TRANSPORTATION RESEARCH RECORD 781

Maintaining the Maintenance Management System

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1980

Transportation Research Record 781
Price $8.40

mode
1 highway transportation

subject areas
40 maintenance
41 construction and maintenance equipment

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Maintaining the maintenance management system.

(Transportation research record; 781)
1. Roads–Maintenance and repair–Management–Congresses.
I. National Research Council (U.S.). Commission on Sociotechnical Systems. II. Series. TE7.H5 no. 781 [TE220]
380.5s 81-1185 ISBN 0-309-03111-7 ISSN 0361-1981
[625.7'6'068] AACR2

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Contents

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Foreword

A Workshop on Maintaining the Maintenance Management System was held July 6-8, 1980, at Hilton Head, South Carolina, and was the fourth in a series of maintenance management workshops. The workshop was cosponsored by the American Association of State Highway and Transportation Officials (AASHTO), the South Carolina Department of Highways and Public Transportation, the Federal Highway Administration (FHWA), and the Transportation Research Board.

The Iowa Maintenance Study in 1961 led to what has come to be called maintenance management. Several states and Canadian provinces initiated comprehensive research programs leading to the first workshop at Ohio State University in 1968. The purpose of the workshop was to provide an opportunity for states to compare notes and to learn about this new development. Emphasis was on work measurement, planning and scheduling, and reporting of work accomplishment. The proceedings were published in HRB Special Report 100.

By 1970, maintenance management was in widespread use; the workshop that year at the University of Illinois emphasized problems encountered in implementing performance standards and reporting systems, establishing maintenance levels, and organizational structure and training. The proceedings and related papers were published in Highway Research Record 347.

During the next five years the extent of maintenance needs was delineated through the maintenance management system, and it became obvious that many legislative bodies were not allocating adequate resources to maintenance. In 1975, a third workshop was held in Las Vegas, Nevada; its focus was on the interface between maintenance managers and such decision makers as budget and fiscal managers, system analysts, and personnel analysts. Proceedings were not published.

Presentations published in this Transportation Research Record represent a combination of reports reflecting the experience of participants involved in managing mature systems, refinements for components of maintenance management systems, and concepts that are just beginning to attract the attention of maintenance managers to whom this report is addressed.

Quality standards are fundamental to any maintenance management system and discussions of the subject have been included in all of the workshops. To date, no one has established a way of providing objective quality standards; however, improvements are continually being made. Two sophisticated approaches (as compared with those reported in earlier workshops) are herein put forth. Ram B. Kulkarni outlines a procedure that uses decision analysis that has been tested on an experimental basis for two maintenance elements. Work is continuing and maintenance managers are encouraged to monitor future developments closely. In a second report, Michael J. Markow describes the development of models of practical use in maintenance policy planning and management. The example cited illustrates the use of data to provide factual guidance to making objective decisions; however, at this stage of development managers must be imaginative and innovative because procedural manuals do not yet exist to guide analyses of this type. It is hoped that this work will spur efforts in the area to the end that practice manuals can be prepared.

The second session on measuring performance also introduces a number of advanced or new concepts. Pavement maintenance management, a subsystem of pavement management, is hampered by the difficulty of acquiring suitable maintenance data and of relating data to performance. Photographic or television imagery provides an enormous amount of data at very low cost but extraction of pertinent data is very difficult; hence, only limited use is being made of the material. Theodore H. Poister's effort in his report on an initial stage of a study has a broader aim than use of performance indicators as a tool for fairly allocating funds to districts (the primary use in the pioneering Ohio work). He envisions it as a tool to review progress and trends in the provision of transportation services, for budget justification, for in-depth program evaluation and program analysis, to encourage employee motivation, to assess the performance of contractors, to provide quality control checks on efficiency measurements, and to improve communications between citizens and government. For example, given the overall objective of fast, safe, and efficient highway transportation, the most straightforward measures of effectiveness would relate to the costs incurred by users, and accident rates; travel times and maintenance expenditures should be reflected therein.

Another concept in the forefront of modern management is simulation. James Pruett's paper describes the development of a mathematical model that provides highway maintenance engineers with a computer-aided laboratory in which to test and evaluate various alternative courses of action. This innovative work also requires imagination by maintenance managers, but the lack of handbooks will probably inhibit immediate and widespread acceptance of the concepts presented.

Finally, risk assessment is an inherent responsibility of management. For example, what is the risk of an accident if a maintenance crew assigned to fixing a pothole neglects replacement of a crash attenuator? Attempts are being made to place values and to make an assessment of risk to aid managers toward soundly based decisions. A large storehouse of knowledge exists on risk assessment procedures, but very little of this knowledge has been adapted for use by maintenance managers.

Financial support from the National Highway Institute (FHWA) for the workshop and for publication of the proceedings is gratefully acknowledged.

REMARKS BY SECRETARY WILLIAM N. ROSE, FLORIDA DEPARTMENT OF TRANSPORTATION

I am pleased to be here today. I could stretch a point and tell you that I am surprised any of us are here -- or that this meeting is being held.

It was not to long ago, in 1965, that I attended a Highway Research Board meeting in Washington for the specific purpose of learning about the development of maintenance management systems in the State of Virginia and in the Province of Ontario. At that Research Board Session the Maintenance Committee was discussing whether or not to proceed with research aimed at developing maintenance management concepts that could be applied in all state highway agencies. Following a very professional presentation by the Virginia Department of Highways, I was convinced that the highway maintenance management practices being developed by the Virginia Department in its research project were applicable to the management problems faced by maintenance engineers throughout the country. These practices seemed to hold a potential to effectively improve the utilization of resources applied to highway maintenance.

The second part of that meeting involved lengthy explanations by state highway maintenance engineers representing several of our largest states explaining why maintenance operations could not be managed in the manner proposed by proponents of the Virginia research findings. Unpredictable weather, unanticipated damage caused by accidents, fluctuating seasonal conditions, and other unanticipated demands on state maintenance forces were factors which rendered highway maintenance impossible to manage--planned quantities of work supported by planned allocations of resources -- manpower, equipment, and materials. It was simply assumed by many of the senior members of the maintenance committee that the need for maintenance forces to react to unusual and unanticipated conditions could not be accommodated in a management system.

Fortunately, maintenance management research did continue. State after state developed and implemented maintenance management practices. Now virtually every state in the union has applied some maintenance management concept to highway maintenance operations. In 15 short years, the highway industry has come from a position of skepticism to the situation we find ourselves in today -- our problem is not, <u>if</u> management systems are needed, but how can we refine and improve current maintenance management systems to make them more effective. If the program for this series of meetings at Hilton Head was distributed at that Highway Research Board meeting 15 years ago, I am sure all of us would have been barred from the meeting. I might add that those states most vocal in their opposition to maintenance management concepts being applied in state highway agencies at the 1965 meeting are all represented here today -- as a matter of fact, some of them are recognized as leaders and innovators in development and implementation of their management processes.

I have been involved in helping state, county and city public works agencies improve management practices for the past twenty (20) years. I have enjoyed being involved with several agencies in helping to develop highway maintenance management systems. New ideas are developing every day.

There is a trend developing that I expect most of you know about. It would be inappropriate not to mention that trend as we begin our meetins this week. Our ability to define the quantities of work necessary to adequately maintain highways and to allocate resources for the accomplishment of those activities has enabled every state to improve the utilization of scarce resources -- manpower, equipment, and materials purchased with hard to come by tax dollars. That capability not only permits us to better utilize state resources, it permits state highway agencies for the first time to effectively develop contracts that will permit performance of routine maintenance services by private contractors. Several public agencies around the country have elected to perform all of their public works maintenance services by private contract and have enjoyed a 15 to 30 percent reduction in the costs of performing those services with public forces. This same productivity improvement opportunity exists for every state highway agency.

In Florida we are embarking on several demonstration projects to establish the criteria for switching from state force to private contract. The first bids for selected maintenance activities were opened this past April. Bids, after being adjusted by adding a 31 percent overhead and supervision factor, were about 15 percent less than the cost of performing the same work with state forces.

While preliminary indications are that costs can be reduced by 15 percent -- I expect even greater improvement as the demonstration projects develop more data and department engineers develop more effective contracting techniques. Similar projects are underway in Pennsylvania where the Department of Transportation is contracting for the management of highway maintenance forces.

I think we are at the same point today in the development and acceptance of the concept of contracting for maintenance services that we were in 1965 when we were considering applications of maintenance management practices to highway maintenance work. Fifteen (15) years from now, the concept of doing most maintenance work by private contract will be accepted throughout the country.

State highway agencies have developed a very effective contracting system for the construction of new highways. We have excellent plans, special provisions, specification and contract wording coupled with an excellent contract administration and construction inspection system that ensures performance of contract construction according to specification. As we develop a similar capability to define maintenance contracts and to administer and inspect contract maintenance work, we will be organizing to perform highway maintenance just as we now do for highway construction -- developing a force of highly qualified engineers, technicians, and administrators to oversee work by private enterprise.

I'd like to propose that this committee seriously consider the conduct of further research to develop those practices necessary to effectively design and administer maintenance contracts. Let's meet back here again in 15 years and see if we haven't made as much progress in performing maintenance work by private contract as we have in the past 15 years in developing and implementing highway maintenance management systems.

REMARKS BY DEPUTY FEDERAL HIGHWAY ADMINISTRATOR JOHN S. HASSELL, JR., BEFORE THE NATIONAL RESEARCH COUNCIL, HILTON HEAD, SOUTH CAROLINA, JULY 7, 1980

It is indeed a pleasure for me to be here and to discuss highway maintenance and some of the challenges we are facing in this area. I want to thank the Transportation Research Board for holding this workshop and inviting me to speak to you today.

These are times of inflation and energy shortages, a combination that serves to make our efforts in the maintenance of our highway system a demanding task. We have been asked to carry out our goals of preserving the Nation's highway systems, and providing for their safe and efficient use, at the same time that we have been faced with reduced budgets and, in many cases, manpower reductions as well. The present decrease in motor fuel tax revenues, coupled with spiraling inflation, compounds the highway maintenance situation.

These are not new problems, by any means. Mr. Francis Turner, former Director of the Bureau of Public Roads, said to the Highway Research Board in 1968: "As in the past, there will in the future be just so much money available for highway purposes, and any dollar wasted on inefficient maintenance practices is a dollar deducted from the funds available for new facilities."

We have the same problems today. In fact, highway maintenance has now become a major issue and we are facing a highway program for the 80's that will be restructured to preserving the highways we already have.

FHWA's Interest in Highway Maintenance

Although legislative restraints prohibit the use of Federal funds for highway maintenance, the FHWA has a deep interest in seeing that the highways are properly maintained because of the tremendous Federal investment in construction of these roadways. Indeed, Title 23 states in Section 116, "It shall be the duty of the State highway department to maintain, or cause to be maintained, any project constructed under the provisions of this chapter . . ." and "If at anytime the Secretary shall find that any project constructed under the provisions of this chapter, . . ., is not being properly maintained, he shall call such fact to the attention of the State highway department. If within 90 days . . . such project has not been put in proper conditions of maintenance, the Secretary shall withhold approval of further projects of all types in the entire State . . ." Congress and the FHWA view maintenance very seriously.

The States have also shown their interest in the proper maintenance of the highways by placing increasing amounts of their funds into maintenance. The 1980 Highway Needs and Performance Study is finding that State disbursements for maintenance have kept pace with, and in many States, exceeded the rate of cost increases. In fact, maintenance is the one area of the highway program where expenditures have remained stable in constant dollars.

However, Congress is still very concerned and in the Surface Transportation Assistance Act of 1978 Congress required guidelines for Interstate Maintenance. As a result of the 1978 Highway Act, the FHWA has recently issued a regulation that requires State highway agencies to submit an initial plan to explain how they are going to manage their Interstate Maintenance program by July 25. These reports will include a discussion of the State's method of program management, including copies of operating documents, and a general description of the resources and activity levels the State intends to devote to meeting the stated objectives in each cited element.

The law also requires an annual certification by the State that it <u>does</u> have an Interstate Maintenance program and that it's routes are being maintained in accordance with that program. Each year the State will be required to update its initial program and provide information to FHWA on: condition of interstate routes and deficiencies, maintenance priorities, maintenance budget and exceptions and/or revisions to the initial submission.

The regulation provides for sanction procedures whereby the Secretary of Transportation can reduce the State's Interstate apportionment by 10 percent for failure to certify as required or if it has been determined that the State is not adequately maintaining its Interstate routes in accordance with its own maintenance program.

Allow me to illustrate a few of the problems that we now face in the Interstate System which have major implications for maintenance.

The designated 42,500 mile Interstate System deteriorated from 1975 to 1980. During this period, pavement conditions changed from 4 percent of all mileage needing rehabilitation or reconstruction to 13 percent needing resurfacing and 13 percent of all bridges on the Interstate System are deficient. In addition, an average of 2,000 miles (or 4.7% of the total system) is reaching its 20 year design age each year. Federal Interstate completion and Interstate 3R funds (including the Interstate 10 percent state match) now account for about 98 percent of all capital improvements on the Interstate System. This means that States are using virtually none of their other Federal (such as Primary System) or State-only funds for Interstate Resurfacing, Restoration, and Rehabilitation (I-3R) work. The updated pavement and bridge deck needs were estimated at $20.1 billion (in 1979 dollars) for the 10-year study period in comparison to the previous estimate of $18.5 billion (in 1975 dollars) for a 20-year period. Since the earlier study, in 1975, over $500 million has been obligated for 3R projects. Overall, the study indicates an average annual need of about $2.0 billion whereas the 1977 study showed an annual need of $0.9 billion (in 1975 dollars).

With these conditions, the financial situation all Government agencies are facing and the congressional direction we have, I believe you can see why the FHWA is very concerned about maintenance.

However, much more than concern is needed if we are to address the highway maintenance problem. We have become increasingly aware of the need to properly manage the highway systems themselves. This need we have categorized under the title of Pavement Management (PM), and have divided it into six major categories: planning, design, construction, maintenance, pavement monitoring and research.

Effective PM involves the use of feedback of information on pavement performance, pavement maintenance, pavement rehabilitation activities, and the cost of providing and maintaining pavements. Our goal must be to improve the process of coordinating and managing all activities related to pavements to reduce the life-cycle cost for providing and maintaining pavements in a serviceable condition.

Most States have adopted the concept of maintenance management to improve the productivity in highway maintenance through effective planning, scheduling, reporting, monitoring, and budgeting of maintenance activities. The States have developed the tool to use this management philosophy either internally with their own forces or through the expertise of a consultant.

Ongoing and Future Activities

The FHWA has over the years participated, at the request of the States, in research to develop maintenance management systems in order to increase maintenance productivity and utilize resources more efficiently. An effective Federal/State relationship in the area of highway maintenance has resulted principally due to the States' and FHWA's keen interest in improved management and the cooperative attitude both agencies have.

We are fortunate in that so many State highway agencies recognize that pavement maintenance can significantly affect pavement performance. The maintenance required to keep a pavement above some planned serviceability threshold is a measure of the effectiveness of pavement management in programming, design and construction quality. In this vein, maintenance activities and expenditures provide essential feedback into the programming, design, and construction of new pavements. Maintenance must be carefully planned and implemented to include proper reporting and easy data retrieval.

One of our most meaningful contributions to the systematic management approach to highway maintenance has been the introduction of the concept of Value Engineering. This concept is simply the systematic application of recognized techniques that identify the function of a product or service, establish a dollar value for that function, and reliably provide the necessary function at the lowest overall cost.

One of the major steps leading toward increased value-for-dollar maintenance techniques has been that of increased mechanization of maintenance in order to increase productivity. Multiple-use equipment has been introduced to reduce fleet sizes and it quickly became evident that keeping downtime to a minimum was the one way to ensure adequate return on investment.

Problems with downtime, which is actually maintenance time for the equipment, quickly gave rise to the equipment support system. Guided by input from the various State highway maintenance organizations, the FHWA awarded a research project concerning equipment management. The input from a dozen or so States was analyzed and a design manual for an equipment management system resulted.

On-site surveys of the equipment management and functions in 9 States included evaluation of existing systems and system elements and the documentation of management practices. Equipment managers and users at all levels were interviewed as part of the program to determine how to improve equipment management information and operations. On the basis of these surveys, common equipment management objectives, based on apparent levels of demand for equipment services, structures, or equipment cost, and opportunities for management improvement were established.

In other areas of maintenance research bridges, have come under detailed maintenance studies, and over the past 2 years we have been working with the AASHTO Highway Subcommittee on Maintenance in the development of a guide for bridge maintenance management. Its purpose is to provide a summary of current successful management techniques, bridge maintenance specifications and work standards that various State highway agencies use and it will provide guidance for all bridge maintenance personnel in managing the structure maintenance program. The concept of a preventive maintenance program for bridges is stressed in order to protect the costly capital investment.

As we have developed our maintenance management concept, we began to assist the States in promoting maintenance management through a program of process reviews for highway maintenance management. The objective of these process reviews is to evaluate the management process of the State highway agencies maintenance program to better understand the development of effective and adequate maintenance programs for highway facilities. To further demonstrate our interest in the management of highway maintenance by a systematic approach, FHWA headquarters and division offices have sent qualified representatives to various State highway departments to receive training in maintenance management with the intent of having these persons handle future process reviews.

Closing

I think you can see from what I have said that we in FHWA are vitally interested in all phases of this important subject-and these programs, and others that are planned, are but a part of our efforts to improve the maintenance management system and the quality of highway maintenance.

I am happy to note that the workshop will address many major issues of highway maintenance and I wish you a full and complete program. I expect that many of you will contribute as much to the discussions as you learn and that all of you will benefit from the sessions.

I feel confident this workshop will give you insight into techniques to maintain the management system. There is a great need to preserve the system with refinements due to the shortage of precious highway dollars. The results of this workshop should help all States to accomplish better and more cost effective maintenance.

A SYSTEMATIC PROCEDURE FOR THE DEVELOPMENT OF MAINTENANCE LEVELS OF SERVICE

Ram B. Kulkarni, Kamal Golabi, Fred N. Finn and
Rubin Johnson, Woodward-Clyde Consultants

One of the basic requirements for the proper management of highway maintenance activities is the establishment of maintenance levels-of-service, i.e., at what levels or conditions should a maintenance activity be initiated. A systematic methodology was developed for determining the maintenance levels-of-service that would maximize the user benefits subject to the constraints of available resources. This paper describes a demonstration of the methodology for two maintenance problems in a state.

The necessary inputs for the methodology were obtained from the data base of information currently available to the state transportation department. The data base included information available in the literature, studies conducted within the department, information available from maintenance management systems, and experience and judgment of knowledgeable individuals within the department. Results of the analysis produced levels-of-service that were intuitively satisfactory. Sensitivity analyses were conducted to determine the impact of conditions such as budget cuts and changes in the relative weights of different considerations on the determination of optimum levels-of-service.

While the demonstration phase of the project was limited to two problems, the results indicate that the methodology can work and should be implementable by state agencies.

Maintenance levels-of-service are defined as threshold conditions at which maintenance is considered to be needed. As such, these levels-of-service will influence work scheduling requirements, resource allocations and work priorities. Selection of the maintenance levels-of-service is influenced by a number of considerations such as safety, comfort, protection of investment, environmental impact, and aesthetics.

At the present time there is no systematic, structured procedure for establishing maintenance levels-of-service or to adjust such levels when resources are constrained or increased. Woodward-Clyde Consultants has completed a study for the National Cooperative Highway Research Program (NCHRP) to develop a methodology for establishing levels-of-service based on well documented principles of decision analysis.

The purpose of this report is to describe the methodology by means of a demonstration of the procedures for two maintenance problems in the state of Louisiana.

In order to facilitate the description of the procedures the following terminology has been established.

1. Maintenance Element - a part of the highway system that requires maintenance (e.g., traveled-way, roadside, drainage, traffic services).
2. Maintenance Condition - a deficient condition of a maintenance element that needs to be repaired or corrected (e.g., cracking and rutting--for traveled-way; grass growth and litter and debris--for roadside).
3. Maintenance Activity - work required to repair or correct a maintenance condition (e.g., filling--for cracking; mowing--for grass growth).
4. Level-of-Service (quality standard) - threshold deficiency level of a maintenance condition that should trigger an appropriate maintenance activity (e.g., grass should be mowed when it is 12 inches high; a drainage ditch should be cleaned when 50 percent of its area is blocked).
5. Considerations - the factors used in evaluating the performance of maintenance elements (e.g., safety, riding comfort, economics, aesthetics).
6. Attribute - a numerical scale for measuring the effect on a given consideration (e.g., frequency of accidents--for safety; roughness--for riding comfort).

Approach

The methodology to select maintenance levels-of-service involves the following steps:

1. Structuring the problem.
2. Estimation of the effects of alternative maintenance levels-of-service on various considerations (e.g., safety, aesthetics).
3. Evaluation of the effects of alternative maintenance levels-of-service.

4. Determination of the optimum combination of maintenance levels-of-service.
5. Sensitivity analysis.
6. Recommendations.

A computer program ASOP (acronym for Algorithm for the Selection of Optimum Policy) has been written for implementation of all calculations required by the methodology.

Structuring the Problem

The following tasks are involved in structuring the problem:

1. Select maintenance elements (e.g., shoulders, pavement).
2. Select maintenance conditions (e.g., edge of traveled-way drop-off) for each maintenance element (e.g., shoulders).
3. Specify alternative levels-of-service for each maintenance condition.
4. Select considerations (e.g., safety) for each maintenance element (e.g., shoulders).
5. Select attributes (e.g., percentage of drivers who cannot recover) for various considerations (e.g., safety).
6. Identify the maintenance conditions (e.g., edge of traveled-way drop-off) which affect each attribute (e.g., percentage of drivers who cannot recover).

The implementation of the above tasks in Louisiana is described below.

Select Maintenance Elements

For the demonstration example, two maintenance elements--shoulders and roadside vegetation--were analyzed.

Select Maintenance Conditions for Each Maintenance Element

For shoulders, the edge of traveled-way drop-off is the maintenance condition of concern.

For roadside vegetation, the maintenance conditions of concern may include grass growth, weed growth, and brush and tree growth. The discussions with the Louisiana landscape specialist indicated that a combined mowing and herbicide spraying program is used for the maintenance of roadside vegetation.

Select Alternative Levels-of-Service for Each Maintenance Condition

The following procedure can be used to generate alternative levels-of-service. The department specialists for a given maintenance condition are asked to assume that there are no constraints of resources (dollars, manpower, etc.) for the particular maintenance condition under consideration. How would the specialists improve the level-of-service for that condition? Discussion of this question would provide a level-of-service which is generally higher than the current level-of-service used by the agency. Next, the specialists are told that there are moderate and severe budget cuts, successively for the maintenance condition. In order to accommodate the budget cuts, a reduced level-of-service would have to be adopted. How would the agency reduce the level-of-service in each case? Responses to this question would generate two levels-of-service which are generally lower than the current level-of-service. If it is meaningful in practice, some intermediate levels-of-service may also be considered.

At the conclusion of this step, a spectrum of alternative levels-of-service ranging from the highest (ideal) to the lowest (barely tolerable) are generated. Table 1 shows the alternative levels-of-service selected for edge of traveled-way drop-off and vegetation growth.

Table 1. Alternative levels-of-service for maintenance conditions of given maintenance elements.

Maintenance element	Maintenance conditions	Alternative levels-of-service
Shoulders	Edge of traveled-way drop-off	(1) Repair when drop-off is 1-inch. (2) Repair when drop-off is 2 inches. (3) Repair when drop-off is 3 inches. (4) Repair when drop-off is 4 inches. (5) Repair when drop-off is 5 inches.
Roadside Vegetation	Vegetation growth	(1) Mow 500,000 acres and spray 120,000 acres annually. (Mow full right-of-way before grass reaches 8 inches.)
		(2) Mow 300,000 acres and spray 120,000 acres annually. (Urban area: mow full width before grass reaches 8 inches. Rural area: mow 30 feet from edge of traveled surface after grass exceeds 12 inches.)
		(3) Mow 200,000 acres and spray 60,000 acres annually. (Urban area: mow full width after grass exceeds 18 inches. Rural area: mow one machine pass after the grass exceeds 18 inches.)
		(4) Mow 150,000 acres and spray 60,000 acres annually. (Mow for safety only.)

For edge of traveled-way drop-off, the alternative levels-of-service were specified in terms of the threshold amount of drop-off at which a shoulder should be repaired.

For roadside vegetation growth, the current maintenance practice in Louisiana consists of a combined mowing and herbicide spraying program. It was, therefore, appropriate to consider alternative levels-of-service in terms of increased or decreased amounts of mowing and spraying. Appropriate combinations of numbers of acres mowed and numbers of acres sprayed were selected in consultation with the department specialists to represent four alternative levels-of-service for controlling roadside vegetation. For a proper understanding and implementation of the levels-of-service in the field, it was also necessary to specify for each level-of-service the threshold height at which grass would be mowed and the width of mowing. Since urban and rural areas present different roadside environments, different provisions for these areas were made under each level-of-service.

Table 1 shows the alternative levels-of-service for roadside vegetation both in terms of (1) number of acres mowed and sprayed and (2) threshold height of grass and width of mowing for urban and rural areas.

Select Considerations for Each Maintenance Element

Considerations are the factors which affect highway users through the choice of maintenance levels-of-service for a given maintenance element. With regard to maintenance of shoulders, safety and preservation of investment appear to be the pertinent considerations. Aesthetics and environmental pollution are the appropriate considerations with regard to roadside vegetation maintenance. It should be noted that even though economics (maintenance cost) is an important consideration, it is viewed as a constraint on the system rather than as a user-related consideration.

