia Department of Highways rather than academic titles. Only 10 percent of the research effort is "fundamental"; the remainder is applied. To conduct the research program, approximately 30 full-time professionals, 10 part-time faculty members, and 15 graduate students are employed by the Council.

Attitudes and Policy of the Virginia Highway Research Council

As noted previously, the Virginia Highway Research Council is the research branch of the Virginia Department of Highways, although the University of Virginia does have a policy-making role in a broad sense. The Council enjoys an excellent working relationship with the personnel in all facets of the operations of the Virginia Department of Highways. The management of the Virginia Department of Highways is a most enlightened and progressive one and plays a very positive role in upgrading the technology employed in highway design and construction. It is the conviction of the research staff of the Council that a more favorable environment for innovation does not exist in any other highway department in the country.

The following comments characterize the innovative effort in Virginia:

1. The innovations program has the overt support of top management of the Virginia Department of Highways including the Commissioner, the Chief Engineer, and the other top executives.
2. The highest achievement of the research personnel is considered to be an innovation in the practices of the Virginia Department of Highways. That is to say, the publication of papers and contributions to national transportation problems rank behind contributions to the Virginia Department of Highways.
3. Troubleshooting is frequently done and is considered to be excellent experience for those in applied research.
4. The follow-up to assure implementation is considered to be a part of any project and is the responsibility of the research personnel conducting the work.
5. All recommendations from research are made to the Chief Engineer, who follows up to see that they are either implemented or not adopted for good cause.
6. The University location is a vital asset, since it makes specialists available and makes possible the temporary assignment of specialists to a crisis-type item.
7. Faculty members are employees of the Council rather than engaged to work on a contract basis.
8. The Council is proceeding toward the innovations group concept. In addition to conducting research, the group is responsible for other aspects of the innovation package, which include (a) delineating opportunities for beneficial change, (b) securing information by internal research or from the research of others, (c) providing implementation impetus, and (d) aiding in implementation.
9. The greatest deficiency in proceeding toward the innovations group concept for us is that of a positive approach toward using the work of others.

SUMMARY

I have tried to stress the point that state highway agencies in reality need to be organized specifically to accommodate a persistent innovations effort and that it is vital that an innovations group not be considered identical with a research group or a research effort.

If research is conducted by contract with an outside agency, then there should in my opinion be full-time personnel in the highway agency to accommodate the other aspects of the innovation package, especially the upgrading of technology from the work of others.

Innovations can be hastened by deliberately organizing to accommodate change and by assigning the specific responsibility for implementation to an individual and his staff. Also, I would add that new technology will eventually be adopted by the casual "diffusion" process, but this process will be extremely slow and expensive.

Finally, I will overtly answer the question the title poses: No, no, a thousand times no; relying solely on clear and persuasive language in reports will not accomplish rapid implementation. Only a system designed to provide clear-cut responsibility, daily impetus, and managerial involvement will enable an agency to take advantage of rapid advancements in technology.

THE FEDERAL HIGHWAY ADMINISTRATION'S IMPLEMENTATION PROGRAM

Milton P. Criswell, Federal Highway Administration

•IN many organizations in the highway community the emphasis on research implementation was accelerated by the conclusions and recommendations of the AASHO study in the late 1960's to find better ways and means to implement research results. We would probably find that, as a result of this AASHO emphasis, most states now have a successful implementation process that enables them to apply the research results from their own programs.

In the Federal Highway Administration the major development was the establishment of the Implementation Division in the Office of Development. The primary objective of the Implementation Division program as identified in the Federally Coordinated Program of Research and Development is "to stimulate and expand the application and the practical use of the products of highway research and development." To implement usable research from FHWA programs requires a technology transfer across jurisdictional boundaries in a manner similar to states accepting the results of other states.

In the past, this process has been slow because there has generally not been any formal or informal mechanism that would accelerate the implementation process across these boundaries. The key word is accelerate. In fact, if one asks what the real significance is of creating an implementation group in FHWA, one could say the major function of this group is to accelerate the movement and use of research results across jurisdictional lines, from state to state and from federal to state.

We believe meeting two major goals is foremost in achieving this objective. The first goal is to develop an environment conducive to the national coordination and acceptance of cooperative implementation efforts by FHWA, the state highway departments, and other highway users. Some key factors in developing this environment—or, as it has been called in FHWA, "an attitude of approval"—are the following:

1. Obtaining the interest for full cooperation and support of top management, including both state and federal organizations. In FHWA, the commitment of top management is very visible. In addition to the Implementation Division, FHWA also has personnel directly involved in implementation activities in the field regions and divisions, and a Regional Implementation Coordinator is to be established in each regional office. Other organizational components in FHWA with major roles in implementation activities are the Region 15 Research and Development Demonstration Projects Division, with responsibility for the Demonstration Projects Program; the Construction Methods and Practices Branch of the Office of Highway Operations, which is responsible for the Federal-Aid Experimental Construction Projects Program; and the National Highway Institute, which is responsible for developing and conducting programs relating to educating and training for the highway community. Dovetailing these personnel and their related programs with the activities of the Implementation Division is essential to an effective and efficient program.

2. Involving practicing engineers in the research and development process. As a matter of interest, in FHWA we follow the practice of involving operations people during the budgeting, conceptual, and performance phases of research efforts to ensure, first, that we are addressing real-world problems in the FCP and, second, that, at such time as it becomes apparent that usable research results will be produced, the implementers can take these results, translate them into user form, and then take the necessary steps to implement the results on a widespread basis. To achieve this, we have evolved a counterpart relationship among implementation managers, operations personnel, and research FCP project managers.

3. Providing sufficient funds for the necessary field test and evaluation of the research to be sure that results are ready for the practicing engineer and that he is able to apply the results with confidence. In FHWA, the experimental projects and demonstration projects programs have a key role under this item.

4. Providing solutions to the real problems of practicing engineers. Regardless of how successfully a research study may turn out, if it is not addressed to solving a real problem, you will have a difficult time implementing the findings.

5. Presenting research findings in a form or language that can be readily understood and immediately used by the practicing engineer. A research report does not meet this objective.

6. Providing educational programs so practicing engineers will better understand the benefits involved with adopting new technology. The National Highway Institute has a key role in this area.

7. Providing a management framework that is flexible, avoids duplication of effort, minimizes coordination requirements, is responsive to needs, and does not involve a lot of red tape.

The second goal is to be able to assess in a systematic way the success of the program and the benefits realized.

MANAGEMENT PLAN FOR IMPLEMENTATION

To meet these objectives and goals, a management plan was developed by the Implementation Division that is intended to form the basis for a coordinated, comprehensive, and cooperative FHWA-state approach to implementation. This plan is the major instrument for the FCP implementation program. It provides a role for other FHWA offices in Washington and in the field and for the state highway departments. It relates existing programs, such as experimental projects and demonstration projects, to newer implementation activities in identification, planning, packaging, and promotion.

The plan considers the necessary interrelationships required of research, management, and operating personnel in the FHWA, the states, and other government agencies and in HRB and other non-government highway organizations that are involved in highway-related research implementation processes. Effective consideration of these relationships is vital because the total resources that can be assigned to implementation activities are limited. No one organization is large enough or situated in a position so that it can do the job by itself. Although primarily a state-federal cooperative effort, there will be spin-off to other users such as counties, municipalities, and other federal agency programs.

STAGES IN IMPLEMENTATION

The plan recognizes six significant stages in the implementation process. These stages are identification, planning, packaging, promotion, evaluation, and adoption.