Select Attributes for Various Considerations

An attribute is a numerical scale for measuring the effect of alternative maintenance levels-of-service on a given consideration. Table 2 lists the attributes of various considerations for each maintenance element.

Table 2. Considerations, attributes, and maintenance conditions affecting each attribute.

Maintenance element	Considerations	Attributes	Maintenance conditions affecting an attribute
Shoulders	Safety	Percentage of drivers who cannot recover	Edge of traveled-way drop-off
	Protection of investment	Percent change in pavement rehabilition cost	Edge of traveled-way drop-off
Roadside vegetation	Aesthetics	Index of pleasing appearance (4-point scale)	Vegetation growth
	Ecology	Index of environmental pollution (4-point scale)	Vegetation growth

Identify the Maintenance Conditions Which Affect Each Attribute

The maintenance conditions affecting each attribute are shown in Table 2.

Estimation of Effects of Alternative Maintenance Levels-of-Service on Various Considerations

The effect of alternative maintenance levels-of-service on a given consideration (e.g., safety) is estimated in terms of the attribute of the consideration (e.g., percentage of drivers who cannot recover). The effects were estimated in Louisiana by interviewing the department specialists for given attributes. To assist the specialists in the estimation, pertinent information and data available in the literature were reviewed with the specialists.

Because of limitations and applicability associated with information in the literature it was concluded that this source could not be used directly to establish the effects or impact of levels-of-service on pertinent considerations. Based on these conclusions, the specialists were asked to extrapolate the available information to the real-world situation, based on their experience and judgment.

Percentage of Drivers Who Cannot Recover

Assessment of the percentage of drivers who cannot recover for given amounts of edge of traveled-way drop-off was done in two steps:

1. What percentage of drivers will encounter the drop-off problem (i.e., accidentally drive over the edge of the traveled-way)?
2. Of the drivers who encounter the problem, what percentage would not be able to make a normal recovery?

Table 3 shows the results of the assessments. It is acknowledged that some of the estimates may be high. More time and background information would be necessary to improve on these estimates of the impact of various levels-of-service. The methodology, per se, would not be affected by any changes in these estimates.

Table 3. Effect of alternative levels-of-service of edge of traveled-way drop-off on percentage of drivers who cannot recover.

Threshold amount of edge of traveled-way drop-off	Percentage of drivers who drive over the edge of traveled-way	Percentage of drivers who cannot recover if they drive over the edge of traveled-way	Percentage of drivers who cannot recover
	(a)	(b)	(c = ab/100)
1"	15	0.01	0.0015
2"	14	0.5	0.07
3"	13	15	1.95
4"	12	55	6.60
5"	10	90	9.0

Percent Change in Pavement Rehabilitation Cost

High levels of allowable drop-off at the edge of the traveled-way may require extra preparation work on the edge of the pavement at the time an overlay is applied. No quantitative information was found in the literature to indicate the influence of edge of traveled-way drop-off on the change in pavement rehabilitation costs. Therefore, the specialists had to rely on their experience and judgment to estimate the amount of additional pavement work required prior to an overlay as a function of the amount of edge of traveled-way drop-off.

Table 4 shows the assessment of percent change in pavement rehabilitation cost for various amounts of edge of traveled-way drop-off.

Index of Pleasing Appearance

The alternative levels-of-service for roadside vegetation define a 4-point scale for the index of pleasing appearance. It is reasonable to assume that the levels-of-service incorporating higher amounts of mowing and spraying would enable the maintenance engineer to provide a more pleasing appearance to the roadside.

Table 4. Effect of alternative levels-of-service of edge of traveled-way drop-off on percent change in pavement rehabilitation cost.

Threshold amount of edge of traveled-way drop-off	Percent change in pavement rehabilitation cost
1"	0
2"	1
3"	5
4"	12
5"	15

Index of Environmental Pollution

The potential for environmental pollution is a function of the amount of herbicide spraying. The alternative levels-of-service for roadside vegetation, which specify the number of acres sprayed with herbicides, define a 4-point scale for the index of environmental pollution.

Evaluation of the Effects of Alternative Maintenance Levels-of-Service on Various Considerations (E.g., Safety, Aesthetics)

The objective of this step is to establish a preference (value) structure for evaluating the effects of alternative levels-of-service on various considerations, such as safety, aesthetics, etc. The effects on the considerations are measured in terms of the selected attributes. For example, for edge of traveled-way drop-off the effect of level-of-service on safety is measured in terms of the percentage of drivers who cannot recover.

The assessment of preferences involves two steps:

1. Assessing individual value functions of different attributes. The objective of this step is to determine how much better (or worse) one level of an attribute (e.g., percentage of drivers who cannot recover = 5) is relative to another (e.g., percentage of drivers who cannot recover = 10). This assessment is best done by those individuals in a state agency who are most knowledgeable with regard to a given attribute.
2. Assessing value tradeoffs between different attributes. If a decision problem involves multiple attributes and limited resources, it may not be possible to achieve the best levels of all the attributes. The decision maker, therefore, is required to think about how much he/she may be willing to sacrifice on one attribute (e.g., aesthetics) in order to improve another (e.g., change in rehabilitation cost). These value tradeoffs determine the relative weights of the attributes. The assessment of value tradeoffs should involve individuals who are responsible for setting and implementing maintenance levels-of-service.

The first step was completed during meetings with the department specialists with regard to edge of traveled-way drop-off and roadside vegetation control. The second step was completed during a group session which involved maintenance engineers from both headquarters and the district offices. The details of the specialists' meetings as well as the group session are provided below.

Assessing Different Drop-Off Attributes With Specialists

The objective of these meetings was to assess relative values of different levels of the attributes relevant to edge of traveled-way drop-off. The attributes were: percentage of drivers who cannot recover and percent change in pavement rehabilitation costs.

A general procedure used in assessing relative values of an attribute involves the following steps:

1. A range for an attribute is selected such that it would contain the highest and the lowest assessed levels of the attribute. For example, the attribute "percentage of drivers who cannot recover" had highest and lowest assessed levels of 9 and 0.0015, respectively (see Table 4). A range of 0 to 10 was, therefore, chosen for this attribute. Similarly, an appropriate range for "percent change in pavement rehabilitation cost" was 0 to 35.
2. The end-points of the range of an attribute are assigned arbitrary values, a common choice being 0 and 1. Then, a midvalue point on the range of the attribute is assessed. To illustrate this procedure, consider the attribute "percentage of drivers who cannot recover." We denote this attribute by θ_1 and its value function by $V_1(.)$. Values of 0 and 1 are assigned to the end-points of θ_1. Noting that lower levels of θ_1 are more desirable, we get

$$V_1(10) = 0 \text{ and } V_1(0) = 1.$$

Now, we want to assess a point, say θ_1^*, which has a value of 0.5; i.e., θ_1^* is the midvalue point on the range of θ_1.

To do this, different levels of θ_1 are successively proposed to the specialist. The specialist is asked to examine a given level of θ_1 and judge whether that level divides the total range of θ_1 into two parts, each having the same value. The analyst attempts to bracket the midvalue point by approaching it from both ends. For example, one can start with $\theta_1 = 1$. The specialist is asked: "Which is better--decreasing the percentage of drivers who cannot recover from 10 to 1 or decreasing it from 1 to 0?" Let us say the specialist indicates that decreasing the attribute from 10 to 1 is better. Next, $\theta_1 = 9$ is proposed. The question is asked: "Which is better--decreasing the percentage of drivers who cannot recover from 10 to 9 or decreasing it from 9 to 0?" The specialist may say that decreasing the attribute from 9 to 0 is better. By systematically varying the proposed levels of the attribute, one can zero in on the midvalue point, θ_1^*.

3. The end points and θ_1^* provide three points on the value function $V_1(.)$. Additional points may be assessed by dividing each of the two ranges, 0 to θ_1^* and θ_1^* to 10, into two equal value parts. A smooth curve can be drawn through the end points and the assessed intermediate points. A mathematical equation can be derived to best fit this curve. This equation represents the individual value function $V_1(.)$ for θ_1. The computer program ASOP automatically fits a quadratic value function, given the end points and the midvalue point for an attribute. The form of the function is

$$V_i(\theta_i) = a + b\theta_i + c\theta_i^2.$$

Using the above procedure in Louisiana, the individual value functions for the following attributes were assessed:

θ_1 = percentage of drivers who cannot recover.
θ_2 = percent change in pavement rehabilitation cost.

Both the value functions were linear. This implies that a change in the same magnitude in the attribute anywhere in its range has the same value.

Assessing Different Roadside Vegetation Attributes With Specialists

The objective of these meetings was to assess the individual value functions for the following attributes:

θ_3 = index of pleasing appearance.
θ_4 = index of environmental pollution.

Both roadside vegetation attributes are represented on a 4-point discrete scale. Each point is associated with an alternative maintenance level-of-service (see Table 1). The procedure for assessing midvalue points discussed previously is not practical in the case of an attribute represented on a discrete scale with a limited number of points. The reason is that none of the points on the scale may provide a midvalue point. An alternative procedure, based on the concept of willingness to pay, was used.

To illustrate this procedure, consider the index of pleasing appearance. The participants were asked how much more they would be willing to pay in order to improve the index of pleasing appearance from its lowest level (number of acres mowed = 150,000; number of acres sprayed = 60,000) to each of the other levels. Following some discussion, the response of the participants was that they would be willing to pay 50 percent more to go to Level 3 and 200 percent more to go to Level 2. With regard to Level 1, the specialists did not see much benefit in moving from Level 2 to Level 1, and hence were willing to pay very little to go from Level 2 to Level 1. However, it was indicated that other individuals in the department, particularly those at the district level, might respond differently about going from Level 2 to Level 1. For this reason, it was decided to obtain group consensus on this question of how much one would be willing to pay to increase the maintenance level-of-service from Level 2 to Level 1. The group session, which is discussed in the next section, indicated that the group would be willing to pay about 8 percent more to go from Level 2 to Level 1.

The above assessments provided relative values of the four levels of the index of pleasing appearance (θ_3). Letting $V_3(i)$ denote the value of the i^{th} level, we get

$$V_3(3) = 1.5\ V_3(4)$$
$$V_3(2) = 3\ V_3(4)$$
$$V_3(1) = 3.08\ V_3(4).$$

If $V_3(4)$ is set to 1, the other relative values would be: $V_3(3) = 1.5$, $V_3(2) = 3$ and $V_3(1) = 3.08$. Since the end points of a value function were assumed to be 0 and 1, a linear transformation of the relative values was made by subtracting the minimum value (i.e., 1) and dividing by the range (i.e., 2.08).

Thus, the relative values are:

$$V_3(1) = 1;\ V_3(4) = 0$$
$$V_3(2) = \frac{3 - 1}{3.08 - 1} = 0.96$$

and

$$V_3(3) = \frac{1.5 - 1}{3.08 - 1} = 0.24$$

With regard to the index of environmental pollution (θ_4), the specialists were asked: "How much would it be worth to reduce the number of acres sprayed from the highest level (defined as 150,000) to each of the other two levels (120,000 and 60,000)?" Assuming the cost of the highest level to be 100 units, the response of the specialists was that, from the viewpoint of reducing pollution, it would be worth 15 and 30 units, respectively, to reduce the amount of spraying from the highest level to Levels 2 and 3. This yielded the following relative values of the levels of θ_4:

$$V_4(2) = 1.15\ V_4(1)$$
$$V_4(3) = 1.30\ V_4(1).$$

Since the fourth level (see Table 2) involves the same number of acres sprayed as the third level, it follows that $V_4(4) = V_4(3)$. By assigning the values of 0 and 1 to the end points of the scale, we get

$$V_4(1) = 0;\ V_4(2) = \frac{1.15 - 1}{1.30 - 1} = 0.5$$
$$V_4(3) = \frac{1.3 - 1}{1.3 - 1} = 1 = V_4(4).$$

The results of assessment of individual value functions are summarized in Table 5.

Table 5. Assessment of individual value functions of various attributes.

Attribute	Best level	Worst level	Midvalue point for a continuous attribute	Values of intermediate levels for a discrete attribute
1. Percentage of drivers who cannot recover	0	10	5	--
2. Percent increase in pavement rehabilitation cost	0	35	17.5	--
3. Index of pleasing appearance	1	4	--	Value of level 2 = 0.96 Value of level 3 = 0.24
4. Index of environmental pollution	4	1	--	Value of level 2 = 0.5 Value of level 3 = 1.0

Group Session for the Assessment of Value Trade-offs

The specifications of a value function over multiple attributes requires the assessment of trade-offs between competing attributes based on the value judgments of decision makers. In public policy decisions, a number of individuals may share the responsibility of deciding acceptable tradeoffs. It would, therefore, seem desirable that value judgments of decision makers be somehow "pooled" to obtain a "group consensus" that would be used in lieu of the opinion of any one individual. It is generally assumed that group consensus would have greater validity than individual value judgments in the assessment of tradeoffs. The technique used for trying to obtain group consensus values was the Delphi procedure.

The Delphi group sessions included eight individuals within the Louisiana Department of Transportation and Development who were involved in establishing current levels-of-service.

The sessions included a period of orientation during which pertinent background information was discussed. The procedures were explained and illustrative examples were acted out for the group.

Assessment Forms. Three assessment forms were used in the group sessions.

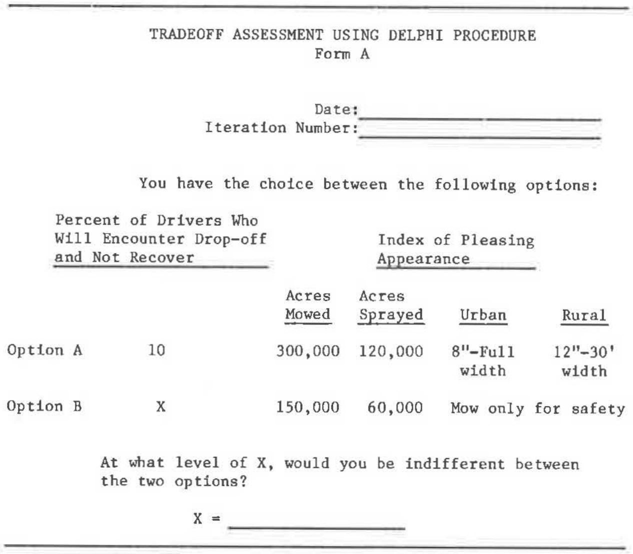
Form A: assessment of tradeoff between percentage of drivers who cannot recover and index of pleasing appearance.

Form B: assessment of tradeoff between percent change in pavement rehabilitation cost and index of pleasing appearance.

Form C: assessment of tradeoff between percentage of drivers who cannot recover and index of environmental pollution.

A blank copy of assessment Form A is shown in Figure 1.

Figure 1. Form A.



TRADEOFF ASSESSMENT USING DELPHI PROCEDURE
Form A

Date: ________________
Iteration Number: ________________

You have the choice between the following options:

	Percent of Drivers Who Will Encounter Drop-off and Not Recover	Index of Pleasing Appearance			
		Acres Mowed	Acres Sprayed	Urban	Rural
Option A	10	300,000	120,000	8"-Full width	12"-30' width
Option B	X	150,000	60,000	Mow only for safety	

At what level of X, would you be indifferent between the two options?

X = ____________

The results from the group sessions are summarized in Table 6.

Determination of the Optimum Combination of Maintenance Levels-of-Service

The objective of this step is to find the optimum combination of maintenance levels-of-service for all of the maintenance conditions included in the system. The criterion used for optimization is to maximize the overall value of highway user benefits subject to the constraints of available resources (dollars, person-days, etc.). The user benefits are specified in terms of the effects of levels-of-service on various considerations, such as safety, aesthetics, and protection of investment. The effects on these considerations are measured by the appropriate attributes, such as percentage of driver who cannot recover, index of pleasing appearance, and percent change in pavement rehabilitation cost.

Table 6. Consensus value tradeoffs between different pairs of attributes.

	Percentage of drivers who cannot recover		Index of pleasing appearancex	
Option A	10	Balancing Reward	1	Penalty
Option B	5.9		4	
	Percent increase in pavement rehabilitation cost		Index of pleasing appearance	
Option A	35		1	
Option B	15.4		4	
	Percentage of drivers who cannot recover		Index of environmental pollution	
Option A	10		4	
Option B	8.6		1	

Optimization Program

Mathematically the optimization problem is formulated as follows:

Let X_{ij} denote a binary variable such that

X_{ij} = 1 if the j^{th} alternative level-of-service (e.g., repair when edge of traveled-way drop-off is 2 inches) is selected for the i^{th} maintenance condition (e.g., edge of traveled-way drop-off).

= 0 if the j^{th} alternative level-of-service is not selected.

The objective of the analysis is to determine X_{ij} for all i and j to maximize $V(\theta_1,\theta_2,\ldots,\theta_n)$ subject to the following constraints:

$$\sum_i \sum_j C_{ij}X_{ij} \le \text{available budget, } B$$

$$\sum_i \sum_j M_{ij}X_{ij} \le \text{available person-days, } M$$

$$\sum_j X_{ij} = 1$$ (Only one of the alternative levels-of-service for each maintenance condition is to be selected.)

in which C_{ij} = cost of implementing the j^{th} level-of-service for the i^{th} maintenance condition, and

M_{ij} = person-days required for implementing the j^{th} level-of-service for the i^{th} maintenance condition.

A nonlinear integer programming algorithm has been developed to solve the above optimization problem. The algorithm has been coded in the computer program ASOP.

Estimation of Attribute Levels. The following estimation model is used in the program:

$$\theta = \sum_i \sum_j B_{ij} X_{ij}$$

in which θ = an attribute

X_{ij} = 1 if the j^{th} level-of-service for the i^{th} maintenance condition is selected.

= 0 if the j^{th} level-of-service is not selected.

B_{ij} = coefficient which estimates the incremental effect of X_{ij} on θ.

The first summation in the above equation is over all the maintenance conditions which affect θ, and the second summation is over all alternative levels-of-service for each of these maintenance conditions.

For the demonstration example in Louisiana, each attribute is affected by only one maintenance condition. Percentage of drivers who cannot recover (θ_1) and percent change in pavement rehabilitation cost (θ_2) are affected only by edge of traveled-way drop-off. Similarly, index of pleasing appearance (θ_3) and index of environmental pollution (θ_4) are affected only by roadside vegetation growth.

Program Output

The program output consists of the following parts:

Print Input Data. All input data are printed so that the accuracy of the data can be checked and information useful in evaluating the results is readily available.

Print Parameters of Value Function. The program computes the constants of the value function for each attribute in a quadratic form. These constants are printed.

The tradeoff information is used to calculate the scaling constants (relative weights) of different attributes. The scaling constants are also printed.

Print Estimation Coefficients. The estimation coefficients, B_{ij} are printed for each attribute.

Print Results of Base Case Analysis. The output describes the optimum solution, i.e., the level-of-service which should be adopted for each maintenance condition so as to maximize overall value (to highway users) while satisfying the resource constraints. The actual resources required to implement the optimum solution are displayed. The overall value of the optimum solution (on a scale of 0 to 1) is printed along with the contributions of the various attributes to the overall value.

Results of Base Case Analysis

Figure 2 shows the results of the base case analysis included in the program output. The optimum levels-of-service are:

1. Repair when edge of traveled-way drop-off is 1-inch.
2. Mow 300,000 acres and spray 120,000 acres. (This vegetation control program would allow mowing grass full width before it reaches 8 inches in urban areas and mowing grass 30 feet from the edge of the traveled surface after it exceeds 12 inches in rural areas.)

Figure 2. Results of the base case analysis.

```
Complete Enumeration

The selected policy is:

Edge of traveled-way drop-off      Repair when drop-off is 1-inch.
Vegetation growth                  Mow 300,000 acres and spray
                                     120,000 acres.

                     Costs of the Selected Policy

Materials (thousands of dollars)   Available - 5130, used - 5130
Thousands of Labor-Hours           Available - 644, used -  644
Equipment (thousands of dollars)   Available - 3380, used - 3377

                     Evaluation of the Attributes

Safety--percent of drivers who cannot recover
Individual value - 1.000           Weighted value -  .438

Percent change in rehabilitation costs
Individual value - 1.000           Weighted value -  .321

Pleasing appearance
Individual value - 0.962           Weighted value - 0.173

Environmental pollution
Individual value - .500            Weighted value -  .031

                  THE VALUE OF THIS POLICY IS 0.96
```

The levels-of-service currently used in Louisiana for the two maintenance conditions are also the optimum levels-of-service selected by the program. This was to be expected because only a few variables had to be considered for the example, the analysis assumed the resources currently used for the two maintenance conditions, and the value judgments of those involved in setting the current levels-of-service were used. The strength of the methodology is that it will consistently select optimum levels-of-service when a large number of maintenance conditions were analyzed and when changes in the current maintenance budget become necessary. The overall value of the optimum solution is 0.96. The optimum levels-of-service provide the highest user benefits possible for the two maintenance conditions. No improvement in these levels-of-service would be possible even if higher amounts of resources were available. An examination of the contributions of the four attributes to the overall value reveals that the two attributes related to edge of traveled-way drop-off (percentage of drivers who cannot recover and percent change in rehabilitation cost) contribute 79 percent of the total value, while the remaining 21 percent of the total is contributed by the roadside vegetation attributes.

Sensitivity Analysis

The objective of this step is to assess the influence of changes in some of the major inputs and assumptions on the selection of the optimum combination of levels-of-service. The output of this analysis would identify the parameters to which the selection of optimum levels-of-service is very sensitive. The assessment of such parameters would obviously warrant more careful consideration.

The computer program ASOP has been designed to perform the following types of sensitivity analyses when requested by the user:

1. Effect of Changes in Available Resources. Available amounts of one or more resources may be changed and the effect on optimum levels-of-service may be examined.
2. Changes in Tradeoffs. The tradeoffs used in the base case analysis represent group consensus values obtained in the Delphi procedure. These tradeoffs yield the relative weights of various attributes. If significant differences of opinions were observed during the group session, different tradeoffs between attributes may be used in finding optimum levels-of-service. If the effect on optimum levels-of-service is significant, the differences in opinions are clearly critical and need to be resolved before levels-of-service can be selected.
3. Mandatory Inclusion of Specified Levels-of-Service. For certain important maintenance conditions, relatively high levels-of-service may be required; for example, the edge of traveled-way drop-off may be required to be less than 1-inch. The program can fix such levels-of-service and optimize on the remaining maintenance conditions.
4. Mandatory Exclusion of Specified Levels-of-Service. Certain levels-of-service may be considered to be impractical or infeasible. For example, with respect to edge of traveled-way drop-off, the lowest level-of-service (repair when drop-off is 5 inches) may be excluded from the analysis. The program will eliminate such a level-of-service from the search for the optimum solution.
5. Exclusion of Best Solution. This option would find the second best solution. If the value of this solution is nearly as good as that of the best solution, but the resources required for the second best solution are significantly lower than those required for the best solution, then the second best solution may be preferred.

In conducting the sensitivity analyses for the demonstration example in Louisiana, advantage can be taken of the fact that none of the attributes is simultaneously affected by both the maintenance conditions. Consequently, it is possible to determine the complete contribution of a given level-of-service of each maintenance condition to the overall value. The results are shown in Figure 2.

Recommendations

Recommendations are formulated after evaluating the results of the base case and the sensitivity analyses. The recommendations should include the following:

1. The optimum level-of-service for each maintenance condition in the system.
2. Resources which would be used in implementing the optimum levels-of-service.
3. Scenarios (e.g., budget cuts) which would require significant changes in the optimum levels-of-service.

Conclusions

The effort in Louisiana shows that it is feasible to use the methodology developed in this project to select levels-of-service for highway maintenance which would maximize user benefits subject to the constraints of available resources. The types of inputs required for the analysis can be obtained from the data base of information currently available to a state transportation department. The data base includes information available in the literature, studies conducted within the department, information available from maintenance management systems, and experience and judgment of knowledgeable individuals within the department.

The methodology requires the assessment of value judgments regarding tradeoffs between different considerations, such as safety, protection of investment, aesthetics, and environmental pollution. A Delphi procedure was used in Louisiana to obtain group consensus regarding tradeoffs from a number of individuals responsible for selecting levels-of-service both in the field and at headquarters. Certain improvements in the implementation of the Delphi procedure would seem desirable based on the experience in Louisiana. However, the types of assessment questions which need to be asked in the Delphi procedure are certainly practical and relevant to individuals involved in highway maintenance.

It would be desirable to provide certain types of objective data to the participants in the Delphi exercise in order to obtain more consistent and reliable value judgments. Examples of such data include statistics on accidents resulting from driving over the edge of traveled-way with various amounts of drop-off and surveys of user opinions regarding aesthetics of roadside vegetation under varying levels-of-service. These kinds of data are currently not available. The initial implementation of the methodology will identify the critical parameters on which objective data would be most useful. Limited studies to collect these data can be undertaken. The reliability of the results of the methodology would be expected to increase with the availability of additional data.

The computer program prepared for the use of the methodology facilitates the analysis significantly. The program is designed such that the assessed data can be directly input and all parameters (such as value coefficients, relative weights, and regression coefficients) are computed internally in the program. This relieves the user of the burden of making external calculations, which would require some theoretical background in decision analysis techniques.

The demonstration example in Louisiana involved only two maintenance conditions--namely, edge of traveled-way drop-off and roadside vegetation growth. The complete system of highway maintenance could involve 20 to 25 maintenance conditions of practical significance.

Acknowledgements

This study was conducted under the National Highway Research Program, Project 14-5. The opinions and findings expressed or implied in this paper are those of the authors. They are not necessarily those of the Transportation Research Board, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, nor the individual participating states.

The authors wish to acknowledge the efforts of the Louisiana Department of Transportation and Development for their assistance in the demonstration phase of the project. Special thanks are extended to Mr. Gerald Ray for his assistance.