Identification

Identification consists of screening and reviewing current and past products of research and development to determine their relative importance and to evaluate their potential for implementation. The identification process answers two basic questions: (a) Was the research implemented or recommended for implementation by the sponsoring organization? (b) How useful and important is it to others? The plan attempts to establish an organized approach to identification, which we believe is essential to ensure complete and adequate coverage of the research and development activities of all highway organizations. For example, through discussions with our research counterparts at all working levels in the Office of Research, more than 100 items were identified from the FCP research and development program that were considered potentially implementable in FY 1973 from FHWA contract and staff efforts as well as items that research personnel had knowledge of through various contacts with other sources. Implementation managers discussed each identified item with personnel in the operating offices to zero in on those items that had the greatest potential and payoff for implementation.

The principal mechanism being used by the Implementation Division for identifying implementable results from state highway department research and development programs is an Implementation Data Report Form. This form is generally prepared after an item has first been applied in practice or recommended for application. It provides brief, minimum information to initially determine national implementation potential and importance. States have been very cooperative in completing the form, and we have received over 250 reports to date.

An initial screening of these reports has identified about 58 items where states indicated potential usefulness of the results outside their state. According to the information provided for each item, the state furnishing the report indicated not only that the results had been implemented and satisfactory results obtained but also that it believed the accomplishments had potential for implementation in most or some other states.

Planning

Once an item has been identified and judged to have potential, the planning stage provides answers to the following questions: Where do we go from here and how? What and how much needs to be done to obtain implementation? Who is going to do what?

The planning process consists of specifically preparing the individual or group strategy to identify and accomplish the necessary steps to achieve effective implementation. For some items, this may be a very simple and rapid task. For others, a very detailed and complex strategy may be required, particularly when additional work is required for the "packaging" and "promotion" stages. The important thing is to make a plan scaled to the effort that is needed and to the importance of the item. I might note that, for every research result from the FHWA contract and staff programs identified as potentially implementable in FY 1973, an implementation manager prepared an action plan for implementing the product that included strategy and target dates for major milestones.

Depending on the complexity of the item, the difficulty of implementation, or the resources required, a technical advisory group composed of representatives of the various FHWA offices may be utilized to assist in the planning efforts. For example, to plan the implementation of an air quality training course resulting from a California Division of Highways research effort, a working committee of three representatives—one from the Implementation Division, one from the Office of Environmental Policy, and one from the National Highway Institute—was established to ensure that this course was reponsive to the views of operations personnel as well as suitable for follow-on work to be undertaken by the National Highway Institute.

Packaging

When implementation of new technology is encouraged or recommended, there should be a package of user-oriented material developed for the potential user. Interaction between research and operations personnel is a key element in its development. The user package is intended to provide a complete "how-to-use" kit so that the potential user can begin to apply it immediately.

Often, the formal research report is not suitable as an operating tool to apply new technology. Translation into field orders, manuals, specifications or standards, graphs, data tables, and other similar documents is needed. Training materials, films, and other explanatory and education documents may also be needed to assist in the implementation. Generally a combination of these preparations, assemblies, and translations constitute the "user package." Their size and complexity depend on the need. There is no pat formula. The Implementation Division is responsible for packages prepared for FHWA programs. For items emanating from the HP&R program, the state highway organizations are being encouraged to prepare the user package for items produced from their own research programs that have been applied within their state. This approach is being followed because some form of package or document was probably used to accomplish implementation and the same material is a logical starting point for a package that may be useful to others. The mechanism used by a state to implement its own results may help others to implement the same results.

A special implementation line item has been established in the HP&R Part II Work Programs to assist the states in funding this work. The Implementation Division is coordinating this overall effort to avoid duplication, to assess the effectiveness of this activity, and to provide feedback to those concerned. As part of the coordination, we are creating a new department in Public Roads magazine to report on user packages in preparation and, in addition, will issue periodic status reports pertaining to ongoing activities in these areas. As user packages are received, the Implementation Division will start efforts to promote nationwide application of these products to appropriate users.