The NCHRP Project Engineer was Mr. Ian Kingham and the authors wish to express their appreciation for his encouragement and advice during the project.

Mr. Ezio Alviti and Mr. Fereidoon Sioshansi assisted in various parts of the project and their efforts are hereby acknowledged.

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ENGINEERED PERFORMANCE STANDARDS

Marshall L. Stivers, P.E., Florida Department of Transportation

Maintennace Management was adopted by most states because it provided managers with the ability to plan, organize, direct and control maintenance activities. Although Florida's system has significantly advanced since its implementation, we still were concerned about our inability to consistently verify our performance standards. These standards were initially established and modified each year based on subjective judgment resulting in considerable and often non-conclusive discussion. Realizing that Performance Standards are the basic building block of a properly functioning Maintenance Management System (MMS), we decided to seek professional assistance. In 1974 we entered into a research contract with the University of Florida Industrial Engineering Department to develop a method of analyzing maintenance crew activities to be used to create "Engineered Standards". The final product of the research developed a method utilizing motion pictures supplemented with stopwatch times. The results of this type of analization enables an observer to determine the actual percentage of time each worker was engaged in productive work. Using this process, a standards committee can not ascertain the correct blend of resources required to perform an activity and has resulted in assigning unused workers to other tasks. Generally this analysis produces an increase in productivity which was our desired goal and at the same time it has improved the credibility of Maintenance Management with all levels of management.

Most states adopted a Maintenance Management System (MMS) because it provided managers with the ability to plan, organize, direct and control maintenance activities. While many variations of Maintenance Management Systems exist, most accomplish the same basic function of providing managers with a timely overview of field operations. In spite of occasional short term setbacks in MMS development, the Florida Department of Transportation has significantly advanced its reliability since implementation. This implementation, which began in 1973, was the result of an opportunity to study, develop, and design our own system using in-house personnel. Not only did this opportunity provide a custom-made system, its developers retained a familiarity of the system enabling them to continue improving the benefits received. However, throughout this process, we were concerned with our inability to consistently verify performance standards to any degree of certainty.

Initially our Standards were established using subjective judgements and were confirmed by field reports of crew operations. Periodic adjustments to these standards were also based on subjective judgement which oftentimes results in considerable and sometimes non-conclusive discussion. It soon became apparent that without a clear cut scientific method of determining an accurate standard, our entire MMS was lacking.

Realizing that Performance Standards are the basic building block of a properly functioning MMS, we began to investigate the "State of the Art" in other states. The response to our inquiries led us to the conclusion that other states had not developed a procedure to produce the desired results either. Their responses did, however, verify our earlier conclusion that the development of such a procedure was indeed possible. The traditional time-and-motion studies, which we currently utilized, not only were costly and time consuming, they also did not readily lend themselves to developing credibility with most Department of Transportation managers. At this point we convinced top management to allow us to develop a methodology to analyze maintenance crew activities. With their approval we decided to seek professional assistance in the art of Methods Engineering.

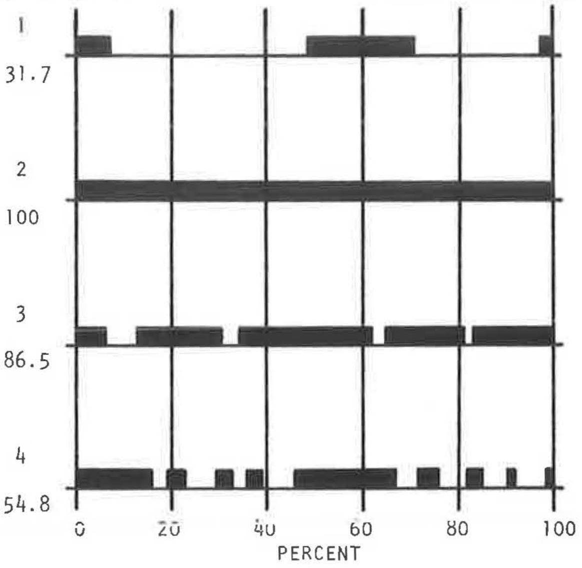
In 1974, we entered into a research contract with the University of Florida's Industrial Engineering Department to develop a method for analyzing maintenance crew activities. The end result of this method would be to create "Engineered Standards". This research finalized a procedure which recommended the extensive usage of a movie camera supplemented by stopwatch timing as used in time-in-motion studies. The results of this type of analyzation enabled observers to determine the actual percentage of time each worker was engaged in productive work and also provided a training medium for crews, supervisors and performance standards development committees.

The "Engineered Standard" study procedure requires two persons, a clipboard, a stopwatch, a 16mm movie camera and projector, a movie film editor and a film splicer. With these resources, plus transportation, the majority of maintenance operations can be studied. Normally each work activity consists of a series of basic cycles which are repeated several times at different locations during the workday. A crew study requires only the observations of a complete cycle and not the entire daily operation. While some inefficiencies may exist outside of the work cycles, the primary goal of the observer is to determine the labor, equipment and materials required to perform each cycle. The number of cycle observations required must be sufficient to provide a statistical pattern, normally this is a minimum of ten (10) and a maximum of fifty (50) observations.

To perform a cycle observation with a study team the following procedure is used:

1. Designate one individual to operate the stopwatch and clipboard; the other person will operate the movie camera.
2. As the work cycle begins the stopwatch is started and the clipboard operator begins a time-and-motion study. When the action becomes too fast to take hand notes or if the work method should be recorded for later reviewing, the camera operator will begin filming. At this time the camera operator advises the stopwatch operator who stops his hand note procedure and notes the time filming began. When the filming ends, the stopwatch operator notes and enters the time and resumes taking hand notes until the end of the cycle. Each cycle may require several starts and stops of the filming. This method not only saves money, when compared to continuous filming, it also provides a detailed record of the operations.
3. Combine stopwatch and clipboard observations onto Multiple Man (Crew) Activity Chart. Table 1 is an example of a four man pavement symbols crew observation.
4. Produce Activity Graphs using Activity Chart data. Table 2 is an example of the same four man pavement symbols crew. The heavy line indicates when a worker is busy or performing necessary work. By observation you can see the percentage of time when each worker is busy during the cycle and conversly you can determine when no productive effort is evident. These percentages are totaled and shown as a composite for the crew. In this case, to accomplish the cycle a four (4) man crew utilized approximately 273% of the 400% of available time. (Four (4) men times 100% = 400%)

Table 2



TOTAL TIME: Busy = 273.0%
Idle = 127.0%

After fifteen (15) observations of the same operation, the average busy time dropped to 214% out of a possible 400%. Further analysis determined that two (2) men performed the cycle operations as fast as the four (4) man crew and required less man-hours to accomplish each cycle. Based on these observations, a determination was made to establish two (2) man work crews for this activity for experimental purposes. These crews were allowed to develop their own working procedures and after a short adjustment period the crew study group performed observations of similar work cycles. Tables 3 and 4 show the Multiple Man Activity Chart and the Activity Graph for a two (2) man crew performing the identical operations in the same locations used to develop the information shown in Tables 1 and 2. Note that the total busy time for the two (2) man crew is 184% out of a possible 200% available.

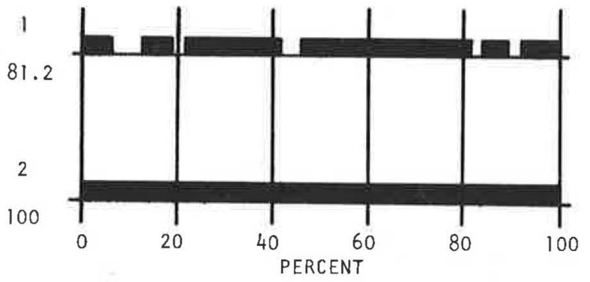
TABLE I - MILTIPLE MAN (CREW) ACTIVITY CHART - ACTIVITY NUMBER 532

First Worker		Second Worker		Third Worker		Fourth Worker	
Name:	Smith	Name:	Brown	Name:	Jones	Name:	White
Title:	Foreman II	Title:	Tech II (Painter)	Title:	Tech II (Beads)	Title:	Tech II (Template)
Run Time	Activity	Run Time	Activity	Run Time	Activity	Run Time	Activity
0.20	Place Cone	0.34	Start Comp.	0.28	Get Beads	0.40	Get Template
0.29	Idle	0.51	Remove Wand	0.60	Idle	0.59	Idle
0.91	Adjust Air	0.57	Begin Painting	0.97	Sprinkle Beads	0.68	Get Template
1.00	Idle	0.90	Idle	1.10	Place Template	0.78	Idle
1.40	Ajust Air	1.05	Painting	1.18	Sprinkle Beads	1.01	Move Template
1.46	Idle	1.52	Idle	1.51	Idle	1.18	Idle
2.50	Load	1.60	Walking	1.65	Walking	1.46	Move Template
2.72	End	1.67	Painting	1.80	Sprinkle Beads	1.66	Idle
		1.85	Idle	1.89	Idle	1.87	Move Template
		2.01	Painting	2.08	Move Template	1.95	Idle
		2.38	Loading	2.37	Sprinkle Beads	2.39	Move Template
		2.72	End	2.49	Idle	2.50	Load
				2.55	Loading	2.72	End
				2.72	End		

TABLE 3 - MULTIPLE MAN (CREW) ACTIVITY CHART
ACTIVITY NUMBER 532

First Worker		Second Worker	
Name:	Smith	Name:	Jones
Title:	Foreman II	Title:	Maint. Tech. II
Run Time	Activity	Run Time	Activity
0.08	Place Cones	0.07	Get Template
0.31	Remove Hoses	0.25	Get Beads
0.50	Begin Painting	0.52	Sprinkle Beads
0.72	Clean Pavement	0.70	Move Template
0.85	Idle	0.88	Get New Template
1.10	Painting	1.11	Sprinkle Beads
1.28	Walking	1.28	Walking
1.39	Painting	1.40	Sprinkle Beads
1.52	Clean Pavement	1.57	Move Template
1.65	Idle	1.85	Sprinkle Beads
1.90	Painting	2.10	Replace Beads
2.11	Replace Hoses	2.30	Idle
2.29	Pick Up Cones	2.44	End
2.44	End		

Table 4



TOTAL TIME:

Busy = 184.2%
Idle - 15.8%

When presented with this information, the Standards Committee agreed to alter the performance standard for the pavement symbols activity using the procedures developed for the "Engineered Standard" method. The results obtained from the new procedure are included on Table 4. This table shows the man-hours per unit rate obtained before and after the 1977-78 implementation date of the new standard. You will note that the results actually received appear smaller than they theoretically should be. This situation was caused by the necessity to modify work procedures which added additional man-hours to complete the same task. These modifications allowed the task to be repeated at two (2) year intervals instead of at six (6) month intervals as in the past. The net result of using the new procedure is approximately a 14% increase in productivity, while decreasing the total workload. Similar results are now being obtained on other activites.

TABLE 5

FISCAL YEAR	MANHOURS/UNIT
75-76	0.0256
76-77	0.0254
77-78	0.0227
78-79	0.0216

Managers of maintenance operations should consider the benefits which may be obtained from the "Engineered Standard" process. The existence of a MMS is not the only criteria to a successful maintenance program. If it were, it would be a simple matter to plan your work and let it run its own course. Maintenance work is difficult at best, it is subject to weather, traffic, monetary and political influences and needs to be constantly managed in order to meet the objectives established by top management. To do this, you will need to review performance data, to constantly evaluate field conditions against planned conditions, and to modify the system to improve results. A MMS quantifies maintenance activities and provides a basic tool to manage maintenance resources. Incorporation of the "Engineered Standards Method" can provide additional insight for the management process, which if used properly, will provide the best maintenance service that can be afforded with the funds that are available.

INCORPORATING QUALITY STANDARDS AND IMPACTS WITHIN HIGHWAY MAINTENANCE MANAGEMENT

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Assessments of future maintenance needs, levels of effort, and costs have traditionally been expressed through predictions of maintenance supply (generally in units like dollars or manhours per lane mile). Although this approach is adequate for many management needs, it does not enable one to explore systematically the effects of changes in maintenance policy on future costs and road performance. However, the increasingly important strategic role to be played by maintenance and rehabilitation, and higher costs of providing maintenance services, have recently focused attention on better management practices to define maintenance demands, establish priorities among maintenance activities, and relate alternative policies to future impacts on road service. This paper describes the development of demand-responsive concepts for maintenance planning and policy formulation, based upon work conducted in separate projects for the Commonwealth of Massachusetts and the Federal Highway Administraiton. Analytical components of the demand-responsive approach include (1) numerical measures of maintenance levels of service, or quality standards; (2) quantitative model to predict the condition or deterioration of specific road features as a function of the relevant physical, environmental and traffic factors; and (3) quantitative models to assess the impacts of maintenance performance, as for example in the areas of preservation of investment, user consequences, and accident prediction.

Historical Perspective

Maintenance programs at the state level historically have been subject to several simultaneous constraints -- budget limitations imposed by the executive or legislative branch, labor and equipment restrictions, seasonal limitations on certain work activities, inability to shift work from emergency to preventive maintenance, and methods of budgeting and appropriation based upon line-item or accounting categories (rather than upon program priorities), to name a few. These constraints have influenced not only the past thinking of maintenance managers, but also the fundamental structure and approach of the maintenance management systems that have evolved over the past fifteen years.

The objectives of the systems developed by individual states were to help plan, budget and manage highway maintenance. To overcome the management weaknesses of the line-item or accounting budget, principles of performance budgeting were introduced. Performance budgets organized planning and control around specific maintenance tasks, permitting a more comprehensive and objective review of the distributions of costs by activity, location, or cost element, and fostering comparisons of projected expenditures versus maintenance program objectives. The planning and scheduling components of these systems enabled managers to allocate scarce resources over a year, and to strike a better balance between maintenance priorities and seasonal resource constraints. A work monitoring subsystem, coupled with proper field reporting procedures, provided comparisons between actual and predicted costs, work performance, productivity, and resource consumption, pinpointing maintenance jurisdictions or activities requiring closer attention.

Furthermore, as part of the performance budgeting approach, maintenance models were developed to predict future labor, equipment and materials costs by activity. The approach taken within these models typically involved either (1) regression relationships between annual maintenance costs (or manhours) per unit of road and relevant physical or operating variables (width, pavement type and thickness, average daily traffic, environmental parameters, etc.); or (2) average workload rates, called quantity standards, observed in past maintenance operations and expressed in terms of annual measures of work per unit of road (e.g. for pavement patching, number of tons of material placed per lane mile). The former allowed some variation by location or in year-to-year predictions to account, say for increases in traffic volume or changes in road characteristics; the latter represented essentially statewide averages of maintenance activity performance, and were thus static over different types of roads and over time.

Although the various state systems in use today differ in their scope and level of detail, in general they are characterized by the fact that, in predicting future maintenance requirements, their primary focus is on the ability to supply maintenance services. In other words, the predictive models employed estimate the labor, equipment, material, or dollar resources needed to produce some level of maintenance effort, but not the factors that caused the maintenance requirement in the first place. Although this approach is open to criticism, it is understandable in light of the organizational and administrative realities surrounding maintenance program development which were true in the past, and persist to some extent to this day.

There were some key advantages to structuring early maintenance models based upon predictions of supply. First, they were a simple and direct means of estimating future budget requirements using an objective analytic approach. Second, they could implicitly account for special local conditions that would affect the aggregate amount of maintenance required (e.g. types of subgrade soil; local climatic conditions; quality of pavement construction; and so forth), and that might otherwise be difficult to represent explicitly.

Perhaps most importantly, however, these supply-oriented models satisfied local management needs. The institution of performance budgeting measures placed budget development on a more rational basis, but it could not eliminate constraints on the maintenance effort imposed by budget ceilings, labor and equipment limitations, and the like. Rather than concerning themselves with the moot issue of actual maintenance demand, therefore, managers directed themselves instead to the pragmatic question of how to accomplish maintenance more efficiently under a fixed level of resources. Performance budgeting concepts, assisted by models based upon maintenance supply, were adequate for this task.

Demand-Responsive Concepts

Motivation

Several trends through the 1970s have advanced maintenance management needs beyond work monitoring, budget prediction and cost control, to broader issues of maintenance policy planning. First, the national highway investment has grown by at least $200 billion in 1979 dollars (1), due largely to near completion of the Interstate program. Many of these highways are approaching ages of 15-20 years; maintenance responsibilities, and the need to estimate and allocate available resources effectively, will increase accordingly. Second, significant changes in the funding of highway maintenance and rehabilitation appear forthcoming, as evidenced by declines in user tax collections and initial Federal involvement through the 3-R program; procedures to allocate available funds, and to assess the impacts of maintenance deferred or foregone, will likely be required. Third, several independent developments -- such as heavier allowable vehicle loads, the advent of new maintenance technologies, and stricter legal interpretations of highway maintenance liability -- collectively imply changes in maintenance needs and methods of performance over time. The tendency is growing to counter arbitrary annual budget restrictions with better information on what impacts the provision or rejection of additional maintenance dollars will cause.

Planning Requirements. Managing this changing maintenance program and developing the capability to assign priorities among ever-increasing maintenance demands requires information and analytic methods to properly assess competing needs, and to evaluate costs and impacts of different policies on a national scale. Moreover, to be comprehensive such management approaches must recognize highway maintenance within a broader context of transportation planning and administration, and to view maintenance policy formulation at several levels.

Strategic. First, at a very broad level are strategic decisions concerning use of maintenance versus capital investment to provide a designated level of road performance. The most prevalent examples of these types of decisions are in pavement design, where a close interaction exists between initial design quality and future maintenance needs. Taken to its extreme for very high-volume roads, this type of decision leads to the design of premium or "zero maintenance" pavements involving significant capital investment but eliminating any practical need for maintenance. However, similar investment-maintenance tradeoffs can be cited regarding pavement maintenance versus programs of periodic reconstruction or strengthening; the need for periodic bridge painting versus use of self-oxidizing steels; and construction of paved waterways versus cleaning and shaping of natural ditches, to name a few. In each case the choice of which policy to follow will depend not only on the cost differential between respective alternatives but also on the relative capacity to provide adequate levels of transportation service into the future.

Competing Activities. At a second level lie decisions among several maintenance activities competing for limited maintenance resources. Given a fixed maintenance budget, any increase in the level of maintenance quality provided under one activity is usually accomplished only at the expense of decreased levels of quality in other activities. Therefore a manager faces the problem of allocating resources in such a way as to remain within budget while minimizing adverse impacts (both short and long range) on the utility, safety, and service life of the highway system.

Timing. At a third level there exists for each maintenance activity a tradeoff between the timing and the intensity of the action to be taken, commonly discussed as a question of "deferred maintenance." The impacts of deferred maintenance must be assessed in terms of, first, the costs of performing perhaps more extensive maintenance later; second, the differences in levels of service to users provided under the two maintenance options; and third, any reduction in the expected remaining life of the facility due to the deferred maintenance.

Commentary. Policy determinations of this type are inherently different from the decisions for which current maintenance management systems were designed. As a result, the models described earlier to predict maintenance requirements on the basis of supply lack the conceptual structure to address these broader management issues. Regression analyses and quantity standards drawn from historical data or existing practices implicitly include a particular level of maintenance performance -- namely, the standards to which the road system has been or is currently being maintained. Moreover, they assume a constant rate of deterioration throughout the road system. Thus the models are insensitive to changes in maintenance policy, and are incapable of evalauating either the costs or the impacts of alternative policies. Moreover, to the extent that the regression models predict directly the costs (or labor manhours) required, without computing first an estimate of damage repaired, they deal with work outputs rather than inputs, and are therefore ill-equipped to treat variations in input values (such as productivity, unit costs, or maintenance technology) among geographic regions or over time.

Required Approach. In general, to be able to evaluate competing maintenance (and investment) strategies requires a fundamentally different approach to maintenance prediction, looking at the demand for maintenance as well as supply. The reason is that different maintenance policies are implicitly statements on particular levels of road quality to be retained or restored. However, the workload (and by implication, the costs) required to achieve a given quality depend upon the prior condition of the road system -- i.e. the total maintenance backlog or deficiency caused by normal wear and tear, aging, and increased probability of failure. In an analytical sense maintenance may thus be viewed as a controlled response to the physical state of the highway network, to upgrade or retain highway quality to an acceptable level.

Treating maintenance as a demand-responsive operation requires that three additional concepts be introduced within existing management models. The first is that predictions of future maintenance effort and costs cannot be extrapolated from past trends, but rather must be based upon structural and operational deficiencies in the road system caused by use and deterioration. The second is that in designing models to be sensitive to the implications of different policies, there must be unambiguous statements of the maintenance policy itself, defining the types of future corrective actions to be taken, and when and where they are to commence. The third is that new relationships need to be identified between the as-maintained state of the highway network and the economic and non-market impacts to both the road agency and the motoring public, providing a measure of the benefits (or disbenefits) of each policy at the costs incurred above.

Since this demand-responsive approach is founded upon the prediction of road condition, it follows that any corrective action that restores the highway condition in some way needs to be accounted for. Thus the scope of this approach must be given an expansive interpretation, to include the relevant effects of betterments, rehabilitation and reconstruction, with those of maintenance. This view simply reflects the common-sense notion that capital investments do in fact influence the future demand for maintenance, and vice versa. Moreover, in this sense the demand-responsive methodology provides a fundamental engineering and economic basis for evaluating maintenance policy against alternative investment strategies.

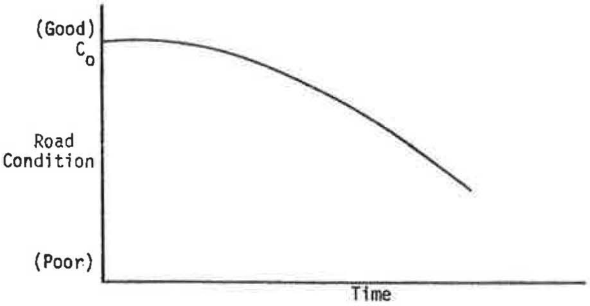
Schematic illustrations of the concepts underlying the demand-responsive approach will be shown in Figures 1 through 8 to be introduced below. The curves in Figures 1 through 8 represent models which, in actual maintenance management systems, would be developed individually for each element of the highway system -- pavements, bridges, drainage systems, signs, and so on -- or for each maintenance activity. For simplicity and generality in the following discussion, however, let us consider these curves for the time being to represent generalized relationships, applicable to a composite maintenance activity over the highway system as a whole.

Maintenance Level of Effort and Costs

Figures 1 through 3 identify those data necessary to predict maintenance level of effort and resulting changes in road condition as a function of different maintenance policies. These data also form the basis for the estimation of future maintenance costs as a function of policy.

Road Deterioration. The changing state of the road system over time is captured within a deterioration relationship defining the system's capacity to withstand the effects of time, traffic loadings, and the environment, as shown in Figure 1. For generality we define road "damage" as any degradation in road condition from its as-constructed state, and "deterioration" to be the net result of accumulated damage. The initial condition C_0 and rate of deterioration depend upon the quality of initial design and construction, and upon past maintenance performed. Thus the deterioration relationship in Figure 1 provides the engineering basis on which one may investigate different maintenance versus investment options.

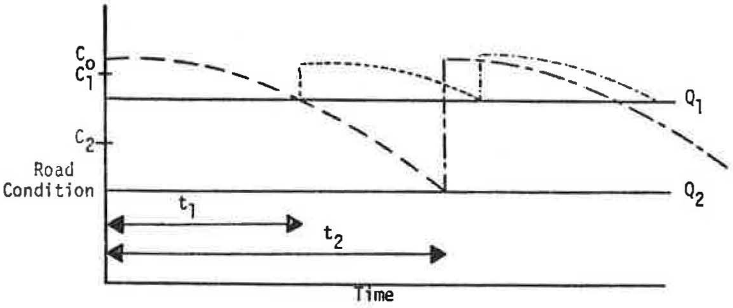
Figure 1. Determining maintenance level of effort under a demand responsive approach: deterioration relationship.



Quality Standards. Maintenance policies may be expressed through "quality standards" defining thresholds at which work should be performed. The interaction between two alternative quality standards, Q_1 and Q_2, and respective road system conditions is illustrated in Figure 2. The different quality standards result (not unexpectedly) in two different trends in road condition over time. If we adopt a simple time average for illustration, the higher quality standard Q_1 results in a higher average system-wide condition C_1. Also, the frequency of maintenance under Q_1 is greater than that under Q_2, in that $t_1 < t_2$.

Under this approach quality standards have a unit of measure commensurate with that of the deterioration model. Decomposing the condition of the road system into its constituent elements, we see, for example, several indices appropriate for pavements. One is a measure of pavement serviceability, such as AASHTO's Present Serviceability Index (PSI), or Canada's Ride Comfort Index (RCI). A second would be a measure of surface damage, such as skid number (SN), roughness value (R), cracking index (CI), or mean rut depth (RD)

Figure 2. Determining maintenance level of effort under a demand responsive approach: quality standards defining thresholds.

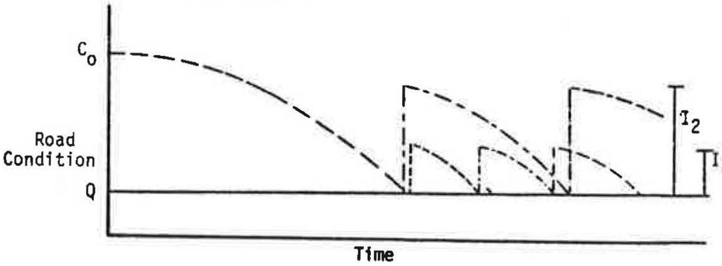


defined by many states employing surface measurement equipment. A third might be a measure of available pavement capacity or response, such as dynamic deflation. Analogous measures could be established for other highway elements; e.g. lineal feet of guardrail damaged, area of bridge deck damage, and depth of siltation in culverts, to name a few.