Promotion

When the user package for a product is completed, the product is ready for the promotion stage in the manner that has been decided earlier during the planning phase. This is the "action stage of implementation." Depending on the plan and the strategy previously developed, promotion is carried out by one or more selected federal-state avenues to reach the potential user. The principal avenues are the Experimental Projects Program, the Demonstration Projects Program, official bodies such as AASHO and ASTM, educational and training programs of the National Highway Institute, films, slides, workshops, publications—whatever may be needed to accomplish the implementation.

Through the Experimental Projects Program, actual field tests and evaluation of new highway construction materials, equipment, and processes that have a high priority for application can be achieved. Through the Demonstration Projects Program, opportunity is provided for states to observe actual field demonstrations that show the practical application of new technology resulting from research and development. Implementation Division personnel work very closely with these offices in the early stages of the promotion process. In many cases, user packages will have been prepared by the Implementation Division or state highway departments for use in these programs. The involvement of FHWA field personnel in promotion activities is considered a key element in the success of this phase. In FHWA this is particularly significant since the primary customers for new technology are the state highway departments and other local highway agencies.

As you are aware, the states are far removed from Washington, D.C., in the organizational chain of command. Therefore, FHWA field and state highway personnel are being invited to become involved in parts of or to take over appropriate nationwide implementation efforts. Two items where national promotion is currently being handled by FHWA field offices are the structural steel acoustic crack detector and magnetic crack definer under Anthony Leone, Regional Bridge Engineer for Region 6 in Fort Worth, and the computerized bridge rating system under Richard Sharp, Regional Bridge Engineer for Region 8 in Denver. State highway department personnel have agreed to participate in FHWA implementation efforts, such as the air quality workshops, which include instructors from the California Division of Highways; the computerized bridge rating system workshops, which include Wyoming Highway Department personnel as instructors; and the recently completed roadway design system demonstrations, which included Texas Highway Department personnel. We believe the involvement of FHWA field and state highway department personnel in these implementation efforts expedites the acceptance of the new technology because these personnel, being users themselves, better understand the needs of their "customers."

In addition, to assist the field, a new series of announcements called Implementation Division Alerts (IDA's) has been instituted. These alerts are intended to provide advance notification of significant products of research that will soon be ready for a major implementation effort. They include sufficient information to allow initiation of preliminary planning and strategy on the implementation approach that will be used within a region on the product highlighted. So far, six IDA's have been issued covering the following products: dryer drum process, delamination detector, computerized bridge rating system, curriculum on managing highway maintenance, epoxy resin coated reinforcing steel, and air quality workshops.

Evaluation

Throughout the several implementation stages, evaluation has an important role. There are two points, however, where it is most critical. One is between the identification and planning stages, when the preliminary decision is made by an implementation advisory group in the FHWA field office or in the Washington headquarters on whether an item is ready for implementation. The second critical point is after implementation has been tried in one place or many places and its value determined.

Identification and documentation of measurable benefits and accomplishments emanating from the application of research results are the most important evaluation goals. Documentation is extremely important to the research implementation program and the overall highway program for two reasons. In conjunction with the user package, it is a most effective tool for encouraging implementation by others. It is also the most visible evidence of the values of research and development programs to present to the public, to administrators, and to program sponsors in Congress and the state legislatures.

Adoption

The adoption stage of implementation consists of the actions taken to make the item part of a standard procedure or practice. In some cases, the approval develops over time without a distinct action. In others, it consists of an order, specification, or standard that is prepared to officially adopt the item. Final actions may be taken by appropriate AASHO committees or by state or FHWA offices.

CONCLUSION

I have given a brief review of the FHWA implementation program. We believe it is on the right track and offers an excellent opportunity for success. As the program begins to jell and states start to receive user-oriented materials from other states and FHWA that benefit their operations, I am confident the necessary environment will be achieved to provide the solid foundation required for a successful implementation program.