For some highway elements, however, it may be theoretically possible to identify a physical measure of condition, but it may not be practical to use within a quality standard. Consider, for instance, the replacement of defective signal lamps, which usually must be done soon after failure. A possible measure for signal condition would be "probability of lamp failure within the next so-many months," but it is typically more convenient for the quality standard to use instead some frequency of lamp replacement which anticipates lamp failure. Figure 2 demonstrates that for a given deterioration curve, specifying the frequency of maintenance is equivalent to establishing some implicit quality level. This concept may be used to advantage in the identification of quality standards for particular maintenance activities.

Variation in Application of Standards. In Figure 2 it was assumed in each case that all current maintenance deficiencies were fully corrected. A more realistic situation, however, is that at any given time only a portion of the accumulated damage in the system is repaired through maintenance. From a policy perspective this type of decision can be controlled by how the quality standards are applied on a system-wide basis. Figure 3 illustrates two different applications of a given quality standard Q: one results in relatively frequent but minor correction I_1, while the other undertakes less frequent but major I_2. Note that neither I_1 or I_2 are sufficient to restore the system to its initial condition at construction.

Figure 3. Determining maintenance level of effort under a demand responsive approach: application of quality standards defining extent of repair.



There are three general ways in which the application of quality standards may be varied to produce different levels of repair. One is by adjusting quality standards among different activities which in some sense substitute for one another. For example, the extent to which corrections of pavement damage are remedied by overlays (as opposed to routine maintenance activities) will influence the magnitude of I achieved overall in a given work period. A second way is by assigning different quality standards among various links within the network. Since repair of some locations will implicitly be given priority over other locations, this variation in quality standards will also affect the extent of improvement I on a system-wide basis. Finally, quality standards (and their associated maintenance actions) may be restricted to those classes of damage most critical to road integrity and performance. For example, the "percent of pavement area cracked" may be interpreted to include only cracks greater than a certain width; "guardrail damage," to comprise broken and severely deformed sections, but not dented ones; and "grass height requiring mowing," evaluated only within a certain distance of the pavement edge, but not over the entire mowable area. Qualifications of this type intentionally limit the extent of improvement I in comparison to the total deterioration absorbed by the system.

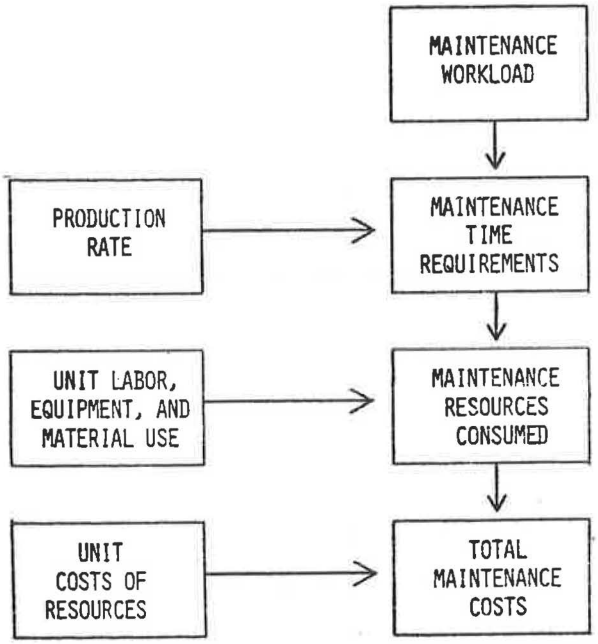
Maintenance Costs. In Figures 2 and 3 the total maintenance level of effort over the system life under policy Q is a function of the product of the frequency of maintenance (proportional to 1/t) and the improvement in condition I each time maintenance is performed. The costs of different maintenance policies may then be computed by calculating the costs to accomplish respective improvements I, discounting these at an appropriate rate according to their projected time of occurence t, and summing the discounted totals for each policy alternative.

From our discussions earlier, the units of measure of system condition C, and therefore of the extent of improvement I, may be in terms of serviceability indices, damage indices, or road response indices. Regardless of the measure of I employed, however, it is obvious that an improvement in condition must be accompanied by the correction of a certain amount of damage, whether for example in square feet of pavement cracking filled, lineal feet of guardrail straightened, number of signal lamps replaced or lineal feet of drainage lines cleaned. The explicit measure of damage corrected we will call the maintenance workload W. In mathematical terms, then, an improvement in condition I implies a particular maintenance workload W, or I → W. (In some cases the units of I and W may be identical. In others a function must be identified relating I and W.)

Maintenance workload provides the basis for estimating maintenance costs, as shown in Figure 4. To a given workload may be applied a production rate (e.g. average number of damage units repaired per day) to obtain overall crew time requirements. Workload and crew time may be translated into resources consumed (manhours, equipment hours, materials quantities) through unit labor, equipment and materials usage (e.g. number of laborers or pieces of equipment per crew, materials quantity required per unit of damage), all a function of the maintenance technology employed. Finally, resource requirement may be multiplied by the respective unit costs of labor, equipment and materials to obtain total maintenance costs desired.

The relationships in Figure 4 point to the supply side of maintenance, and are thus similar to models employed in contemporary maintenance management systems discussed earlier in this paper. The difference between the two approaches (that in Figure 4 versus existing models) is in the estimation of the workload itself. Whereas existing models predict workload (or some proxy for workload) directly from past experience, in Figures 2 and 3 we have predicted it based upon demand-side considerations of system condition and maintenance policy. The separation of demand-side and supply-side contributions to maintenance costs (represented by Figures 2, 3, and 4 respectively) is a particularly valuable management capability where, as identified at the beginning of this paper, several aspects of highway maintenance and operation are changing simultaneously.

Figure 4. Calculation of the maintenance costs.



For example, the demand-side relationships in Figures 2-3 account for not only variations in maintenance policy, but also for the effects of higher (perhaps unforeseen) traffic volumes and weights, unusually adverse weather conditions, and changes in highway design and construction standards. For a given maintenance policy the contributions of these effects to maintenance costs are transmitted via changes in the maintenance workload.

On the other hand, the supply-side relationships in Figure 4 account explicitly for changes in maintenance technology, work practices, supervisory requirements, crew productivity, and unit costs of maintenance resources. The contributions of these factors to total maintenance costs are superimposed upon, but independent of, the costs attributable to total workload arising through maintenance demand.

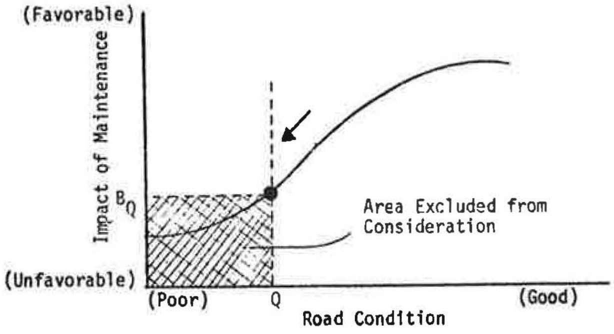
Maintenance Impacts

Better maintenance policies will generally cost more. In evaluating the merits of different policies, therefore, one cannot look only at the costs incurred, but must also judge whether what is gained under higher quality standards is worth the additional dollars spent. Fortunately, the process of predicting the impacts of maintenance is directly compatible with the demand-responsive concepts introduced in Figures 2-3 earlier. The mechanics of assessing maintenance impacts are illustrated in Figures 5-8.

The relationship needed to predict maintenance impacts is illustrated schematically in Figure 5. The measure of road condition shown on the abcissa is identical to that discussed in Figures 1-3. Consistent with other aspects of our example, maintenance impacts are shown in very general form on the ordinate. These impacts may in fact encompass diverse results of maintenance performance, such as the contribution to remaining road life, decreases in user operating costs, and increases in motorist safety and convenience. (For simplicity we assume, both in Figures 5-7 and in the discussion below, that maintenance impacts are cast in the form of relative benefits. However, they may also be represented as disbenefits as for example, in added congestion costs due to road occupancy for maintenance. The conceptual approaches to both benefits and disbenefits would be similar.)

As before, the condition denoted by the quality standard Q defines the threshold at which maintenance will be performed; Q is a control variable expressing maintenance policy. In Figures 2-3 it was assumed that the system condition does not fall below Q. From Figure 5, then, the minimum level of impacts that can be experienced in the road system is B_Q, and the points lying within the hatched area denote conditions and impacts that should be absent within a road system subjected to a quality standard Q.

Figure 5. Determining maintenance impacts under a demand responsive approach: maintenance impact relationship.



Performing maintenance will improve the system in some sense, thereby also providing positive impacts to the road agency or the motoring public. Figure 6 illustrates this for the case of modest maintenance improvement I_1; and Figure 7, for a more substantial improvement I_2. (Refer to Figure 3 for illustrations of different levels of maintenance improvement.) Both of these improvements are gauged from the same quality level Q. On the other hand, Figure 8 illustrates the effects on maintenance impacts of varying both the quality standard Q and the associated level of improvement I.

Figure 6. Determining maintenance impacts under a demand responsive approach: benefits from maintenance.

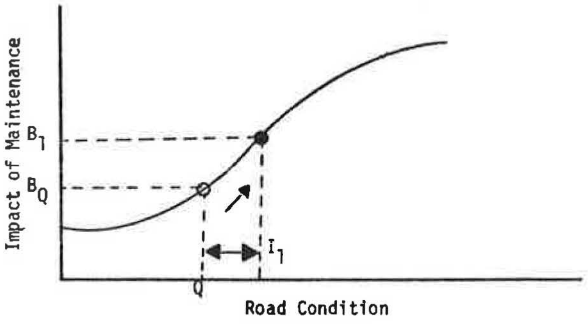
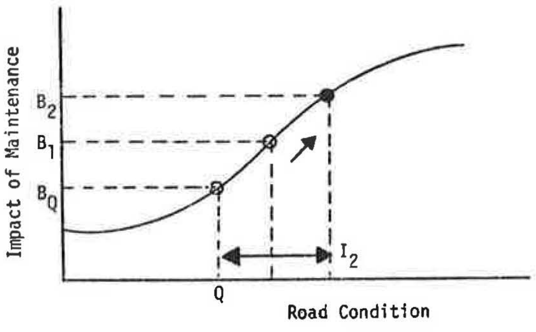


Figure 7. Determining maintenance impacts under a demand responsive approach: greater benefits from increased maintenance.

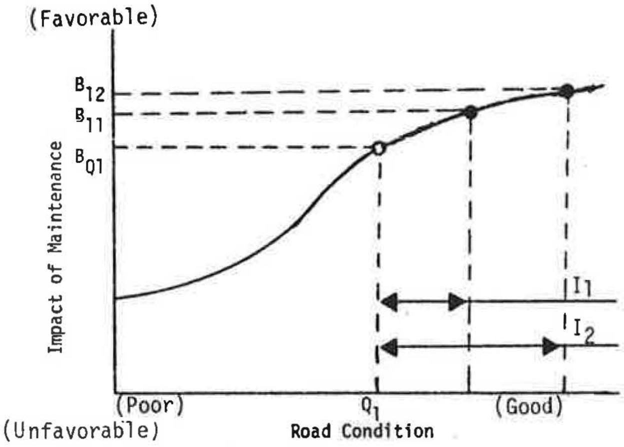


The benefits of maintenance accrue among several aspects of highway structure and operation. We have chosen three major areas of impacts -- preservation of the road investment, user travel and operating costs, and safety -- for initial investigation under a research project for FHWA. Others could also have been chosen -- highway aesthetics or environmental effects, for example. The point is that some, but not all, maintenance impacts can be reduced to monetary benefits. This fact in turn implies a need for a multidimensional analysis of maintenance impacts above and beyond traditional approaches such as benefit-cost comparisons.

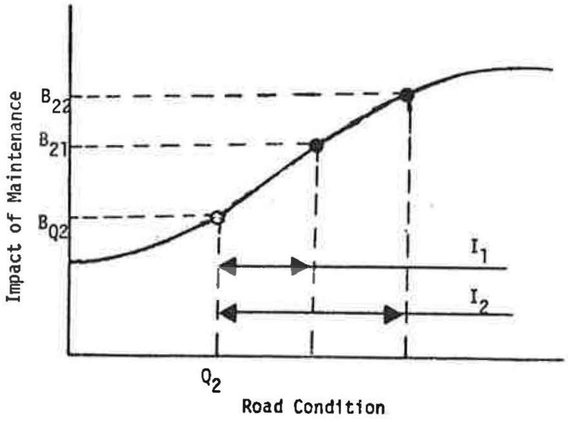
Another point has to do with the magnitude of benefits received for a given improvement in road system condition. This relationship depends upon the shape of the impacts vs. road condition function, which we have hypothesized in Figures 5-8 to take the form of an S-curve. The assumption here is that the marginal benefits of maintenance performance are greatest within some mid-range of highway system condition. If the system has deteriorated completely, then virtually nothing is to be gained by doing modest amounts of maintenance; wholesale repairs, overlays, and rehabilitation are needed instead to restore more favorable impacts. On the other hand, performing excessive maintenance can lead to diminishing returns. In

Figure 8. Maintenance impacts under different quality standards and levels of improvement.

A. Maintenance improvements under higher quality standards.



B. Maintenance improvements under lower quality standards.



such cases, the costs of providing this very high degree of maintenance may be questioned, particularly if the reallocation of maintenance dollars among other maintenance activities (or road sections) presents the possibility for greater marginal benefits.

Management Implementation

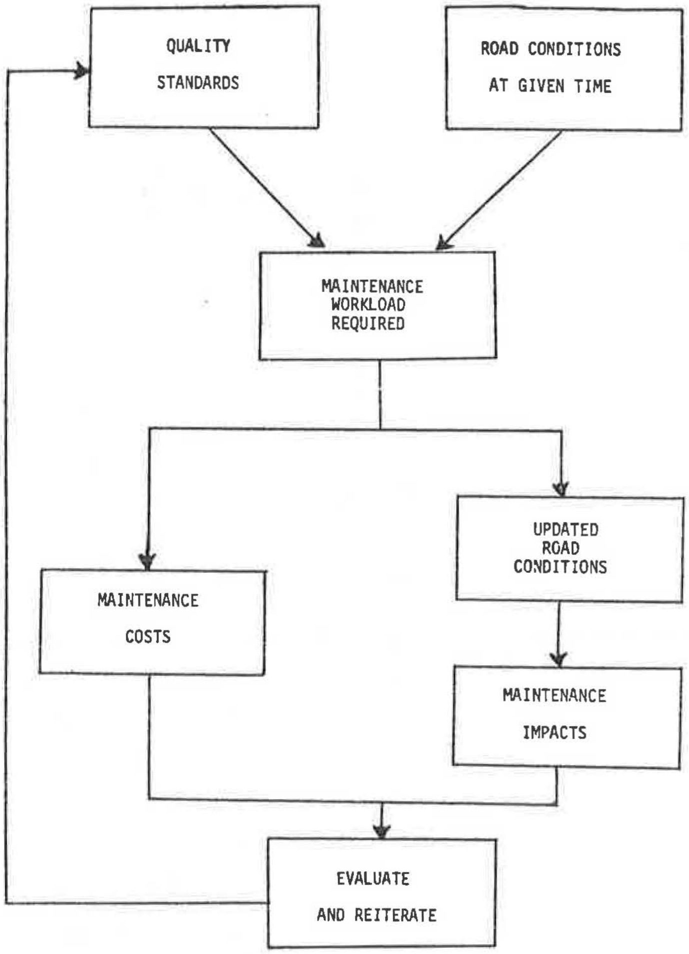
The concepts embodied in Figures 1 through 8 collectively define a management approach to evaluating future maintenance policies or strategies. Organization of these ideas within a unified structure is shown in Figure 9, whose key elements are summarized below.

Annual maintenance is viewed as a demand-responsive operation; that is, a function of the demand accumulated in the highway system in a given year. This deterioration can be estimated from the initial condition of the system (i.e. its as-constructed quality), its rate of deterioration over time, and past maintenance performed. Beyond these physical conditions, however, maintenance workload requirements are also subject to policy decisions defining the type, location, and extent of work to be provided. Maintenance policies are expressed through quality standards specified for the set of maintenance activities over all sections of the road system. Elements of this demand-responsive methodology were introduced in Figures 1-3 and are summarized in the top half of Figure 9.

For a given strategy the estimated maintenance workload may then be costed according to the procedures set forth in Figure 4. At the same time, the simulated accomplishment of this maintenance will improve the condition of the road system, generating a set of maintenance impacts as envisioned in Figures 5 through 8. The calculation of costs and impacts of a given strategy are thus seen as parallel computations in Figure 9.

Maintenance policy evaluation entails a comparison of both relative costs and relative impacts between the strategy under consideration and other maintenance and investment options available. If maintenance impacts could be reduced completely to monetary units, then techniques such as benefit-cost or net-present-value analyses could be applied to determine the optimal strategy. However, in the more general case where impacts are multidimensional, it becomes difficult to state what the "best" maintenance strategy should be. We have

Figure 9. Approach to demand-responsive maintenance management.



therefore suggested in Figure 9 an iterative approach, wherein the results of one strategy can be analyzed to suggest further options more favorable in terms of costs, impacts, or both. By adjusting quality standards through successive trials, maintenance managers can identify a maintenance policy encompassing acceptable (or at least non-objectionable) costs and impacts. Although this procedure requires a subjective assessment of the impacts of different strategies, its value lies in the fact that the consequences of performing or, alternatively, deferring different highway maintenance activites are explicitly spelled out (with costs) for each maintenance policy considered.

Broadly speaking, the approach in Figure 9 may be applied to address two types of situations. The first situation would be to constrain the values of the impacts desired -- in other words, to establish some range of road system benefits that must be sustained through maintenance and rehabilitation, and not to allow the road system to degrade below the established threshold. Through the iterative procedures in Figure 9 one could infer both the maintenance policies and costs necessary to accomplish this target level of service. The second type of situation would be to constrain costs -- in other words, impose a budget limitation. The iterative methodology in Figure 9 could again be applied, this time to vary maintenance policies to attempt to maximize (in a subjective sense) favorable impacts while remaining within the cost ceiling.

Applications

The demand-responsive concepts above are now the subject of research, to formulate them within models of practical use in maintenance policy planning and management. Two projects are worthy of note.

The first project, completed in 1978, involved the design and development of a statewide highway maintenance management system for the Commonweath of Massachusetts. Included within this system is a budgeting component to enable the state to predict maintenance work requirements and costs one to two years hence, for submission as part of the state's routine process of legislative fiscal review and approval. This budgeting system is unique in that it employs numerical quality standards as expressions of maintenance policy, and analytic predictions of resulting system conditions and maintenance impacts. The relevant models were developed in preliminary form for the 50-odd activities to be managed under the system, and are described in (2). Massachusetts is now completing its collection of road inventory data and maintenance unit cost and production information necessary to implement the budgeting procedure.

As a follow-on to the Massachusetts work, we are now conducting a DOT University Research Project through FHWA to formalize the concepts of demand-responsive maintenance predictions and to derive generalized models of deterioration and of maintenance impacts, with associated quality standards, for the activities listed in Table 1. Models will be developed in analytical form suitable for inclusion in maintenance planning or management systems if desired.

Table 1. Candidate activities for FHWA study.

1. ROAD SURFACE
    - Flexible Pavement Patching
    - Rigid Pavement Crack and Joing Sealing
    - Flexible Pavement Overlays
2. ROADSIDE AND RIGHT OF WAY
    - Clean, Reshape Ditches
    - Litter Pickup
3. TRAFFIC SERVICES
    - Pavement Lane and Edge Shaping
    - Relamp Signals
4. STRUCTURES (Conditional)
    - Deck Repair
5. APPURTENANCES (Conditional)
    - Repair Guardrail

As examples of the types of models proposed, Figures 10 and 11 give two examples drawn from our earlier Massachusetts work, showing respectively deterioration and impact models for the activity of placing thin surfacings to improve pavement skid resistance. Figure 10 shows plots of exponential functions relating decline in average skid number (ignoring seasonal effects) to cumulative traffic levels. The families of curves illustrate sensitivity of the model to calibration parameters included in the exponential relationship. Similarly, Figure 11 illustrates the projected effect of the decline in average skid number on the ratio of wet accidents to total accidents. Again, the family of relationships is attributable to the calibration parameters employed (Note that the "B" term in Figure 11 is different in meaning from that in Figure 10). The quality standard in this case is expressed as the minimum acceptable skid number that is to be allowed. Analogous models and standards were developed for other pavement and highway maintenance activities as well.

The DOT University Research Project with RHWA is scheduled to be completed in June 1981.

Acknowledgements

The work reported herein was performed by the author under the two projects mentioned above. The Massachusetts work was conducted through CMT Incorporated under contract to Byrd, Tallamy, MacDonald and Lewis for the Commonwealth of Massachusetts. I wish to acknowledge the interest and cooperation of Mr. L.G. Byrd of BTML and Mr. Robert Keef of the Maintenance Management Section, Massachusetts Department of Public Works. The DOT University Research Project is being performed in the Department of Civil Engineering at the Massachusetts Institute of Technology. Mr. William Kenis of FHWA is the Contract Monitor.

Figure 10. Skid relationship.

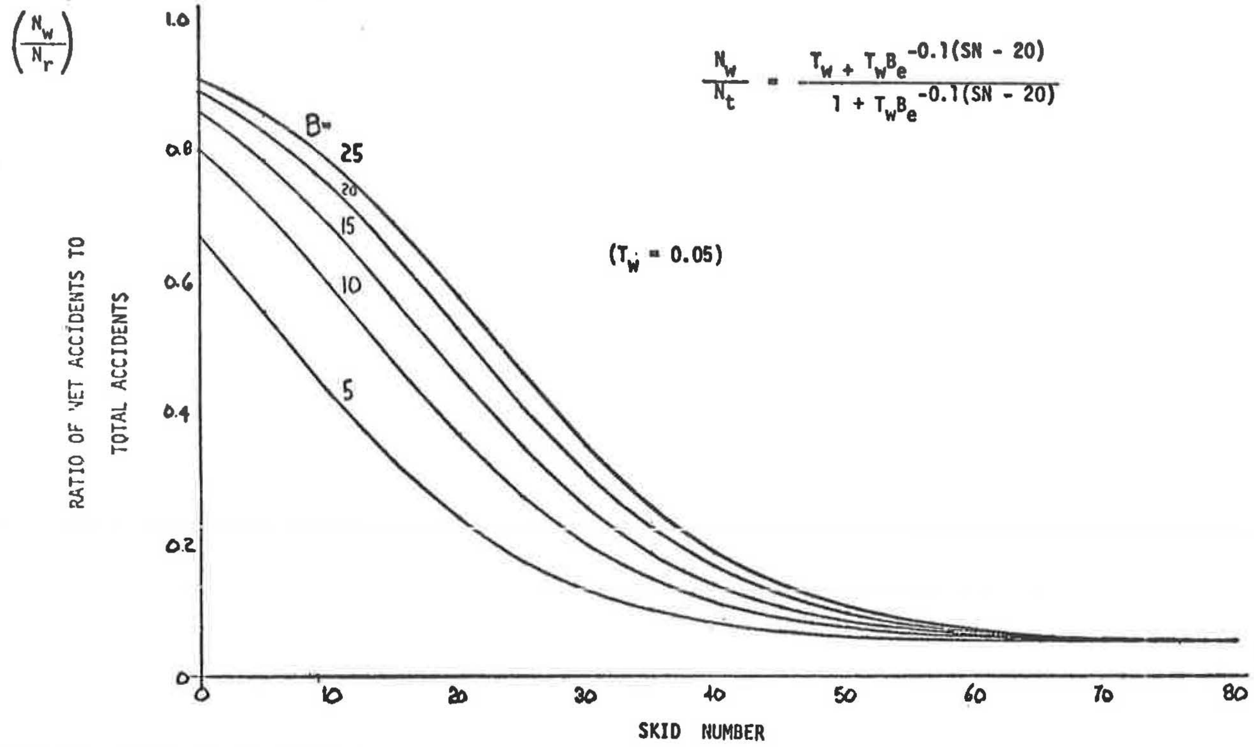
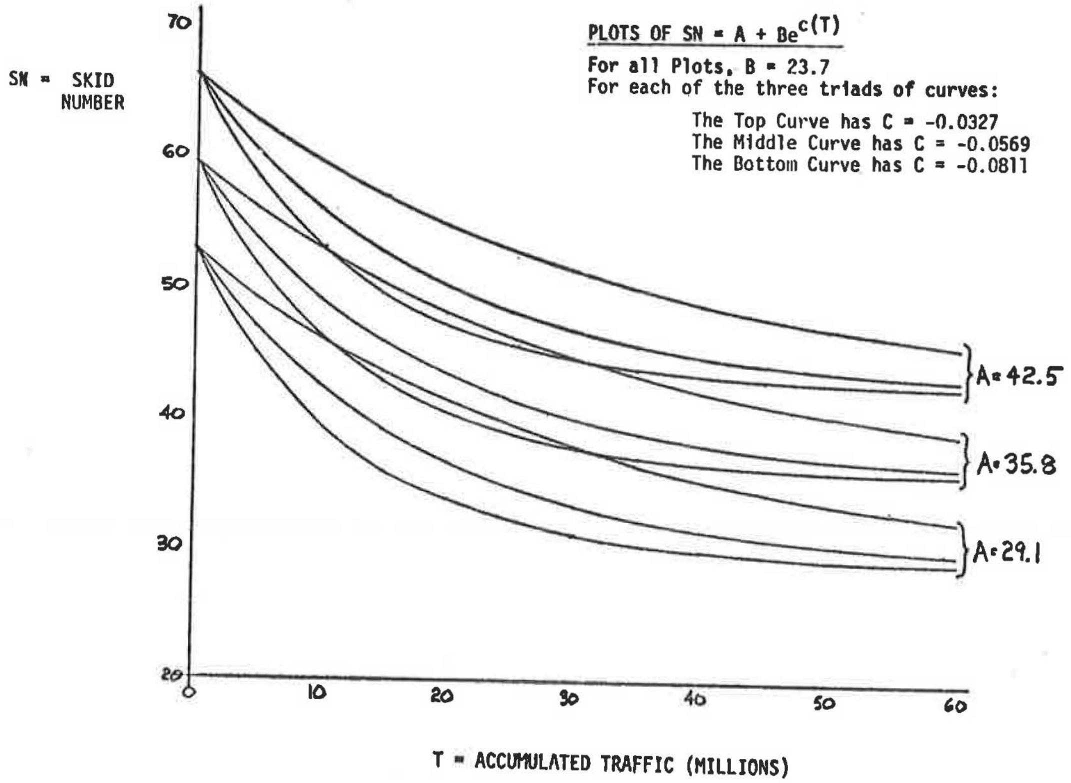


Figure 11. Model of wet pavement accident frequency as function of skid number.



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TRANSPORTATION RESEARCH RECORD 781

Maintaining the Maintenance Management System

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1980

Transportation Research Record 781
Price $8.40

mode
1 highway transportation

subject areas
40 maintenance
41 construction and maintenance equipment

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Maintaining the maintenance management system.

(Transportation research record; 781)
1. Roads–Maintenance and repair–Management–Congresses.
I. National Research Council (U.S.). Commission on Sociotechnical Systems. II. Series. TE7.H5 no. 781 [TE220]
380.5s 81-1185 ISBN 0-309-03111-7 ISSN 0361-1981
[625.7'6'068] AACR2

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Contents

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Foreword

A Workshop on Maintaining the Maintenance Management System was held July 6-8, 1980, at Hilton Head, South Carolina, and was the fourth in a series of maintenance management workshops. The workshop was cosponsored by the American Association of State Highway and Transportation Officials (AASHTO), the South Carolina Department of Highways and Public Transportation, the Federal Highway Administration (FHWA), and the Transportation Research Board.

The Iowa Maintenance Study in 1961 led to what has come to be called maintenance management. Several states and Canadian provinces initiated comprehensive research programs leading to the first workshop at Ohio State University in 1968. The purpose of the workshop was to provide an opportunity for states to compare notes and to learn about this new development. Emphasis was on work measurement, planning and scheduling, and reporting of work accomplishment. The proceedings were published in HRB Special Report 100.

By 1970, maintenance management was in widespread use; the workshop that year at the University of Illinois emphasized problems encountered in implementing performance standards and reporting systems, establishing maintenance levels, and organizational structure and training. The proceedings and related papers were published in Highway Research Record 347.

During the next five years the extent of maintenance needs was delineated through the maintenance management system, and it became obvious that many legislative bodies were not allocating adequate resources to maintenance. In 1975, a third workshop was held in Las Vegas, Nevada; its focus was on the interface between maintenance managers and such decision makers as budget and fiscal managers, system analysts, and personnel analysts. Proceedings were not published.

Presentations published in this Transportation Research Record represent a combination of reports reflecting the experience of participants involved in managing mature systems, refinements for components of maintenance management systems, and concepts that are just beginning to attract the attention of maintenance managers to whom this report is addressed.

Quality standards are fundamental to any maintenance management system and discussions of the subject have been included in all of the workshops. To date, no one has established a way of providing objective quality standards; however, improvements are continually being made. Two sophisticated approaches (as compared with those reported in earlier workshops) are herein put forth. Ram B. Kulkarni outlines a procedure that uses decision analysis that has been tested on an experimental basis for two maintenance elements. Work is continuing and maintenance managers are encouraged to monitor future developments closely. In a second report, Michael J. Markow describes the development of models of practical use in maintenance policy planning and management. The example cited illustrates the use of data to provide factual guidance to making objective decisions; however, at this stage of development managers must be imaginative and innovative because procedural manuals do not yet exist to guide analyses of this type. It is hoped that this work will spur efforts in the area to the end that practice manuals can be prepared.

The second session on measuring performance also introduces a number of advanced or new concepts. Pavement maintenance management, a subsystem of pavement management, is hampered by the difficulty of acquiring suitable maintenance data and of relating data to performance. Photographic or television imagery provides an enormous amount of data at very low cost but extraction of pertinent data is very difficult; hence, only limited use is being made of the material. Theodore H. Poister's effort in his report on an initial stage of a study has a broader aim than use of performance indicators as a tool for fairly allocating funds to districts (the primary use in the pioneering Ohio work). He envisions it as a tool to review progress and trends in the provision of transportation services, for budget justification, for in-depth program evaluation and program analysis, to encourage employee motivation, to assess the performance of contractors, to provide quality control checks on efficiency measurements, and to improve communications between citizens and government. For example, given the overall objective of fast, safe, and efficient highway transportation, the most straightforward measures of effectiveness would relate to the costs incurred by users, and accident rates; travel times and maintenance expenditures should be reflected therein.

Another concept in the forefront of modern management is simulation. James Pruett's paper describes the development of a mathematical model that provides highway maintenance engineers with a computer-aided laboratory in which to test and evaluate various alternative courses of action. This innovative work also requires imagination by maintenance managers, but the lack of handbooks will probably inhibit immediate and widespread acceptance of the concepts presented.

Finally, risk assessment is an inherent responsibility of management. For example, what is the risk of an accident if a maintenance crew assigned to fixing a pothole neglects replacement of a crash attenuator? Attempts are being made to place values and to make an assessment of risk to aid managers toward soundly based decisions. A large storehouse of knowledge exists on risk assessment procedures, but very little of this knowledge has been adapted for use by maintenance managers.

Financial support from the National Highway Institute (FHWA) for the workshop and for publication of the proceedings is gratefully acknowledged.

REMARKS BY SECRETARY WILLIAM N. ROSE, FLORIDA DEPARTMENT OF TRANSPORTATION

I am pleased to be here today. I could stretch a point and tell you that I am surprised any of us are here -- or that this meeting is being held.

It was not to long ago, in 1965, that I attended a Highway Research Board meeting in Washington for the specific purpose of learning about the development of maintenance management systems in the State of Virginia and in the Province of Ontario. At that Research Board Session the Maintenance Committee was discussing whether or not to proceed with research aimed at developing maintenance management concepts that could be applied in all state highway agencies. Following a very professional presentation by the Virginia Department of Highways, I was convinced that the highway maintenance management practices being developed by the Virginia Department in its research project were applicable to the management problems faced by maintenance engineers throughout the country. These practices seemed to hold a potential to effectively improve the utilization of resources applied to highway maintenance.

The second part of that meeting involved lengthy explanations by state highway maintenance engineers representing several of our largest states explaining why maintenance operations could not be managed in the manner proposed by proponents of the Virginia research findings. Unpredictable weather, unanticipated damage caused by accidents, fluctuating seasonal conditions, and other unanticipated demands on state maintenance forces were factors which rendered highway maintenance impossible to manage-- planned quantities of work supported by planned allocations of resources -- manpower, equipment, and materials. It was simply assumed by many of the senior members of the maintenance committee that the need for maintenance forces to react to unusual and unanticipated conditions could not be accommodated in a management system.

Fortunately, maintenance management research did continue. State after state developed and implemented maintenance management practices. Now virtually every state in the union has applied some maintenance management concept to highway maintenance operations. In 15 short years, the highway industry has come from a position of skepticism to the situation we find ourselves in today -- our problem is not, <u>if</u> management systems are needed, but how can we refine and improve current maintenance management systems to make them more effective. If the program for this series of meetings at Hilton Head was distributed at that Highway Research Board meeting 15 years ago, I am sure all of us would have been barred from the meeting. I might add that those states most vocal in their opposition to maintenance management concepts being applied in state highway agencies at the 1965 meeting are all represented here today -- as a matter of fact, some of them are recognized as leaders and innovators in development and implementation of their management processes.

I have been involved in helping state, county and city public works agencies improve management practices for the past twenty (20) years. I have enjoyed being involved with several agencies in helping to develop highway maintenance management systems. New ideas are developing every day.

There is a trend developing that I expect most of you know about. It would be inappropriate not to mention that trend as we begin our meetins this week. Our ability to define the quantities of work necessary to adequately maintain highways and to allocate resources for the accomplishment of those activities has enabled every state to improve the utilization of scarce resources -- manpower, equipment, and materials purchased with hard to come by tax dollars. That capability not only permits us to better utilize state resources, it permits state highway agencies for the first time to effectively develop contracts that will permit performance of routine maintenance services by private contractors. Several public agencies around the country have elected to perform all of their public works maintenance services by private contract and have enjoyed a 15 to 30 percent reduction in the costs of performing those services with public forces. This same productivity improvement opportunity exists for every state highway agency.

In Florida we are embarking on several demonstration projects to establish the criteria for switching from state force to private contract. The first bids for selected maintenance activities were opened this past April. Bids, after being adjusted by adding a 31 percent overhead and supervision factor, were about 15 percent less than the cost of performing the same work with state forces.

While preliminary indications are that costs can be reduced by 15 percent -- I expect even greater improvement as the demonstration projects develop more data and department engineers develop more effective contracting techniques. Similar projects are underway in Pennsylvania where the Department of Transportation is contracting for the management of highway maintenance forces.

I think we are at the same point today in the development and acceptance of the concept of contracting for maintenance services that we were in 1965 when we were considering applications of maintenance management practices to highway maintenance work. Fifteen (15) years from now, the concept of doing most maintenance work by private contract will be accepted throughout the country.

State highway agencies have developed a very effective contracting system for the construction of new highways. We have excellent plans, special provisions, specification and contract wording coupled with an excellent contract administration and construction inspection system that ensures performance of contract construction according to specification. As we develop a similar capability to define maintenance contracts and to administer and inspect contract maintenance work, we will be organizing to perform highway maintenance just as we now do for highway construction -- developing a force of highly qualified engineers, technicians, and administrators to oversee work by private enterprise.

I'd like to propose that this committee seriously consider the conduct of further research to develop those practices necessary to effectively design and administer maintenance contracts. Let's meet back here again in 15 years and see if we haven't made as much progress in performing maintenance work by private contract as we have in the past 15 years in developing and implementing highway maintenance management systems.

REMARKS BY DEPUTY FEDERAL HIGHWAY ADMINISTRATOR JOHN S. HASSELL, JR., BEFORE THE NATIONAL RESEARCH COUNCIL, HILTON HEAD, SOUTH CAROLINA, JULY 7, 1980

It is indeed a pleasure for me to be here and to discuss highway maintenance and some of the challenges we are facing in this area. I want to thank the Transportation Research Board for holding this workshop and inviting me to speak to you today.

These are times of inflation and energy shortages, a combination that serves to make our efforts in the maintenance of our highway system a demanding task. We have been asked to carry out our goals of preserving the Nation's highway systems, and providing for their safe and efficient use, at the same time that we have been faced with reduced budgets and, in many cases, manpower reductions as well. The present decrease in motor fuel tax revenues, coupled with spiraling inflation, compounds the highway maintenance situation.

These are not new problems, by any means. Mr. Francis Turner, former Director of the Bureau of Public Roads, said to the Highway Research Board in 1968: "As in the past, there will in the future be just so much money available for highway purposes, and any dollar wasted on inefficient maintenance practices is a dollar deducted from the funds available for new facilities."

We have the same problems today. In fact, highway maintenance has now become a major issue and we are facing a highway program for the 80's that will be restructured to preserving the highways we already have.

FHWA's Interest in Highway Maintenance

Although legislative restraints prohibit the use of Federal funds for highway maintenance, the FHWA has a deep interest in seeing that the highways are properly maintained because of the tremendous Federal investment in construction of these roadways. Indeed, Title 23 states in Section 116, "It shall be the duty of the State highway department to maintain, or cause to be maintained, any project constructed under the provisions of this chapter . . ." and "If at anytime the Secretary shall find that any project constructed under the provisions of this chapter, . . ., is not being properly maintained, he shall call such fact to the attention of the State highway department. If within 90 days . . . such project has not been put in proper conditions of maintenance, the Secretary shall withhold approval of further projects of all types in the entire State . . ." Congress and the FHWA view maintenance very seriously.

The States have also shown their interest in the proper maintenance of the highways by placing increasing amounts of their funds into maintenance. The 1980 Highway Needs and Performance Study is finding that State disbursements for maintenance have kept pace with, and in many States, exceeded the rate of cost increases. In fact, maintenance is the one area of the highway program where expenditures have remained stable in constant dollars.

However, Congress is still very concerned and in the Surface Transportation Assistance Act of 1978 Congress required guidelines for Interstate Maintenance. As a result of the 1978 Highway Act, the FHWA has recently issued a regulation that requires State highway agencies to submit an initial plan to explain how they are going to manage their Interstate Maintenance program by July 25. These reports will include a discussion of the State's method of program management, including copies of operating documents, and a general description of the resources and activity levels the State intends to devote to meeting the stated objectives in each cited element.

The law also requires an annual certification by the State that it does have an Interstate Maintenance program and that it's routes are being maintained in accordance with that program. Each year the State will be required to update its initial program and provide information to FHWA on: condition of interstate routes and deficiencies, maintenance priorities, maintenance budget and exceptions and/or revisions to the initial submission.

The regulation provides for sanction procedures whereby the Secretary of Transportation can reduce the State's Interstate apportionment by 10 percent for failure to certify as required or if it has been determined that the State is not adequately maintaining its Interstate routes in accordance with its own maintenance program.

Allow me to illustrate a few of the problems that we now face in the Interstate System which have major implications for maintenance.

The designated 42,500 mile Interstate System deteriorated from 1975 to 1980. During this period, pavement conditions changed from 4 percent of all mileage needing rehabilitation or reconstruction to 13 percent needing resurfacing and 13 percent of all bridges on the Interstate System are deficient. In addition, an average of 2,000 miles (or 4.7% of the total system) is reaching its 20 year design age each year. Federal Interstate completion and Interstate 3R funds (including the Interstate 10 percent state match) now account for about 98 percent of all capital improvements on the Interstate System. This means that States are using virtually none of their other Federal (such as Primary System) or State-only funds for Interstate Resurfacing, Restoration, and Rehabilitation (I-3R) work. The updated pavement and bridge deck needs were estimated at \$20.1 billion (in 1979 dollars) for the 10-year study period in comparison to the previous estimate of \$18.5 billion (in 1975 dollars) for a 20-year period. Since the earlier study, in 1975, over \$500 million has been obligated for 3R projects. Overall, the study indicates an average annual need of about \$2.0 billion whereas the 1977 study showed an annual need of \$0.9 billion (in 1975 dollars).

With these conditions, the financial situation all Government agencies are facing and the congressional direction we have, I believe you can see why the FHWA is very concerned about maintenance.

However, much more than concern is needed if we are to address the highway maintenance problem. We have become increasingly aware of the need to properly manage the highway systems themselves. This need we have categorized under the title of Pavement Management (PM), and have divided it into six major categories: planning, design, construction, maintenance, pavement monitoring and research.

Effective PM involves the use of feedback of information on pavement performance, pavement maintenance, pavement rehabilitation activities, and the cost of providing and maintaining pavements. Our goal must be to improve the process of coordinating and managing all activities related to pavements to reduce the life-cycle cost for providing and maintaining pavements in a serviceable condition.

Most States have adopted the concept of maintenance management to improve the productivity in highway maintenance through effective planning, scheduling, reporting, monitoring, and budgeting of maintenance activities. The States have developed the tool to use this management philosophy either internally with their own forces or through the expertise of a consultant.

Ongoing and Future Activities

The FHWA has over the years participated, at the request of the States, in research to develop maintenance management systems in order to increase maintenance productivity and utilize resources more efficiently. An effective Federal/State relationship in the area of highway maintenance has resulted principally due to the States' and FHWA's keen interest in improved management and the cooperative attitude both agencies have.

We are fortunate in that so many State highway agencies recognize that pavement maintenance can significantly affect pavement performance. The maintenance required to keep a pavement above some planned serviceability threshold is a measure of the effectiveness of pavement management in programming, design and construction quality. In this vein, maintenance activities and expenditures provide essential feedback into the programming, design, and construction of new pavements. Maintenance must be carefully planned and implemented to include proper reporting and easy data retrieval.

One of our most meaningful contributions to the systematic management approach to highway maintenance has been the introduction of the concept of Value Engineering. This concept is simply the systematic application of recognized techniques that identify the function of a product or service, establish a dollar value for that function, and reliably provide the necessary function at the lowest overall cost.

One of the major steps leading toward increased value-for-dollar maintenance techniques has been that of increased mechanization of maintenance in order to increase productivity. Multiple-use equipment has been introduced to reduce fleet sizes and it quickly became evident that keeping downtime to a minimum was the one way to ensure adequate return on investment.

Problems with downtime, which is actually maintenance time for the equipment, quickly gave rise to the equipment support system. Guided by input from the various State highway maintenance organizations, the FHWA awarded a research project concerning equipment management. The input from a dozen or so States was analyzed and a design manual for an equipment management system resulted.

On-site surveys of the equipment management and functions in 9 States included evaluation of existing systems and system elements and the documentation of management practices. Equipment managers and users at all levels were interviewed as part of the program to determine how to improve equipment management information and operations. On the basis of these surveys, common equipment management objectives, based on apparent levels of demand for equipment services, structures, or equipment cost, and opportunities for management improvement were established.

In other areas of maintenance research bridges, have come under detailed maintenance studies, and over the past 2 years we have been working with the AASHTO Highway Subcommittee on Maintenance in the development of a guide for bridge maintenance management. Its purpose is to provide a summary of current successful management techniques, bridge maintenance specifications and work standards that various State highway agencies use and it will provide guidance for all bridge maintenance personnel in managing the structure maintenance program. The concept of a preventive maintenance program for bridges is stressed in order to protect the costly capital investment.

As we have developed our maintenance management concept, we began to assist the States in promoting maintenance management through a program of process reviews for highway maintenance management. The objective of these process reviews is to evaluate the management process of the State highway agencies maintenance program to better understand the development of effective and adequate maintenance programs for highway facilities. To further demonstrate our interest in the management of highway maintenance by a systematic approach, FHWA headquarters and division offices have sent qualified representatives to various State highway departments to receive training in maintenance management with the intent of having these persons handle future process reviews.

Closing

I think you can see from what I have said that we in FHWA are vitally interested in all phases of this important subject-and these programs, and others that are planned, are but a part of our efforts to improve the maintenance management system and the quality of highway maintenance.

I am happy to note that the workshop will address many major issues of highway maintenance and I wish you a full and complete program. I expect that many of you will contribute as much to the discussions as you learn and that all of you will benefit from the sessions.

I feel confident this workshop will give you insight into techniques to maintain the management system. There is a great need to preserve the system with refinements due to the shortage of precious highway dollars. The results of this workshop should help all States to accomplish better and more cost effective maintenance.

A SYSTEMATIC PROCEDURE FOR THE DEVELOPMENT OF MAINTENANCE LEVELS OF SERVICE

Ram B. Kulkarni, Kamal Golabi, Fred N. Finn and
Rubin Johnson, Woodward-Clyde Consultants

One of the basic requirements for the proper management of highway maintenance activities is the establishment of maintenance levels-of-service, i.e., at what levels or conditions should a maintenance activity be initiated. A systematic methodology was developed for determining the maintenance levels-of-service that would maximize the user benefits subject to the constraints of available resources. This paper describes a demonstration of the methodology for two maintenance problems in a state.

The necessary inputs for the methodology were obtained from the data base of information currently available to the state transportation department. The data base included information available in the literature, studies conducted within the department, information available from maintenance management systems, and experience and judgment of knowledgeable individuals within the department. Results of the analysis produced levels-of-service that were intuitively satisfactory. Sensitivity analyses were conducted to determine the impact of conditions such as budget cuts and changes in the relative weights of different considerations on the determination of optimum levels-of-service.

While the demonstration phase of the project was limited to two problems, the results indicate that the methodology can work and should be implementable by state agencies.

Maintenance levels-of-service are defined as threshold conditions at which maintenance is considered to be needed. As such, these levels-of-service will influence work scheduling requirements, resource allocations and work priorities. Selection of the maintenance levels-of-service is influenced by a number of considerations such as safety, comfort, protection of investment, environmental impact, and aesthetics.

At the present time there is no systematic, structured procedure for establishing maintenance levels-of-service or to adjust such levels when resources are constrained or increased. Woodward-Clyde Consultants has completed a study for the National Cooperative Highway Research Program (NCHRP) to develop a methodology for establishing levels-of-service based on well documented principles of decision analysis.

The purpose of this report is to describe the methodology by means of a demonstration of the procedures for two maintenance problems in the state of Louisiana.

In order to facilitate the description of the procedures the following terminology has been established.

1. Maintenance Element - a part of the highway system that requires maintenance (e.g., traveled-way, roadside, drainage, traffic services).
2. Maintenance Condition - a deficient condition of a maintenance element that needs to be repaired or corrected (e.g., cracking and rutting--for traveled-way; grass growth and litter and debris--for roadside).
3. Maintenance Activity - work required to repair or correct a maintenance condition (e.g., filling--for cracking; mowing--for grass growth).
4. Level-of-Service (quality standard) - threshold deficiency level of a maintenance condition that should trigger an appropriate maintenance activity (e.g., grass should be mowed when it is 12 inches high; a drainage ditch should be cleaned when 50 percent of its area is blocked).
5. Considerations - the factors used in evaluating the performance of maintenance elements (e.g., safety, riding comfort, economics, aesthetics).
6. Attribute - a numerical scale for measuring the effect on a given consideration (e.g., frequency of accidents--for safety; roughness--for riding comfort).

Approach

The methodology to select maintenance levels-of-service involves the following steps:

1. Structuring the problem.
2. Estimation of the effects of alternative maintenance levels-of-service on various considerations (e.g., safety, aesthetics).
3. Evaluation of the effects of alternative maintenance levels-of-service.

4. Determination of the optimum combination of maintenance levels-of-service.
5. Sensitivity analysis.
6. Recommendations.

A computer program ASOP (acronym for Algorithm for the Selection of Optimum Policy) has been written for implementation of all calculations required by the methodology.

Structuring the Problem

The following tasks are involved in structuring the problem:

1. Select maintenance elements (e.g., shoulders, pavement).
2. Select maintenance conditions (e.g., edge of traveled-way drop-off) for each maintenance element (e.g., shoulders).
3. Specify alternative levels-of-service for each maintenance condition.
4. Select considerations (e.g., safety) for each maintenance element (e.g., shoulders).
5. Select attributes (e.g., percentage of drivers who cannot recover) for various considerations (e.g., safety).
6. Identify the maintenance conditions (e.g., edge of traveled-way drop-off) which affect each attribute (e.g., percentage of drivers who cannot recover).

The implementation of the above tasks in Louisiana is described below.

Select Maintenance Elements

For the demonstration example, two maintenance elements--shoulders and roadside vegetation--were analyzed.

Select Maintenance Conditions for Each Maintenance Element

For shoulders, the edge of traveled-way drop-off is the maintenance condition of concern.

For roadside vegetation, the maintenance conditions of concern may include grass growth, weed growth, and brush and tree growth. The discussions with the Louisiana landscape specialist indicated that a combined mowing and herbicide spraying program is used for the maintenance of roadside vegetation.

Select Alternative Levels-of-Service for Each Maintenance Condition

The following procedure can be used to generate alternative levels-of-service. The department specialists for a given maintenance condition are asked to assume that there are no constraints of resources (dollars, manpower, etc.) for the particular maintenance condition under consideration. How would the specialists improve the level-of-service for that condition? Discussion of this question would provide a level-of-service which is generally higher than the current level-of-service used by the agency. Next, the specialists are told that there are moderate and severe budget cuts, successively for the maintenance condition. In order to accommodate the budget cuts, a reduced level-of-service would have to be adopted. How would the agency reduce the level-of-service in each case? Responses to this question would generate two levels-of-service which are generally lower than the current level-of-service. If it is meaningful in practice, some intermediate levels-of-service may also be considered.

At the conclusion of this step, a spectrum of alternative levels-of-service ranging from the highest (ideal) to the lowest (barely tolerable) are generated. Table 1 shows the alternative levels-of-service selected for edge of traveled-way drop-off and vegetation growth.

Table 1. Alternative levels-of-service for maintenance conditions of given maintenance elements.

Maintenance element	Maintenance conditions	Alternative levels-of-service
Shoulders	Edge of traveled-way drop-off	(1) Repair when drop-off is 1-inch. (2) Repair when drop-off is 2 inches. (3) Repair when drop-off is 3 inches. (4) Repair when drop-off is 4 inches. (5) Repair when drop-off is 5 inches.
Roadside Vegetation	Vegetation growth	(1) Mow 500,000 acres and spray 120,000 acres annually. (Mow full right-of-way before grass reaches 8 inches.) (2) Mow 300,000 acres and spray 120,000 acres annually. (Urban area: mow full width before grass reaches 8 inches. Rural area: mow 30 feet from edge of traveled surface after grass exceeds 12 inches.) (3) Mow 200,000 acres and spray 60,000 acres annually. (Urban area: mow full width after grass exceeds 18 inches. Rural area: mow one machine pass after the grass exceeds 18 inches.) (4) Mow 150,000 acres and spray 60,000 acres annually. (Mow for safety only.)

For edge of traveled-way drop-off, the alternative levels-of-service were specified in terms of the threshold amount of drop-off at which a shoulder should be repaired.