THE SYNTHESIS OF INFORMATION AS AN IMPLEMENTATION TOOL

Thomas L. Copas, Highway Research Board

•WHAT is a synthesis? It is important that we have general agreement on what a synthesis is and—equally important—is not. Some definitions offered by Webster are "the composition or combination of parts or elements so as to form a whole"; "the combining of often diverse elements into a coherent whole"; and "deductive reasoning". The project statement for NCHRP Project 20-5, "Synthesis of Existing Information Related to Highway Problems", suggests that textbooks, nomographs, and state-of-the-art papers are conventional synthesis methods for maximizing the use of existing knowledge and for minimizing the total effort expended in bringing together useful information.

It has also been stated, "Information synthesis can bring together and interrelate stored information, current research activity, and current engineering practice" (1).

A synthesis, if we accept these definitions, is not intended to develop new information, techniques, or procedures or to serve as a manual or handbook. The synthesis process should survey and evaluate all that is known about a problem that can be brought to bear on its solution.

Why synthesize information? "Distill or Drown: The Need for Reviews" was the title of a 1968 article in a physics magazine (2). The article discussed the information explosion and stressed the need for creative synthesis of facts and ideas. It stated, "No set of information tools is going to enable the scientist to make full use of our information output unless it includes some means for digesting, evaluating and above all condensing the scattered bits of valuable information into coherent and comprehensible packages".

The responsibility for developing a synthesis document should rest with someone who is a recognized authority in the subject area. A panel of other experts should be available to provide additional experience and overall guidance (3). The panel will normally include a practitioner, a researcher, and an author.

Unfortunately, it is not possible to prepare a single synthesis report that will satisfy all levels of users. Nor will a single synthesis always be suitable for both research and management. Their responsibilities and interests are different. Most of the syntheses that have been prepared under NCHRP 20-5 contain a summary that is written for management. The body of the report is directed specifically to the personnel involved with the subject area.

How is the synthesis report developed? There are four major phases in the development of a synthesis:

1. Identification of related literature, people, agencies;
2. Collection of documents and information on practice;
3. Evaluation of documents and practice; and
4. Preparation of the synthesis.

Intermediate or support steps include literature search, document acquisition and review, identification of panel members, scope development, consultant selection, contacts with practitioners and agencies, draft preparation, review, and revisions, publishing, distribution, and follow-up.

Each phase or step has some relationship with research implementation and successful practice. There is much to be gained from synthesizing practice. While many are reluctant to use new methods, nearly all will follow an established practice that has been successful in getting the job done.

How have completed syntheses of highway practice been put to use? "Traffic Control for Freeway Maintenance" has been used as a guide for preparation of agency manuals and as a check document at work sites. "Bridge Approach Design and Construction Practices" has been translated by one foreign government. "Concrete Bridge Deck Durability" has been identified as a basic document in the continuing development of practices and procedures to cope with the problem (4). "Scour at Bridge Waterways" has been translated into Spanish as an "information bulletin". "Principles of Project Scheduling and Monitoring" has been used as a text supplement at the Mississippi Highway Management Course. "Motorist Aid Systems" has been used by AASHO, FHWA, the Congress, and various communication industries. "Construction of Embankments" was reviewed by one highway agency and recommended for distribution on a wide basis to agency field personnel.

Distribution on a nationwide basis to other than highway agencies was attained when AT&T purchased 50 copies each of two syntheses for members of their organization in each state.

I feel also that the synthesis effort is implementing research in other ways that are difficult to document. The panel discussions at the three or four meetings for each topic are useful. The investigative effort causes practitioners and researchers alike to take a fresh look at their work. One director of a midwestern highway agency called the day after a synthesis topic consultant had visited his agency to inform me that he and his staff had benefited from the exchange of views. The opportunity to bring several staff members of the agency together to bear upon a single problem is difficult to measure. But it is useful.

GETTING RESEARCH FINDINGS INTO PRACTICE

The following comments are extracted from the draft of the synthesis on "Getting Research Findings Into Practice" (5). Dr. Reynold Watkins of Utah State University has assisted the panel and staff in the preparation of this draft.