For roadside vegetation growth, the current maintenance practice in Louisiana consists of a combined mowing and herbicide spraying program. It was, therefore, appropriate to consider alternative levels-of-service in terms of increased or decreased amounts of mowing and spraying. Appropriate combinations of numbers of acres mowed and numbers of acres sprayed were selected in consultation with the department specialists to represent four alternative levels-of-service for controlling roadside vegetation. For a proper understanding and implementation of the levels-of-service in the field, it was also necessary to specify for each level-of-service the threshold height at which grass would be mowed and the width of mowing. Since urban and rural areas present different roadside environments, different provisions for these areas were made under each level-of-service.

Table 1 shows the alternative levels-of-service for roadside vegetation both in terms of (1) number of acres mowed and sprayed and (2) threshold height of grass and width of mowing for urban and rural areas.

Select Considerations for Each Maintenance Element

Considerations are the factors which affect highway users through the choice of maintenance levels-of-service for a given maintenance element. With regard to maintenance of shoulders, safety and preservation of investment appear to be the pertinent considerations. Aesthetics and environmental pollution are the appropriate considerations with regard to roadside vegetation maintenance. It should be noted that even though economics (maintenance cost) is an important consideration, it is viewed as a constraint on the system rather than as a user-related consideration.

Select Attributes for Various Considerations

An attribute is a numerical scale for measuring the effect of alternative maintenance levels-of-service on a given consideration. Table 2 lists the attributes of various considerations for each maintenance element.

Table 2. Considerations, attributes, and maintenance conditions affecting each attribute.

Maintenance element	Considerations	Attributes	Maintenance conditions affecting an attribute
Shoulders	Safety	Percentage of drivers who cannot recover	Edge of traveled-way drop-off
	Protection of investment	Percent change in pavement rehabilition cost	Edge of traveled-way drop-off
Roadside vegetation	Aesthetics	Index of pleasing appearance (4-point scale)	Vegetation growth
	Ecology	Index of environmental pollution (4-point scale)	Vegetation growth

Identify the Maintenance Conditions Which Affect Each Attribute

The maintenance conditions affecting each attribute are shown in Table 2.

Estimation of Effects of Alternative Maintenance Levels-of-Service on Various Considerations

The effect of alternative maintenance levels-of-service on a given consideration (e.g., safety) is estimated in terms of the attribute of the consideration (e.g., percentage of drivers who cannot recover). The effects were estimated in Louisiana by interviewing the department specialists for given attributes. To assist the specialists in the estimation, pertinent information and data available in the literature were reviewed with the specialists.

Because of limitations and applicability associated with information in the literature it was concluded that this source could not be used directly to establish the effects or impact of levels-of-service on pertinent considerations. Based on these conclusions, the specialists were asked to extrapolate the available information to the real-world situation, based on their experience and judgment.

Percentage of Drivers Who Cannot Recover

Assessment of the percentage of drivers who cannot recover for given amounts of edge of traveled-way drop-off was done in two steps:

1. What percentage of drivers will encounter the drop-off problem (i.e., accidentally drive over the edge of the traveled-way)?
2. Of the drivers who encounter the problem, what percentage would not be able to make a normal recovery?

Table 3 shows the results of the assessments. It is acknowledged that some of the estimates may be high. More time and background information would be necessary to improve on these estimates of the impact of various levels-of-service. The methodology, per se, would not be affected by any changes in these estimates.

Table 3. Effect of alternative levels-of-service of edge of traveled-way drop-off on percentage of drivers who cannot recover.

Threshold amount of edge of traveled-way drop-off	Percentage of drivers who drive over the edge of traveled-way	Percentage of drivers who cannot recover if they drive over the edge of traveled-way	Percentage of drivers who cannot recover
	(a)	(b)	(c = ab/100)
1"	15	0.01	0.0015
2"	14	0.5	0.07
3"	13	15	1.95
4"	12	55	6.60
5"	10	90	9.0

Percent Change in Pavement Rehabilitation Cost

High levels of allowable drop-off at the edge of the traveled-way may require extra preparation work on the edge of the pavement at the time an overlay is applied. No quantitative information was found in the literature to indicate the influence of edge of traveled-way drop-off on the change in pavement rehabilitation costs. Therefore, the specialists had to rely on their experience and judgment to estimate the amount of additional pavement work required prior to an overlay as a function of the amount of edge of traveled-way drop-off.

Table 4 shows the assessment of percent change in pavement rehabilitation cost for various amounts of edge of traveled-way drop-off.

Index of Pleasing Appearance

The alternative levels-of-service for roadside vegetation define a 4-point scale for the index of pleasing appearance. It is reasonable to assume that the levels-of-service incorporating higher amounts of mowing and spraying would enable the maintenance engineer to provide a more pleasing appearance to the roadside.

Table 4. Effect of alternative levels-of-service of edge of traveled-way drop-off on percent change in pavement rehabilitation cost.

Threshold amount of edge of traveled-way drop-off	Percent change in pavement rehabilitation cost
1"	0
2"	1
3"	5
4"	12
5"	15

Index of Environmental Pollution

The potential for environmental pollution is a function of the amount of herbicide spraying. The alternative levels-of-service for roadside vegetation, which specify the number of acres sprayed with herbicides, define a 4-point scale for the index of environmental pollution.

Evaluation of the Effects of Alternative Maintenance Levels-of-Service on Various Considerations (E.g., Safety, Aesthetics)

The objective of this step is to establish a preference (value) structure for evaluating the effects of alternative levels-of-service on various considerations, such as safety, aesthetics, etc. The effects on the considerations are measured in terms of the selected attributes. For example, for edge of traveled-way drop-off the effect of level-of-service on safety is measured in terms of the percentage of drivers who cannot recover.

The assessment of preferences involves two steps:

1. Assessing individual value functions of different attributes. The objective of this step is to determine how much better (or worse) one level of an attribute (e.g., percentage of drivers who cannot recover = 5) is relative to another (e.g., percentage of drivers who cannot recover = 10). This assessment is best done by those individuals in a state agency who are most knowledgeable with regard to a given attribute.
2. Assessing value tradeoffs between different attributes. If a decision problem involves multiple attributes and limited resources, it may not be possible to achieve the best levels of all the attributes. The decision maker, therefore, is required to think about how much he/she may be willing to sacrifice on one attribute (e.g., aesthetics) in order to improve another (e.g., change in rehabilitation cost). These value tradeoffs determine the relative weights of the attributes. The assessment of value tradeoffs should involve individuals who are responsible for setting and implementing maintenance levels-of-service.

The first step was completed during meetings with the department specialists with regard to edge of traveled-way drop-off and roadside vegetation control. The second step was completed during a group session which involved maintenance engineers from both headquarters and the district offices. The details of the specialists' meetings as well as the group session are provided below.

Assessing Different Drop-Off Attributes With Specialists

The objective of these meetings was to assess relative values of different levels of the attributes relevant to edge of traveled-way drop-off. The attributes were: percentage of drivers who cannot recover and percent change in pavement rehabilitation costs.

A general procedure used in assessing relative values of an attribute involves the following steps:

1. A range for an attribute is selected such that it would contain the highest and the lowest assessed levels of the attribute. For example, the attribute "percentage of drivers who cannot recover" had highest and lowest assessed levels of 9 and 0.0015, respectively (see Table 4). A range of 0 to 10 was, therefore, chosen for this attribute. Similarly, an appropriate range for "percent change in pavement rehabilitation cost" was 0 to 35.
2. The end-points of the range of an attribute are assigned arbitrary values, a common choice being 0 and 1. Then, a midvalue point on the range of the attribute is assessed. To illustrate this procedure, consider the attribute "percentage of drivers who cannot recover." We denote this attribute by θ_1 and its value function by $V_1(.)$. Values of 0 and 1 are assigned to the end-points of θ_1. Noting that lower levels of θ_1 are more desirable, we get

$$V_1(10) = 0 \text{ and } V_1(0) = 1.$$

Now, we want to assess a point, say θ_1^*, which has a value of 0.5; i.e., θ_1^* is the midvalue point on the range of θ_1.

To do this, different levels of θ_1 are successively proposed to the specialist. The specialist is asked to examine a given level of θ_1 and judge whether that level divides the total range of θ_1 into two parts, each having the same value. The analyst attempts to bracket the midvalue point by approaching it from both ends. For example, one can start with $\theta_1 = 1$. The specialist is asked: "Which is better--decreasing the percentage of drivers who cannot recover from 10 to 1 or decreasing it from 1 to 0?" Let us say the specialist indicates that decreasing the attribute from 10 to 1 is better. Next, $\theta_1 = 9$ is proposed. The question is asked: "Which is better--decreasing the percentage of drivers who cannot recover from 10 to 9 or decreasing it from 9 to 0?" The specialist may say that decreasing the attribute from 9 to 0 is better. By systematically varying the proposed levels of the attribute, one can zero in on the midvalue point, θ_1^*.

3. The end points and θ_1^* provide three points on the value function $V_1(.)$. Additional points may be assessed by dividing each of the two ranges, 0 to θ_1^* and θ_1^* to 10, into two equal value parts. A smooth curve can be drawn through the end points and the assessed intermediate points. A mathematical equation can be derived to best fit this curve. This equation represents the individual value function $V_1(.)$ for θ_1. The computer program ASOP automatically fits a quadratic value function, given the end points and the midvalue point for an attribute. The form of the function is

$$V_1(\theta_1) = a + b\theta_1 + c\theta_1^2.$$

Using the above procedure in Louisiana, the individual value functions for the following attributes were assessed:

θ_1 = percentage of drivers who cannot recover.
θ_2 = percent change in pavement rehabilitation cost.

Both the value functions were linear. This implies that a change in the same magnitude in the attribute anywhere in its range has the same value.

Assessing Different Roadside Vegetation Attributes With Specialists

The objective of these meetings was to assess the individual value functions for the following attributes:

θ_3 = index of pleasing appearance.
θ_4 = index of environmental pollution.

Both roadside vegetation attributes are represented on a 4-point discrete scale. Each point is associated with an alternative maintenance level-of-service (see Table 1). The procedure for assessing midvalue points discussed previously is not practical in the case of an attribute represented on a discrete scale with a limited number of points. The reason is that none of the points on the scale may provide a midvalue point. An alternative procedure, based on the concept of willingness to pay, was used.

To illustrate this procedure, consider the index of pleasing appearance. The participants were asked how much more they would be willing to pay in order to improve the index of pleasing appearance from its lowest level (number of acres mowed = 150,000; number of acres sprayed = 60,000) to each of the other levels. Following some discussion, the response of the participants was that they would be willing to pay 50 percent more to go to Level 3 and 200 percent more to go to Level 2. With regard to Level 1, the specialists did not see much benefit in moving from Level 2 to Level 1, and hence were willing to pay very little to go from Level 2 to Level 1. However, it was indicated that other individuals in the department, particularly those at the district level, might respond differently about going from Level 2 to Level 1. For this reason, it was decided to obtain group consensus on this question of how much one would be willing to pay to increase the maintenance level-of-service from Level 2 to Level 1. The group session, which is discussed in the next section, indicated that the group would be willing to pay about 8 percent more to go from Level 2 to Level 1.

The above assessments provided relative values of the four levels of the index of pleasing appearance (θ_3). Letting $V_3(i)$ denote the value of the i^{th} level, we get

$$V_3(3) = 1.5\ V_3(4)$$
$$V_3(2) = 3\ V_3(4)$$
$$V_3(1) = 3.08\ V_3(4).$$

If $V_3(4)$ is set to 1, the other relative values would be: $V_3(3) = 1.5$, $V_3(2) = 3$ and $V_3(1) = 3.08$. Since the end points of a value function were assumed to be 0 and 1, a linear transformation of the relative values was made by subtracting the minimum value (i.e., 1) and dividing by the range (i.e., 2.08).

Thus, the relative values are:

$$V_3(1) = 1;\ V_3(4) = 0$$
$$V_3(2) = \frac{3 - 1}{3.08 - 1} = 0.96$$

and

$$V_3(3) = \frac{1.5 - 1}{3.08 - 1} = 0.24$$

With regard to the index of environmental pollution (θ_4), the specialists were asked: "How much would it be worth to reduce the number of acres sprayed from the highest level (defined as 150,000) to each of the other two levels (120,000 and 60,000)?" Assuming the cost of the highest level to be 100 units, the response of the specialists was that, from the viewpoint of reducing pollution, it would be worth 15 and 30 units, respectively, to reduce the amount of spraying from the highest level to Levels 2 and 3. This yielded the following relative values of the levels of θ_4:

$$V_4(2) = 1.15\ V_4(1)$$
$$V_4(3) = 1.30\ V_4(1).$$

Since the fourth level (see Table 2) involves the same number of acres sprayed as the third level, it follows that $V_4(4) = V_4(3)$. By assigning the values of 0 and 1 to the end points of the scale, we get

$$V_4(1) = 0;\ V_4(2) = \frac{1.15 - 1}{1.30 - 1} = 0.5$$
$$V_4(3) = \frac{1.3 - 1}{1.3 - 1} = 1 = V_4(4).$$

The results of assessment of individual value functions are summarized in Table 5.

Table 5. Assessment of individual value functions of various attributes.

Attribute	Best level	Worst level	Midvalue point for a continuous attribute	Values of intermediate levels for a discrete attribute
1. Percentage of drivers who cannot recover	0	10	5	--
2. Percent increase in pavement rehabilitation cost	0	35	17.5	--
3. Index of pleasing appearance	1	4	--	Value of level 2 = 0.96 Value of level 3 = 0.24
4. Index of environmental pollution	4	1	--	Value of level 2 = 0.5 Value of level 3 = 1.0

Group Session for the Assessment of Value Trade-offs

The specifications of a value function over multiple attributes requires the assessment of trade-offs between competing attributes based on the value judgments of decision makers. In public policy decisions, a number of individuals may share the responsibility of deciding acceptable tradeoffs. It would, therefore, seem desirable that value judgments of decision makers be somehow "pooled" to obtain a "group consensus" that would be used in lieu of the opinion of any one individual. It is generally assumed that group consensus would have greater validity than individual value judgments in the assessment of tradeoffs. The technique used for trying to obtain group consensus values was the Delphi procedure.

The Delphi group sessions included eight individuals within the Louisiana Department of Transportation and Development who were involved in establishing current levels-of-service.

The sessions included a period of orientation during which pertinent background information was discussed. The procedures were explained and illustrative examples were acted out for the group.

Assessment Forms. Three assessment forms were used in the group sessions.

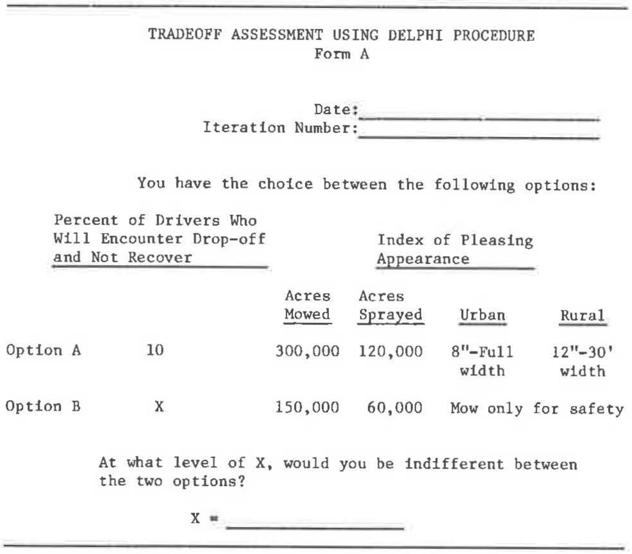
Form A: assessment of tradeoff between percentage of drivers who cannot recover and index of pleasing appearance.

Form B: assessment of tradeoff between percent change in pavement rehabilitation cost and index of pleasing appearance.

Form C: assessment of tradeoff between percentage of drivers who cannot recover and index of environmental pollution.

A blank copy of assessment Form A is shown in Figure 1.

Figure 1. Form A.



TRADEOFF ASSESSMENT USING DELPHI PROCEDURE
Form A

Date:____________
Iteration Number:____________

You have the choice between the following options:

	Percent of Drivers Who Will Encounter Drop-off and Not Recover	Index of Pleasing Appearance			
		Acres Mowed	Acres Sprayed	Urban	Rural
Option A	10	300,000	120,000	8"-Full width	12"-30' width
Option B	X	150,000	60,000	Mow only for safety	

At what level of X, would you be indifferent between the two options?

X = ____________

The results from the group sessions are summarized in Table 6.

Determination of the Optimum Combination of Maintenance Levels-of-Service

The objective of this step is to find the optimum combination of maintenance levels-of-service for all of the maintenance conditions included in the system. The criterion used for optimization is to maximize the overall value of highway user benefits subject to the constraints of available resources (dollars, person-days, etc.). The user benefits are specified in terms of the effects of levels-of-service on various considerations, such as safety, aesthetics, and protection of investment. The effects on these considerations are measured by the appropriate attributes, such as percentage of driver who cannot recover, index of pleasing appearance, and percent change in pavement rehabilitation cost.

Table 6. Consensus value tradeoffs between different pairs of attributes.

	Percentage of drivers who cannot recover		Index of pleasing appearancex	
Option A	10	Balancing Reward	1	Penalty
Option B	5.9		4	
	Percent increase in pavement rehabilitation cost		Index of pleasing appearance	
Option A	35		1	
Option B	15.4		4	
	Percentage of drivers who cannot recover		Index of environmental pollution	
Option A	10		4	
Option B	8.6		1	

Optimization Program

Mathematically the optimization problem is formulated as follows:

Let X_{ij} denote a binary variable such that

X_{ij} = 1 if the j^{th} alternative level-of-service (e.g., repair when edge of traveled-way drop-off is 2 inches) is selected for the i^{th} maintenance condition (e.g., edge of traveled-way drop-off).

= 0 if the j^{th} alternative level-of-service is not selected.

The objective of the analysis is to determine X_{ij} for all i and j to maximize $V(\theta_1,\theta_2,\ldots,\theta_n)$ subject to the following constraints:

$$\sum_i \sum_j C_{ij}X_{ij} \leq \text{available budget, } B$$

$$\sum_i \sum_j M_{ij}X_{ij} \leq \text{available person-days, } M$$

$$\sum_j X_{ij} = 1$$ (Only one of the alternative levels-of-service for each maintenance condition is to be selected.)

in which C_{ij} = cost of implementing the j^{th} level-of-service for the i^{th} maintenance condition, and

M_{ij} = person-days required for implementing the j^{th} level-of-service for the i^{th} maintenance condition.

A nonlinear integer programming algorithm has been developed to solve the above optimization problem. The algorithm has been coded in the computer program ASOP.

Estimation of Attribute Levels. The following estimation model is used in the program:

$$\theta = \sum_{i} \sum_{j} B_{ij} X_{ij}$$

in which θ = an attribute

X_{ij} = 1 if the j^{th} level-of-service for the i^{th} maintenance condition is selected.
= 0 if the j^{th} level-of-service is not selected.

B_{ij} = coefficient which estimates the incremental effect of X_{ij} on θ.

The first summation in the above equation is over all the maintenance conditions which affect θ, and the second summation is over all alternative levels-of-service for each of these maintenance conditions.

For the demonstration example in Louisiana, each attribute is affected by only one maintenance condition. Percentage of drivers who cannot recover (θ_1) and percent change in pavement rehabilitation cost (θ_2) are affected only by edge of traveled-way drop-off. Similarly, index of pleasing appearance (θ_3) and index of environmental pollution (θ_4) are affected only by roadside vegetation growth.

Program Output

The program output consists of the following parts:

Print Input Data. All input data are printed so that the accuracy of the data can be checked and information useful in evaluating the results is readily available.

Print Parameters of Value Function. The program computes the constants of the value function for each attribute in a quadratic form. These constants are printed.

The tradeoff information is used to calculate the scaling constants (relative weights) of different attributes. The scaling constants are also printed.

Print Estimation Coefficients. The estimation coefficients, B_{ij} are printed for each attribute.

Print Results of Base Case Analysis. The output describes the optimum solution, i.e., the level-of-service which should be adopted for each maintenance condition so as to maximize overall value (to highway users) while satisfying the resource constraints. The actual resources required to implement the optimum solution are displayed. The overall value of the optimum solution (on a scale of 0 to 1) is printed along with the contributions of the various attributes to the overall value.

Results of Base Case Analysis

Figure 2 shows the results of the base case analysis included in the program output. The optimum levels-of-service are:

1. Repair when edge of traveled-way drop-off is 1-inch.
2. Mow 300,000 acres and spray 120,000 acres. (This vegetation control program would allow mowing grass full width before it reaches 8 inches in urban areas and mowing grass 30 feet from the edge of the traveled surface after it exceeds 12 inches in rural areas.)

Figure 2. Results of the base case analysis.

```
Complete Enumeration


The selected policy is:

Edge of traveled-way drop-off     Repair when drop-off is 1-inch.
Vegetation growth                 Mow 300.000 acres and spray
                                    120,000 acres.


                         Costs of the Selected Policy

Materials (thousands of dollars)  Available - 5130, used - 5130
Thousands of Labor-Hours          Available - 644, used -  644
Equipment (thousands of dollars)  Available - 3380, used - 3377


                        Evaluation of the Attributes

Safety--percent of drivers who cannot recover
Individual value - 1.000          Weighted value -  .438

Percent change in rehabilitation costs
Individual value - 1.000          Weighted value -  .321

Pleasing appearance
Individual value - 0.962          Weighted value - 0.173

Environmental pollution
Individual value - .500           Weighted value -  .031


                      THE VALUE OF THIS POLICY IS 0.96
```

The levels-of-service currently used in Louisiana for the two maintenance conditions are also the optimum levels-of-service selected by the program. This was to be expected because only a few variables had to be considered for the example, the analysis assumed the resources currently used for the two maintenance conditions, and the value judgments of those involved in setting the current levels-of-service were used. The strength of the methodology is that it will consistently select optimum levels-of-service when a large number of maintenance conditions were analyzed and when changes in the current maintenance budget become necessary. The overall value of the optimum solution is 0.96. The optimum levels-of-service provide the highest user benefits possible for the two maintenance conditions. No improvement in these levels-of-service would be possible even if higher amounts of resources were available. An examination of the contributions of the four attributes to the overall value reveals that the two attributes related to edge of traveled-way drop-off (percentage of drivers who cannot recover and percent change in rehabilitation cost) contribute 79 percent of the total value, while the remaining 21 percent of the total is contributed by the roadside vegetation attributes.

Sensitivity Analysis

The objective of this step is to assess the influence of changes in some of the major inputs and assumptions on the selection of the optimum combination of levels-of-service. The output of this analysis would identify the parameters to which the selection of optimum levels-of-service is very sensitive. The assessment of such parameters would obviously warrant more careful consideration.

The computer program ASOP has been designed to perform the following types of sensitivity analyses when requested by the user:

1. Effect of Changes in Available Resources. Available amounts of one or more resources may be changed and the effect on optimum levels-of-service may be examined.
2. Changes in Tradeoffs. The tradeoffs used in the base case analysis represent group consensus values obtained in the Delphi procedure. These tradeoffs yield the relative weights of various attributes. If significant differences of opinions were observed during the group session, different tradeoffs between attributes may be used in finding optimum levels-of-service. If the effect on optimum levels-of-service is significant, the differences in opinions are clearly critical and need to be resolved before levels-of-service can be selected.
3. Mandatory Inclusion of Specified Levels-of-Service. For certain important maintenance conditions, relatively high levels-of-service may be required; for example, the edge of traveled-way drop-off may be required to be less than 1-inch. The program can fix such levels-of-service and optimize on the remaining maintenance conditions.
4. Mandatory Exclusion of Specified Levels-of-Service. Certain levels-of-service may be considered to be impractical or infeasible. For example, with respect to edge of traveled-way drop-off, the lowest level-of-service (repair when drop-off is 5 inches) may be excluded from the analysis. The program will eliminate such a level-of-service from the search for the optimum solution.
5. Exclusion of Best Solution. This option would find the second best solution. If the value of this solution is nearly as good as that of the best solution, but the resources required for the second best solution are significantly lower than those required for the best solution, then the second best solution may be preferred.

In conducting the sensitivity analyses for the demonstration example in Louisiana, advantage can be taken of the fact that none of the attributes is simultaneously affected by both the maintenance conditions. Consequently, it is possible to determine the complete contribution of a given level-of-service of each maintenance condition to the overall value. The results are shown in Figure 2.

Recommendations

Recommendations are formulated after evaluating the results of the base case and the sensitivity analyses. The recommendations should include the following:

1. The optimum level-of-service for each maintenance condition in the system.
2. Resources which would be used in implementing the optimum levels-of-service.
3. Scenarios (e.g., budget cuts) which would require significant changes in the optimum levels-of-service.

Conclusions

The effort in Louisiana shows that it is feasible to use the methodology developed in this project to select levels-of-service for highway maintenance which would maximize user benefits subject to the constraints of available resources. The types of inputs required for the analysis can be obtained from the data base of information currently available to a state transportation department. The data base includes information available in the literature, studies conducted within the department, information available from maintenance management systems, and experience and judgment of knowledgeable individuals within the department.

The methodology requires the assessment of value judgments regarding tradeoffs between different considerations, such as safety, protection of investment, aesthetics, and environmental pollution. A Delphi procedure was used in Louisiana to obtain group consensus regarding tradeoffs from a number of individuals responsible for selecting levels-of-service both in the field and at headquarters. Certain improvements in the implementation of the Delphi procedure would seem desirable based on the experience in Louisiana. However, the types of assessment questions which need to be asked in the Delphi procedure are certainly practical and relevant to individuals involved in highway maintenance.

It would be desirable to provide certain types of objective data to the participants in the Delphi exercise in order to obtain more consistent and reliable value judgments. Examples of such data include statistics on accidents resulting from driving over the edge of traveled-way with various amounts of drop-off and surveys of user opinions regarding aesthetics of roadside vegetation under varying levels-of-service. These kinds of data are currently not available. The initial implementation of the methodology will identify the critical parameters on which objective data would be most useful. Limited studies to collect these data can be undertaken. The reliability of the results of the methodology would be expected to increase with the availability of additional data.

The computer program prepared for the use of the methodology facilitates the analysis significantly. The program is designed such that the assessed data can be directly input and all parameters (such as value coefficients, relative weights, and regression coefficients) are computed internally in the program. This relieves the user of the burden of making external calculations, which would require some theoretical background in decision analysis techniques.

The demonstration example in Louisiana involved only two maintenance conditions--namely, edge of traveled-way drop-off and roadside vegetation growth. The complete system of highway maintenance could involve 20 to 25 maintenance conditions of practical significance.

Acknowledgements

This study was conducted under the National Highway Research Program, Project 14-5. The opinions and findings expressed or implied in this paper are those of the authors. They are not necessarily those of the Transportation Research Board, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, nor the individual participating states.

The authors wish to acknowledge the efforts of the Louisiana Department of Transportation and Development for their assistance in the demonstration phase of the project. Special thanks are extended to Mr. Gerald Ray for his assistance.

The NCHRP Project Engineer was Mr. Ian Kingham and the authors wish to express their appreciation for his encouragement and advice during the project.

Mr. Ezio Alviti and Mr. Fereidoon Sioshansi assisted in various parts of the project and their efforts are hereby acknowledged.

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ENGINEERED PERFORMANCE STANDARDS

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Maintennace Management was adopted by most states because it provided managers with the ability to plan, organize, direct and control maintenance activities. Although Florida's system has significantly advanced since its implementation, we still were concerned about our inability to consistently verify our performance standards. These standards were initially established and modified each year based on subjective judgment resulting in considerable and often non-conclusive discussion. Realizing that Performance Standards are the basic building block of a properly functioning Maintenance Management System (MMS), we decided to seek professional assistance. In 1974 we entered into a research contract with the University of Florida Industrial Engineering Department to develop a method of analyzing maintenance crew activities to be used to create "Engineered Standards". The final product of the research developed a method utilizing motion pictures supplemented with stopwatch times. The results of this type of analization enables an observer to determine the actual percentage of time each worker was engaged in productive work. Using this process, a standards committee can not ascertain the correct blend of resources required to perform an activity and has resulted in assigning unused workers to other tasks. Generally this analysis produces an increase in productivity which was our desired goal and at the same time it has improved the credibility of Maintenance Management with all levels of management.

Most states adopted a Maintenance Management System (MMS) because it provided managers with the ability to plan, organize, direct and control maintenance activities. While many variations of Maintenance Management Systems exist, most accomplish the same basic function of providing managers with a timely overview of field operations. In spite of occasional short term setbacks in MMS development, the Florida Department of Transportation has significantly advanced its reliability since implementation. This implementation, which began in 1973, was the result of an opportunity to study, develop, and design our own system using in-house personnel. Not only did this opportunity provide a custom-made system, its developers retained a familiarity of the system enabling them to continue improving the benefits received. However, throughout this process, we were concerned with our inability to consistently verify performance standards to any degree of certainty.

Initially our Standards were established using subjective judgements and were confirmed by field reports of crew operations. Periodic adjustments to these standards were also based on subjective judgement which oftentimes results in considerable and sometimes non-conclusive discussion. It soon became apparent that without a clear cut scientific method of determining an accurate standard, our entire MMS was lacking.

Realizing that Performance Standards are the basic building block of a properly functioning MMS, we began to investigate the "State of the Art" in other states. The response to our inquiries led us to the conclusion that other states had not developed a procedure to produce the desired results either. Their responses did, however, verify our earlier conclusion that the development of such a procedure was indeed possible. The traditional time-and-motion studies, which we currently utilized, not only were costly and time consuming, they also did not readily lend themselves to developing credibility with most Department of Transportation managers. At this point we convinced top management to allow us to develop a methodology to analyze maintenance crew activities. With their approval we decided to seek professional assistance in the art of Methods Engineering.

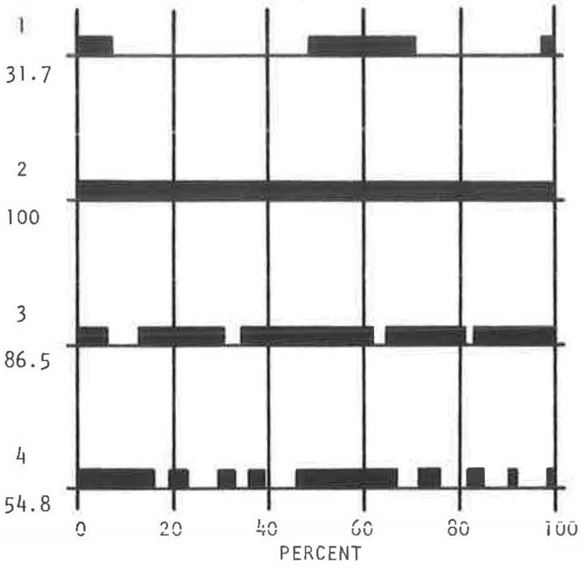
In 1974, we entered into a research contract with the University of Florida's Industrial Engineering Department to develop a method for analyzing maintenance crew activities. The end result of this method would be to create "Engineered Standards". This research finalized a procedure which recommended the extensive usage of a movie camera supplemented by stopwatch timing as used in time-in-motion studies. The results of this type of analyzation enabled observers to determine the actual percentage of time each worker was engaged in productive work and also provided a training medium for crews, supervisors and performance standards development committees.

The "Engineered Standard" study procedure requires two persons, a clipboard, a stopwatch, a 16mm movie camera and projector, a movie film editor and a film splicer. With these resources, plus transportation, the majority of maintenance operations can be studied. Normally each work activity consists of a series of basic cycles which are repeated several times at different locations during the workday. A crew study requires only the observations of a complete cycle and not the entire daily operation. While some inefficiencies may exist outside of the work cycles, the primary goal of the observer is to determine the labor, equipment and materials required to perform each cycle. The number of cycle observations required must be sufficient to provide a statistical pattern, normally this is a minimum of ten (10) and a maximum of fifty (50) observations.

To perform a cycle observation with a study team the following procedure is used:

1. Designate one individual to operate the stopwatch and clipboard; the other person will operate the movie camera.
2. As the work cycle begins the stopwatch is started and the clipboard operator begins a time-and-motion study. When the action becomes too fast to take hand notes or if the work method should be recorded for later reviewing, the camera operator will begin filming. At this time the camera operator advises the stopwatch operator who stops his hand note procedure and notes the time filming began. When the filming ends, the stopwatch operator notes and enters the time and resumes taking hand notes until the end of the cycle. Each cycle may require several starts and stops of the filming. This method not only saves money, when compared to continuous filming, it also provides a detailed record of the operations.
3. Combine stopwatch and clipboard observations onto Multiple Man (Crew) Activity Chart. Table 1 is an example of a four man pavement symbols crew observation.
4. Produce Activity Graphs using Activity Chart data. Table 2 is an example of the same four man pavement symbols crew. The heavy line indicates when a worker is busy or performing necessary work. By observation you can see the percentage of time when each worker is busy during the cycle and conversly you can determine when no productive effort is evident. These percentages are totaled and shown as a composite for the crew. In this case, to accomplish the cycle a four (4) man crew utilized approximately 273% of the 400% of available time. (Four (4) men times 100% = 400%)

Table 2



TOTAL TIME: Busy = 273.0%
Idle = 127.0%

After fifteen (15) observations of the same operation, the average busy time dropped to 214% out of a possible 400%. Further analysis determined that two (2) men performed the cycle operations as fast as the four (4) man crew and required less man-hours to accomplish each cycle. Based on these observations, a determination was made to establish two (2) man work crews for this activity for experimental purposes. These crews were allowed to develop their own working procedures and after a short adjustment period the crew study group performed observations of similar work cycles. Tables 3 and 4 show the Multiple Man Activity Chart and the Activity Graph for a two (2) man crew performing the identical operations in the same locations used to develop the information shown in Tables 1 and 2. Note that the total busy time for the two (2) man crew is 184% out of a possible 200% available.

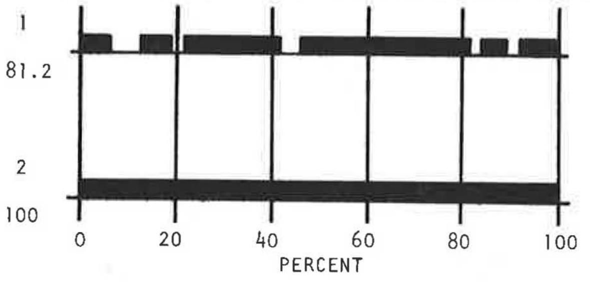
TABLE I - MILTIPLE MAN (CREW) ACTIVITY CHART - ACTIVITY NUMBER 532

First Worker		Second Worker		Third Worker		Fourth Worker	
Name: Smith Title: Foreman II		Name: Brown Title: Tech II (Painter)		Name: Jones Title: Tech II (Beads)		Name: White Title: Tech II (Template)	
Run Time	Activity	Run Time	Activity	Run Time	Activity	Run Time	Activity
0.20	Place Cone	0.34	Start Comp.	0.28	Get Beads	0.40	Get Template
0.29	Idle	0.51	Remove Wand	0.60	Idle	0.59	Idle
0.91	Adjust Air	0.57	Begin Painting	0.97	Sprinkle Beads	0.68	Get Template
1.00	Idle	0.90	Idle	1.10	Place Template	0.78	Idle
1.40	Ajust Air	1.05	Painting	1.18	Sprinkle Beads	1.01	Move Template
1.46	Idle	1.52	Idle	1.51	Idle	1.18	Idle
2.50	Load	1.60	Walking	1.65	Walking	1.46	Move Template
2.72	End	1.67	Painting	1.80	Sprinkle Beads	1.66	Idle
		1.85	Idle	1.89	Idle	1.87	Move Template
		2.01	Painting	2.08	Move Template	1.95	Idle
		2.38	Loading	2.37	Sprinkle Beads	2.39	Move Template
		2.72	End	2.49	Idle	2.50	Load
				2.55	Loading	2.72	End
				2.72	End		

TABLE 3 - MULTIPLE MAN (CREW) ACTIVITY CHART
ACTIVITY NUMBER 532

First Worker		Second Worker	
Name:	Smith	Name:	Jones
Title:	Foreman II	Title:	Maint. Tech. II
Run Time	Activity	Run Time	Activity
0.08	Place Cones	0.07	Get Template
0.31	Remove Hoses	0.25	Get Beads
0.50	Begin Painting	0.52	Sprinkle Beads
0.72	Clean Pavement	0.70	Move Template
0.85	Idle	0.88	Get New Template
1.10	Painting	1.11	Sprinkle Beads
1.28	Walking	1.28	Walking
1.39	Painting	1.40	Sprinkle Beads
1.52	Clean Pavement	1.57	Move Template
1.65	Idle	1.85	Sprinkle Beads
1.90	Painting	2.10	Replace Beads
2.11	Replace Hoses	2.30	Idle
2.29	Pick Up Cones	2.44	End
2.44	End		

Table 4



TOTAL TIME:
Busy = 184.2%
Idle - 15.8%

When presented with this information, the Standards Committee agreed to alter the performance standard for the pavement symbols activity using the procedures developed for the "Engineered Standard" method. The results obtained from the new procedure are included on Table 4. This table shows the man-hours per unit rate obtained before and after the 1977-78 implementation date of the new standard. You will note that the results actually received appear smaller than they theoretically should be. This situation was caused by the necessity to modify work procedures which added additional man-hours to complete the same task. These modifications allowed the task to be repeated at two (2) year intervals instead of at six (6) month intervals as in the past. The net result of using the new procedure is approximately a 14% increase in productivity, while decreasing the total workload. Similar results are now being obtained on other activites.

TABLE 5

FISCAL YEAR	MANHOURS/UNIT
75-76	0.0256
76-77	0.0254
77-78	0.0227
78-79	0.0216

Managers of maintenance operations should consider the benefits which may be obtained from the "Engineered Standard" process. The existence of a MMS is not the only criteria to a successful maintenance program. If it were, it would be a simple matter to plan your work and let it run its own course. Maintenance work is difficult at best, it is subject to weather, traffic, monetary and political influences and needs to be constantly managed in order to meet the objectives established by top management. To do this, you will need to review performance data, to constantly evaluate field conditions against planned conditions, and to modify the system to improve results. A MMS quantifies maintenance activities and provides a basic tool to manage maintenance resources. Incorporation of the "Engineered Standards Method" can provide additional insight for the management process, which if used properly, will provide the best maintenance service that can be afforded with the funds that are available.

INCORPORATING QUALITY STANDARDS AND IMPACTS WITHIN HIGHWAY MAINTENANCE MANAGEMENT

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Assessments of future maintenance needs, levels of effort, and costs have traditionally been expressed through predictions of maintenance supply (generally in units like dollars or manhours per lane mile). Although this approach is adequate for many management needs, it does not enable one to explore systematically the effects of changes in maintenance policy on future costs and road performance. However, the increasingly important strategic role to be played by maintenance and rehabilitation, and higher costs of providing maintenance services, have recently focused attention on better management practices to define maintenance demands, establish priorities among maintenance activities, and relate alternative policies to future impacts on road service. This paper describes the development of demand-responsive concepts for maintenance planning and policy formulation, based upon work conducted in separate projects for the Commonwealth of Massachusetts and the Federal Highway Administraiton. Analytical components of the demand-responsive approach include (1) numerical measures of maintenance levels of service, or quality standards; (2) quantitative model to predict the condition or deterioration of specific road features as a function of the relevant physical, environmental and traffic factors; and (3) quantitative models to assess the impacts of maintenance performance, as for example in the areas of preservation of investment, user consequences, and accident prediction.

Historical Perspective

Maintenance programs at the state level historically have been subject to several simultaneous constraints -- budget limitations imposed by the executive or legislative branch, labor and equipment restrictions, seasonal limitations on certain work activities, inability to shift work from emergency to preventive maintenance, and methods of budgeting and appropriation based upon line-item or accounting categories (rather than upon program priorities), to name a few. These constraints have influenced not only the past thinking of maintenance managers, but also the fundamental structure and approach of the maintenance management systems that have evolved over the past fifteen years.

The objectives of the systems developed by individual states were to help plan, budget and manage highway maintenance. To overcome the management weaknesses of the line-item or accounting budget, principles of performance budgeting were introduced. Performance budgets organized planning and control around specific maintenance tasks, permitting a more comprehensive and objective review of the distributions of costs by activity, location, or cost element, and fostering comparisons of projected expenditures versus maintenance program objectives. The planning and scheduling components of these systems enabled managers to allocate scarce resources over a year, and to strike a better balance between maintenance priorities and seasonal resource constraints. A work monitoring subsystem, coupled with proper field reporting procedures, provided comparisons between actual and predicted costs, work performance, productivity, and resource consumption, pinpointing maintenance jurisdictions or activities requiring closer attention.

Furthermore, as part of the performance budgeting approach, maintenance models were developed to predict future labor, equipment and materials costs by activity. The approach taken within these models typically involved either (1) regression relationships between annual maintenance costs (or manhours) per unit of road and relevant physical or operating variables (width, pavement type and thickness, average daily traffic, environmental parameters, etc.); or (2) average workload rates, called quantity standards, observed in past maintenance operations and expressed in terms of annual measures of work per unit of road (e.g. for pavement patching, number of tons of material placed per lane mile). The former allowed some variation by location or in year-to-year predictions to account, say for increases in traffic volume or changes in road characteristics; the latter represented essentially statewide averages of maintenance activity performance, and were thus static over different types of roads and over time.

Although the various state systems in use today differ in their scope and level of detail, in general they are characterized by the fact that, in predicting future maintenance requirements, their primary focus is on the **ability to supply maintenance services**. In other words, the predictive models employed estimate the labor, equipment, material, or dollar resources needed to produce some level of maintenance effort, but not the factors that caused the maintenance requirement in the first place. Although this approach is open to criticism, it is understandable in light of the organizational and administrative realities surrounding maintenance program development which were true in the past, and persist to some extent to this day.

There were some key advantages to structuring early maintenance models based upon predictions of supply. First, they were a simple and direct means of estimating future budget requirements using an objective analytic approach. Second, they could implicitly account for special local conditions that would affect the aggregate amount of maintenance required (e.g. types of subgrade soil; local climatic conditions; quality of pavement construction; and so forth), and that might otherwise be difficult to represent explicitly.

Perhaps most importantly, however, these supply-oriented models satisfied local management needs. The institution of performance budgeting measures placed budget development on a more rational basis, but it could not eliminate constraints on the maintenance effort imposed by budget ceilings, labor and equipment limitations, and the like. Rather than concerning themselves with the moot issue of actual maintenance demand, therefore, managers directed themselves instead to the pragmatic question of how to accomplish maintenance more efficiently under a fixed level of resources. Performance budgeting concepts, assisted by models based upon maintenance supply, were adequate for this task.

Demand-Responsive Concepts

Motivation

Several trends through the 1970s have advanced maintenance management needs beyond work monitoring, budget prediction and cost control, to broader issues of maintenance policy planning. First, the national highway investment has grown by at least \$200 billion in 1979 dollars (1), due largely to near completion of the Interstate program. Many of these highways are approaching ages of 15-20 years; maintenance responsibilities, and the need to estimate and allocate available resources effectively, will increase accordingly. Second, significant changes in the funding of highway maintenance and rehabilitation appear forthcoming, as evidenced by declines in user tax collections and initial Federal involvement through the 3-R program; procedures to allocate available funds, and to assess the impacts of maintenance deferred or foregone, will likely be required. Third, several independent developments -- such as heavier allowable vehicle loads, the advent of new maintenance technologies, and stricter legal interpretations of highway maintenance liability -- collectively imply changes in maintenance needs and methods of performance over time. The tendency is growing to counter arbitrary annual budget restrictions with better information on what impacts the provision or rejection of additional maintenance dollars will cause.

Planning Requirements. Managing this changing maintenance program and developing the capability to assign priorities among ever-increasing maintenance demands requires information and analytic methods to properly assess competing needs, and to evaluate costs and impacts of different policies on a national scale. Moreover, to be comprehensive such management approaches must recognize highway maintenance within a broader context of transportation planning and administration, and to view maintenance policy formulation at several levels.

Strategic. First, at a very broad level are strategic decisions concerning use of maintenance versus capital investment to provide a designated level of road performance. The most prevalent examples of these types of decisions are in pavement design, where a close interaction exists between initial design quality and future maintenance needs. Taken to its extreme for very high-volume roads, this type of decision leads to the design of premium or "zero maintenance" pavements involving significant capital investment but eliminating any practical need for maintenance. However, similar investment-maintenance tradeoffs can be cited regarding pavement maintenance versus programs of periodic reconstruction or strengthening; the need for periodic bridge painting versus use of self-oxidizing steels; and construction of paved waterways versus cleaning and shaping of natural ditches, to name a few. In each case the choice of which policy to follow will depend not only on the cost differential between respective alternatives but also on the relative capacity to provide adequate levels of transportation service into the future.

Competing Activities. At a second level lie decisions among several maintenance activities competing for limited maintenance resources. Given a fixed maintenance budget, any increase in the level of maintenance quality provided under one activity is usually accomplished only at the expense of decreased levels of quality in other activities. Therefore a manager faces the problem of allocating resources in such a way as to remain within budget while minimizing adverse impacts (both short and long range) on the utility, safety, and service life of the highway system.

Timing. At a third level there exists for each maintenance activity a tradeoff between the timing and the intensity of the action to be taken, commonly discussed as a question of "deferred maintenance." The impacts of deferred maintenance must be assessed in terms of, first, the costs of performing perhaps more extensive maintenance later; second, the differences in levels of service to users provided under the two maintenance options; and third, any reduction in the expected remaining life of the facility due to the deferred maintenance.

Commentary. Policy determinations of this type are inherently different from the decisions for which current maintenance management systems were designed. As a result, the models described earlier to predict maintenance requirements on the basis of supply lack the conceptual structure to address these broader management issues. Regression analyses and quantity standards drawn from historical data or existing practices implicitly include a particular level of maintenance performance -- namely, the standards to which the road system has been or is currently being maintained. Moreover, they assume a constant rate of deterioration throughout the road system. Thus the models are insensitive to changes in maintenance policy, and are incapable of evalauating either the costs or the impacts of alternative policies. Moreover, to the extent that the regression models predict directly the costs (or labor manhours) required, without computing first an estimate of damage repaired, they deal with work outputs rather than inputs, and are therefore ill-equipped to treat variations in input values (such as productivity, unit costs, or maintenance technology) among geographic regions or over time.

Required Approach. In general, to be able to evaluate competing maintenance (and investment) strategies requires a fundamentally different approach to maintenance prediction, looking at the demand for maintenance as well as supply. The reason is that different maintenance policies are implicitly statements on particular levels of road quality to be retained or restored. However, the workload (and by implication, the costs) required to achieve a given quality depend upon the prior condition of the road system -- i.e. the total maintenance backlog or deficiency caused by normal wear and tear, aging, and increased probability of failure. In an analytical sense maintenance may thus be viewed as a controlled response to the physical state of the highway network, to upgrade or retain highway quality to an acceptable level.

Treating maintenance as a demand-responsive operation requires that three additional concepts be introduced within existing management models. The first is that predictions of future maintenance effort and costs cannot be extrapolated from past trends, but rather must be based upon structural and operational deficiencies in the road system caused by use and deterioration. The second is that in designing models to be sensitive to the implications of different policies, there must be unambiguous statements of the maintenance policy itself, defining the types of future corrective actions to be taken, and when and where they are to commence. The third is that new relationships need to be identified between the as-maintained state of the highway network and the economic and non-market impacts to both the road agency and the motoring public, providing a measure of the benefits (or disbenefits) of each policy at the costs incurred above.

Since this demand-responsive approach is founded upon the prediction of road condition, it follows that any corrective action that restores the highway condition in some way needs to be accounted for. Thus the scope of this approach must be given an expansive interpretation, to include the relevant effects of betterments, rehabilitation and reconstruction, with those of maintenance. This view simply reflects the common-sense notion that capital investments do in fact influence the future demand for maintenance, and vice versa. Moreover, in this sense the demand-responsive methodology provides a fundamental engineering and economic basis for evaluating maintenance policy against alternative investment strategies.

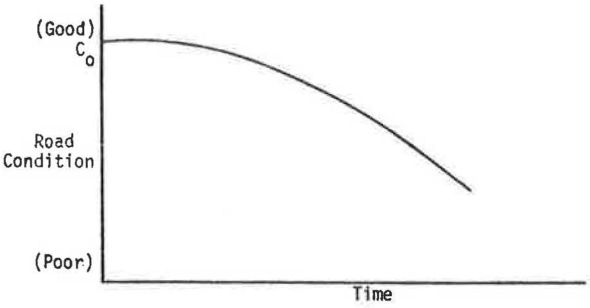
Schematic illustrations of the concepts underlying the demand-responsive approach will be shown in Figures 1 through 8 to be introduced below. The curves in Figures 1 through 8 represent models which, in actual maintenance management systems, would be developed individually for each element of the highway system -- pavements, bridges, drainage systems, signs, and so on -- or for each maintenance activity. For simplicity and generality in the following discussion, however, let us consider these curves for the time being to represent generalized relationships, applicable to a composite maintenance activity over the highway system as a whole.

Maintenance Level of Effort and Costs

Figures 1 through 3 identify those data necessary to predict maintenance level of effort and resulting changes in road condition as a function of different maintenance policies. These data also form the basis for the estimation of future maintenance costs as a function of policy.

Road Deterioration. The changing state of the road system over time is captured within a deterioration relationship defining the system's capacity to withstand the effects of time, traffic loadings, and the environment, as shown in Figure 1. For generality we define road "damage" as any degradation in road condition from its as-constructed state, and "deterioration" to be the net result of accumulated damage. The initial condition C_o and rate of deterioration depend upon the quality of initial design and construction, and upon past maintenance performed. Thus the deterioration relationship in Figure 1 provides the engineering basis on which one may investigate different maintenance versus investment options.

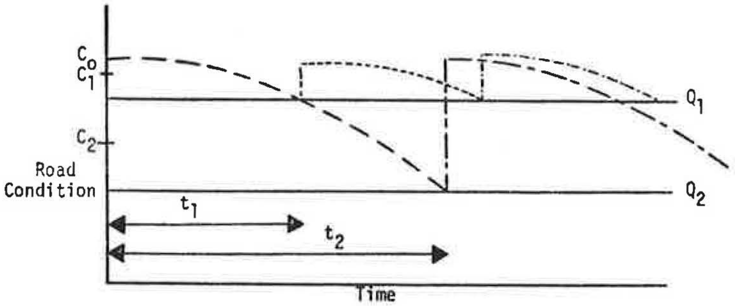
Figure 1. Determining maintenance level of effort under a demand responsive approach: deterioration relationship.



Quality Standards. Maintenance policies may be expressed through "quality standards" defining thresholds at which work should be performed. The interaction between two alternative quality standards, Q_1 and Q_2, and respective road system conditions is illustrated in Figure 2. The different quality standards result (not unexpectedly) in two different trends in road condition over time. If we adopt a simple time average for illustration, the higher quality standard Q_1 results in a higher average system-wide condition C_1. Also, the frequency of maintenance under Q_1 is greater than that under Q_2, in that $t_1 < t_2$.