The time and money put into research cannot be justified unless the research findings are used. The primary use of research results is to change practice—those methods and procedures used to design, construct, and maintain highways. To change practice it is usually necessary to change the "media of practice", i.e., plans, specifications, standards, handbooks, manuals, etc.

Most of the problems of implementing research results derive from four failings. First is the failure to report results, particularly negative findings. The second is a failure in the distribution of reports—too much information and frequently to the wrong people. Another failing occurs when personnel do not have time to read, understand, and evaluate reports or because they are not written clearly and concisely or in appropriate terminology. Finally, applicable research findings sometimes are not put into practice because of resistance to change.

Some of the problems can be overcome through the proper type of organization. A research organization that is set up with the clear knowledge that the end result of the research program is implementation helps considerably in getting the agency's own in-house and contract research into practice. But the implementation of research by others takes a separate procedure. Distribution of research reports to interested offices by the research engineer is one method used. An improvement on this requires the recipient to submit a written report on the applicability of the research results. Another approach uses a committee whose members represent a cross section of the agency. Committee members are assigned reports as they are received, and they present a summary and recommendation to the committee for appropriate action.

Professional associations have a major role in implementing research. The committees and task forces of groups such as AASHO, ASTM, ASCE, ACI, and ITE use research results to prepare specifications, manuals, and guides that can be used by practitioners.

The techniques of implementation are communication and motivation. Communication techniques include the following:

1. Readable and understandable reports—that is, reports written in orderly, direct fashion and in the language of the practitioner;
2. Research information services—the best known in our field is the Highway Research Information Service;
3. The Technical Activities Staff of the HRB, which, through trips to state highway agencies, colleges, and industry, acts to correlate research;
4. Seminars and workshops where one of the objectives is to present research results to potential users; and
5. Demonstration teams that involve the practitioner.

Motivation is a force that can be used to get people to put research results into practice. Some of the means include

1. Administration, which can reward positive efforts toward implementation;
2. The research engineer, who can act as a link between the researcher and the practitioner;
3. Involvement of the practitioner in the research from the beginning through the check-testing of results; and
4. Interloan of personnel among divisions and districts, which frequently will result in fresh points of view being applied to old problems.

The federal-state cooperative highway research implementation program is designed to stimulate implementation efforts, encourage reporting of research results, and obtain feedback on research needs. One effort is the Experimental Projects Program, where the main thrust is to obtain useful results on experimental features in a short space of time. The purposes of the Research and Development Demonstration Projects Program are to promote utilization of research and development and to provide special training opportunities for FHWA and state highway personnel.

There has been much progress by highway agencies in the implementation of research findings, particularly for research conducted within or at the direction of the agency. There is still a time lag in implementing research done by others. It is recommended that highway agencies improve techniques for utilizing research done by others. Additional conclusions and recommendations are as follows:

1. Management is responsible for supporting implementation effort.
2. Communication remains a problem; organized channels of communication should be improved.
3. To increase implementation, practitioners should be involved at all stages of research.
4. The research effort should be planned for implementation—even to the extent of developing draft specifications, instructions for use, etc.
5. A system to evaluate research results is important.
6. Interloan of personnel within an agency is advantageous for getting research into practice.
7. Field visits (including trips to other states) have played a role in gaining acceptance of new materials, techniques, and equipment.
8. Conferences, seminars, and workshops are excellent means of informing personnel of research results.
9. Demonstration projects that show the validity of a new product or procedure have been well received.
10. Increased attention should be given to product evaluation methods.
11. A system tailored to the agency's needs should be developed for receiving, cataloging, and routing research reports.
12. Research findings are not fully implemented until they are reflected in specifications, standards, plans, manuals, handbooks, etc.
13. Those agencies with a committee organization assisted by a full-time research engineer are more successful in evaluating and implementing research results.

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