Under this approach quality standards have a unit of measure commensurate with that of the deterioration model. Decomposing the condition of the road system into its constituent elements, we see, for example, several indices appropriate for pavements. One is a measure of pavement serviceability, such as AASHTO's Present Serviceability Index (PSI), or Canada's Ride Comfort Index (RCI). A second would be a measure of surface damage, such as skid number (SN), roughness value (R), cracking index (CI), or mean rut depth (RD)

Figure 2. Determining maintenance level of effort under a demand responsive approach: quality standards defining thresholds.

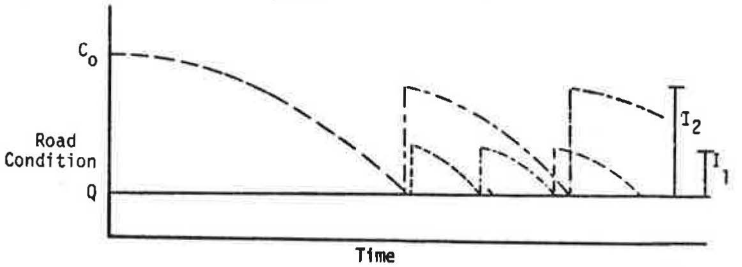


defined by many states employing surface measurement equipment. A third might be a measure of available pavement capacity or response, such as dynamic deflation. Analogous measures could be established for other highway elements; e.g. lineal feet of guardrail damaged, area of bridge deck damage, and depth of siltation in culverts, to name a few.

For some highway elements, however, it may be theoretically possible to identify a physical measure of condition, but it may not be practical to use within a quality standard. Consider, for instance, the replacement of defective signal lamps, which usually must be done soon after failure. A possible measure for signal condition would be "probability of lamp failure within the next so-many months," but it is typically more convenient for the quality standard to use instead some frequency of lamp replacement which anticipates lamp failure. Figure 2 demonstrates that for a given deterioration curve, specifying the frequency of maintenance is equivalent to establishing some implicit quality level. This concept may be used to advantage in the identification of quality standards for particular maintenance activities.

Variation in Application of Standards. In Figure 2 it was assumed in each case that all current maintenance deficiencies were fully corrected. A more realistic situation, however, is that at any given time only a portion of the accumulated damage in the system is repaired through maintenance. From a policy perspective this type of decision can be controlled by how the quality standards are applied on a system-wide basis. Figure 3 illustrates two different applications of a given quality standard Q: one results in relatively frequent but minor correction I_1, while the other undertakes less frequent but major I_2. Note that neither I_1 or I_2 are sufficient to restore the system to its initial condition at construction.

Figure 3. Determining maintenance level of effort under a demand responsive approach: application of quality standards defining extent of repair.



There are three general ways in which the application of quality standards may be varied to produce different levels of repair. One is by adjusting quality standards among different activities which in some sense substitute for one another. For example, the extent to which corrections of pavement damage are remedied by overlays (as opposed to routine maintenance activities) will influence the magnitude of I achieved overall in a given work period. A second way is by assigning different quality standards among various links within the network. Since repair of some locations will implicitly be given priority over other locations, this variation in quality standards will also affect the extent of improvement I on a system-wide basis. Finally, quality standards (and their associated maintenance actions) may be restricted to those classes of damage most critical to road integrity and performance. For example, the "percent of pavement area cracked" may be interpreted to include only cracks greater than a certain width; "guardrail damage," to comprise broken and severely deformed sections, but not dented ones; and "grass height requiring mowing," evaluated only within a certain distance of the pavement edge, but not over the entire mowable area. Qualifications of this type intentionally limit the extent of improvement I in comparison to the total deterioration absorbed by the system.

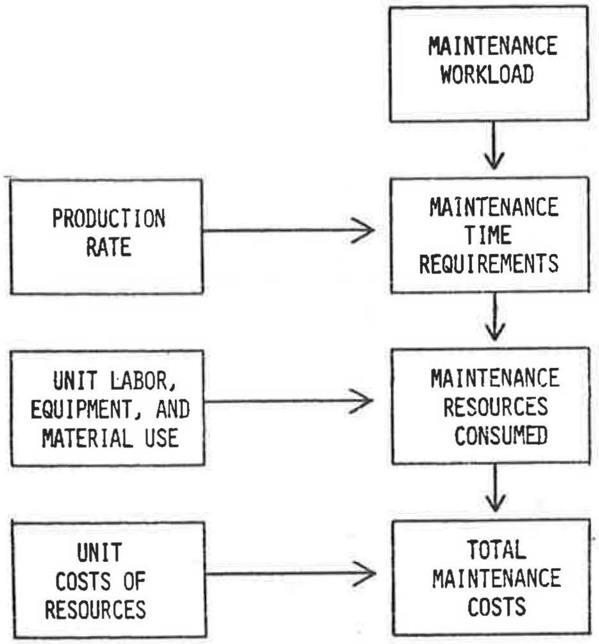
Maintenance Costs. In Figures 2 and 3 the total maintenance level of effort over the system life under policy Q is a function of the product of the frequency of maintenance (proportional to 1/t) and the improvement in condition I each time maintenance is performed. The costs of different maintenance policies may then be computed by calculating the costs to accomplish respective improvements I, discounting these at an appropriate rate according to their projected time of occurence t, and summing the discounted totals for each policy alternative.

From our discussions earlier, the units of measure of system condition C, and therefore of the extent of improvement I, may be in terms of serviceability indices, damage indices, or road response indices. Regardless of the measure of I employed, however, it is obvious that an improvement in condition must be accompanied by the correction of a certain amount of damage, whether for example in square feet of pavement cracking filled, lineal feet of guardrail straightened, number of signal lamps replaced or lineal feet of drainage lines cleaned. The explicit measure of damage corrected we will call the maintenance workload W. In mathematical terms, then, an improvement in condition I implies a particular maintenance workload W, or $I \rightarrow W$. (In some cases the units of I and W may be identical. In others a function must be identified relating I and W.)

Maintenance workload provides the basis for estimating maintenance costs, as shown in Figure 4. To a given workload may be applied a production rate (e.g. average number of damage units repaired per day) to obtain overall crew time requirements. Workload and crew time may be translated into resources consumed (manhours, equipment hours, materials quantities) through unit labor, equipment and materials usage (e.g. number of laborers or pieces of equipment per crew, materials quantity required per unit of damage), all a function of the maintenance technology employed. Finally, resource requirement may be multiplied by the respective unit costs of labor, equipment and materials to obtain total maintenance costs desired.

The relationships in Figure 4 point to the supply side of maintenance, and are thus similar to models employed in contemporary maintenance management systems discussed earlier in this paper. The difference between the two approaches (that in Figure 4 versus existing models) is in the estimation of the workload itself. Whereas existing models predict workload (or some proxy for workload) directly from past experience, in Figures 2 and 3 we have predicted it based upon demand-side considerations of system condition and maintenance policy. The separation of demand-side and supply-side contributions to maintenance costs (represented by Figures 2, 3, and 4 respectively) is a particularly valuable management capability where, as identified at the beginning of this paper, several aspects of highway maintenance and operation are changing simultaneously.

Figure 4. Calculation of the maintenance costs.



For example, the demand-side relationships in Figures 2-3 account for not only variations in maintenance policy, but also for the effects of higher (perhaps unforeseen) traffic volumes and weights, unusually adverse weather conditions, and changes in highway design and construction standards. For a given maintenance policy the contributions of these effects to maintenance costs are transmitted via changes in the maintenance workload.

On the other hand, the supply-side relationships in Figure 4 account explicitly for changes in maintenance technology, work practices, supervisory requirements, crew productivity, and unit costs of maintenance resources. The contributions of these factors to total maintenance costs are superimposed upon, but independent of, the costs attributable to total workload arising through maintenance demand.

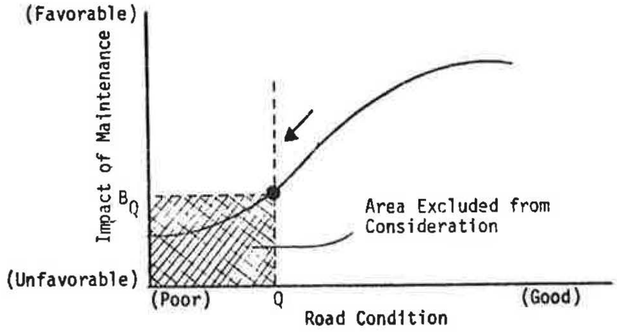
Maintenance Impacts

Better maintenance policies will generally cost more. In evaluating the merits of different policies, therefore, one cannot look only at the costs incurred, but must also judge whether what is gained under higher quality standards is worth the additional dollars spent. Fortunately, the process of predicting the impacts of maintenance is directly compatible with the demand-responsive concepts introduced in Figures 2-3 earlier. The mechanics of assessing maintenance impacts are illustrated in Figures 5-8.

The relationship needed to predict maintenance impacts is illustrated schematically in Figure 5. The measure of road condition shown on the abcissa is identical to that discussed in Figures 1-3. Consistent with other aspects of our example, maintenance impacts are shown in very general form on the ordinate. These impacts may in fact encompass diverse results of maintenance performance, such as the contribution to remaining road life, decreases in user operating costs, and increases in motorist safety and convenience. (For simplicity we assume, both in Figures 5-7 and in the discussion below, that maintenance impacts are cast in the form of relative benefits. However, they may also be represented as disbenefits as for example, in added congestion costs due to road occupancy for maintenance. The conceptual approaches to both benefits and disbenefits would be similar.)

As before, the condition denoted by the quality standard Q defines the threshold at which maintenance will be performed; Q is a control variable expressing maintenance policy. In Figures 2-3 it was assumed that the system condition does not fall below Q. From Figure 5, then, the minimum level of impacts that can be experienced in the road system is B_Q, and the points lying within the hatched area denote conditions and impacts that should be absent within a road system subjected to a quality standard Q.

Figure 5. Determining maintenance impacts under a demand responsive approach: maintenance impact relationship.



Performing maintenance will improve the system in some sense, thereby also providing positive impacts to the road agency or the motoring public. Figure 6 illustrates this for the case of modest maintenance improvement I_1; and Figure 7, for a more substantial improvement I_2. (Refer to Figure 3 for illustrations of different levels of maintenance improvement.) Both of these improvements are gauged from the same quality level Q. On the other hand, Figure 8 illustrates the effects on maintenance impacts of varying both the quality standard Q and the associated level of improvement I.

Figure 6. Determining maintenance impacts under a demand responsive approach: benefits from maintenance.

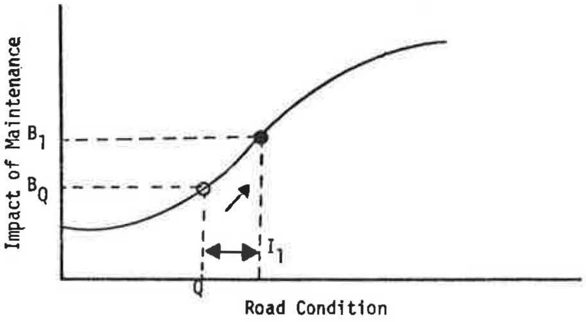
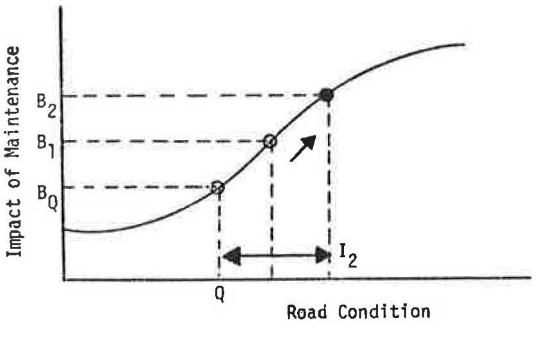


Figure 7. Determining maintenance impacts under a demand responsive approach: greater benefits from increased maintenance.

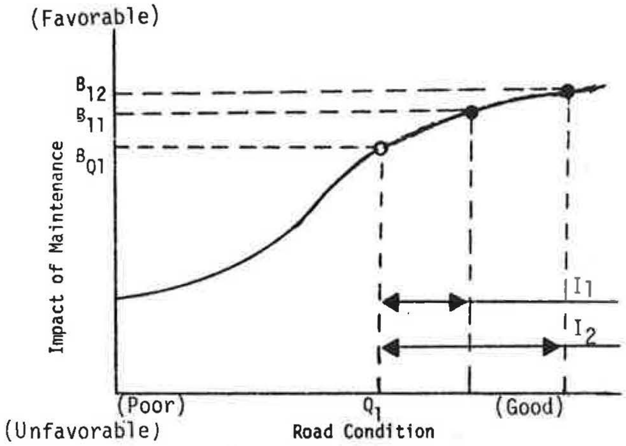


The benefits of maintenance accrue among several aspects of highway structure and operation. We have chosen three major areas of impacts -- preservation of the road investment, user travel and operating costs, and safety -- for initial investigation under a research project for FHWA. Others could also have been chosen -- highway aesthetics or environmental effects, for example. The point is that some, but not all, maintenance impacts can be reduced to monetary benefits. This fact in turn implies a need for a multidimensional analysis of maintenance impacts above and beyond traditional approaches such as benefit-cost comparisons.

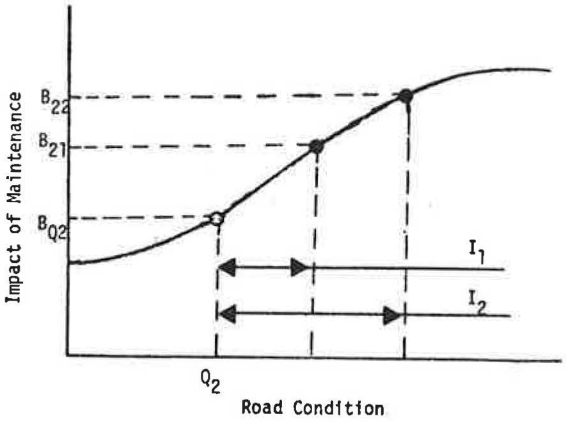
Another point has to do with the magnitude of benefits received for a given improvement in road system condition. This relationship depends upon the shape of the impacts vs. road condition function, which we have hypothesized in Figures 5-8 to take the form of an S-curve. The assumption here is that the marginal benefits of maintenance performance are greatest within some mid-range of highway system condition. If the system has deteriorated completely, then virtually nothing is to be gained by doing modest amounts of maintenance; wholesale repairs, overlays, and rehabilitation are needed instead to restore more favorable impacts. On the other hand, performing excessive maintenance can lead to diminishing returns. In

Figure 8. Maintenance impacts under different quality standards and levels of improvement.

A. Maintenance improvements under higher quality standards.



B. Maintenance improvements under lower quality standards.



such cases, the costs of providing this very high degree of maintenance may be questioned, particularly if the reallocation of maintenance dollars among other maintenance activities (or road sections) presents the possibility for greater marginal benefits.

Management Implementation

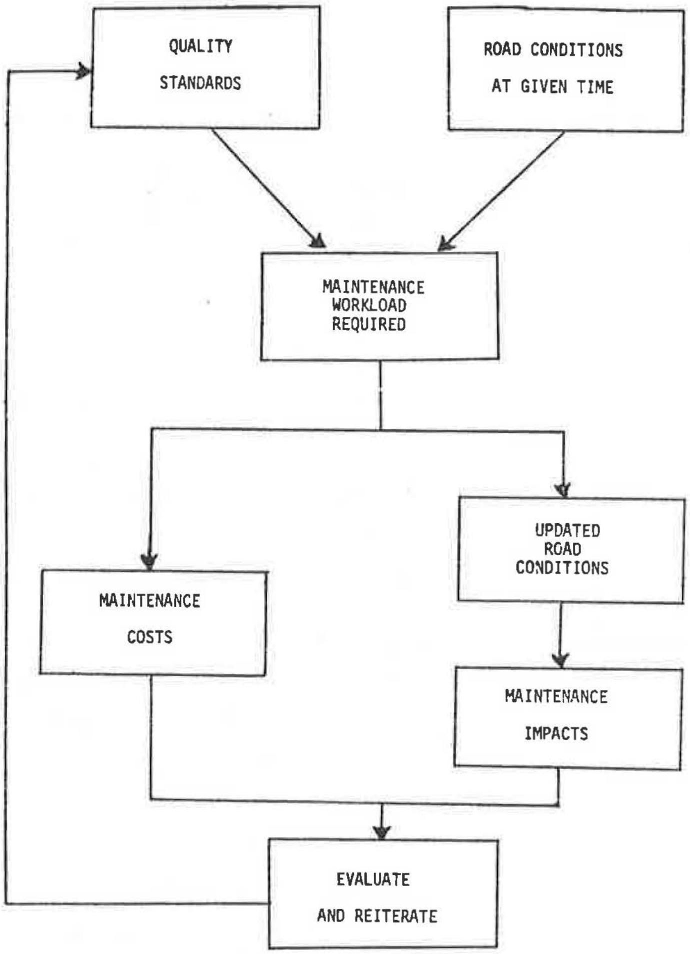
The concepts embodied in Figures 1 through 8 collectively define a management approach to evaluating future maintenance policies or strategies. Organization of these ideas within a unified structure is shown in Figure 9, whose key elements are summarized below.

Annual maintenance is viewed as a demand-responsive operation; that is, a function of the demand accumulated in the highway system in a given year. This deterioration can be estimated from the initial condition of the system (i.e. its as-constructed quality), its rate of deterioration over time, and past maintenance performed. Beyond these physical conditions, however, maintenance workload requirements are also subject to policy decisions defining the type, location, and extent of work to be provided. Maintenance policies are expressed through quality standards specified for the set of maintenance activities over all sections of the road system. Elements of this demand-responsive methodology were introduced in Figures 1-3 and are summarized in the top half of Figure 9.

For a given strategy the estimated maintenance workload may then be costed according to the procedures set forth in Figure 4. At the same time, the simulated accomplishment of this maintenance will improve the condition of the road system, generating a set of maintenance impacts as envisioned in Figures 5 through 8. The calculation of costs and impacts of a given strategy are thus seen as parallel computations in Figure 9.

Maintenance policy evaluation entails a comparison of both relative costs and relative impacts between the strategy under consideration and other maintenance and investment options available. If maintenance impacts could be reduced completely to monetary units, then techniques such as benefit-cost or net-present-value analyses could be applied to determine the optimal strategy. However, in the more general case where impacts are multidimensional, it becomes difficult to state what the "best" maintenance strategy should be. We have

Figure 9. Approach to demand-responsive maintenance management.



therefore suggested in Figure 9 an iterative approach, wherein the results of one strategy can be analyzed to suggest further options more favorable in terms of costs, impacts, or both. By adjusting quality standards through successive trials, maintenance managers can identify a maintenance policy encompassing acceptable (or at least non-objectionable) costs and impacts. Although this procedure requires a subjective assessment of the impacts of different strategies, its value lies in the fact that the consequences of performing or, alternatively, deferring different highway maintenance activites are explicitly spelled out (with costs) for each maintenance policy considered.

Broadly speaking, the approach in Figure 9 may be applied to address two types of situations. The first situation would be to constrain the values of the impacts desired -- in other words, to establish some range of road system benefits that must be sustained through maintenance and rehabilitation, and not to allow the road system to degrade below the established threshold. Through the iterative procedures in Figure 9 one could infer both the maintenance policies and costs necessary to accomplish this target level of service. The second type of situation would be to constrain costs -- in other words, impose a budget limitation. The iterative methodology in Figure 9 could again be applied, this time to vary maintenance policies to attempt to maximize (in a subjective sense) favorable impacts while remaining within the cost ceiling.

Applications

The demand-responsive concepts above are now the subject of research, to formulate them within models of practical use in maintenance policy planning and management. Two projects are worthy of note.

The first project, completed in 1978, involved the design and development of a statewide highway maintenance management system for the Commonweath of Massachusetts. Included within this system is a budgeting component to enable the state to predict maintenance work requirements and costs one to two years hence, for submission as part of the state's routine process of legislative fiscal review and approval. This budgeting system is unique in that it employs numerical quality standards as expressions of maintenance policy, and analytic predictions of resulting system conditions and maintenance impacts. The relevant models were developed in preliminary form for the 50-odd activities to be managed under the system, and are described in (2). Massachusetts is now completing its collection of road inventory data and maintenance unit cost and production information necessary to implement the budgeting procedure.

As a follow-on to the Massachusetts work, we are now conducting a DOT University Research Project through FHWA to formalize the concepts of demand-responsive maintenance predictions and to derive generalized models of deterioration and of maintenance impacts, with associated quality standards, for the activities listed in Table 1. Models will be developed in analytical form suitable for inclusion in maintenance planning or management systems if desired.

Table 1. Candidate activities for FHWA study.

1. ROAD SURFACE
    - Flexible Pavement Patching
    - Rigid Pavement Crack and Joing Sealing
    - Flexible Pavement Overlays
2. ROADSIDE AND RIGHT OF WAY
    - Clean, Reshape Ditches
    - Litter Pickup
3. TRAFFIC SERVICES
    - Pavement Lane and Edge Shaping
    - Relamp Signals
4. STRUCTURES (Conditional)
    - Deck Repair
5. APPURTENANCES (Conditional)
    - Repair Guardrail

As examples of the types of models proposed, Figures 10 and 11 give two examples drawn from our earlier Massachusetts work, showing respectively deterioration and impact models for the activity of placing thin surfacings to improve pavement skid resistance. Figure 10 shows plots of exponential functions relating decline in average skid number (ignoring seasonal effects) to cumulative traffic levels. The families of curves illustrate sensitivity of the model to calibration parameters included in the exponential relationship. Similarly, Figure 11 illustrates the projected effect of the decline in average skid number on the ratio of wet accidents to total accidents. Again, the family of relationships is attributable to the calibration parameters employed (Note that the "B" term in Figure 11 is different in meaning from that in Figure 10). The quality standard in this case is expressed as the minimum acceptable skid number that is to be allowed. Analogous models and standards were developed for other pavement and highway maintenance activities as well.

The DOT University Research Project with RHWA is scheduled to be completed in June 1981.

Acknowledgements

The work reported herein was performed by the author under the two projects mentioned above. The Massachusetts work was conducted through CMT Incorporated under contract to Byrd, Tallamy, MacDonald and Lewis for the Commonwealth of Massachusetts. I wish to acknowledge the interest and cooperation of Mr. L.G. Byrd of BTML and Mr. Robert Keef of the Maintenance Management Section, Massachusetts Department of Public Works. The DOT University Research Project is being performed in the Department of Civil Engineering at the Massachusetts Institute of Technology. Mr. William Kenis of FHWA is the Contract Monitor.

Figure 10. Skid relationship.

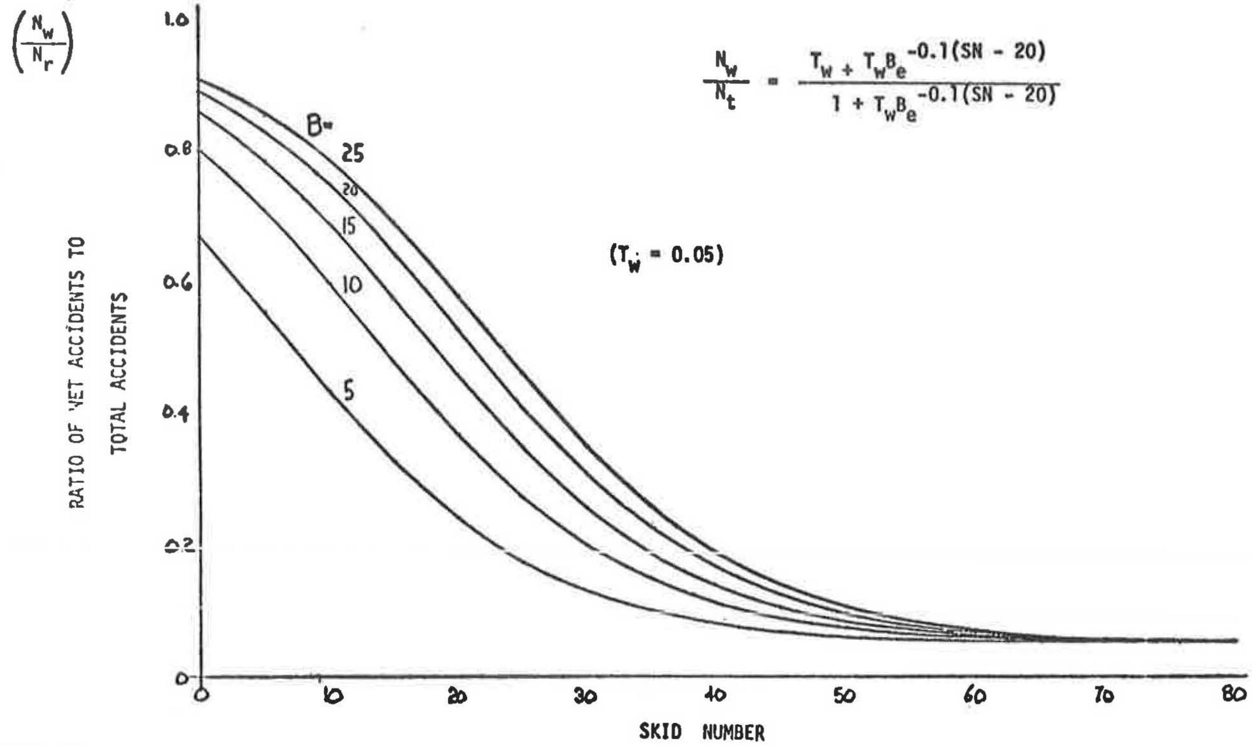
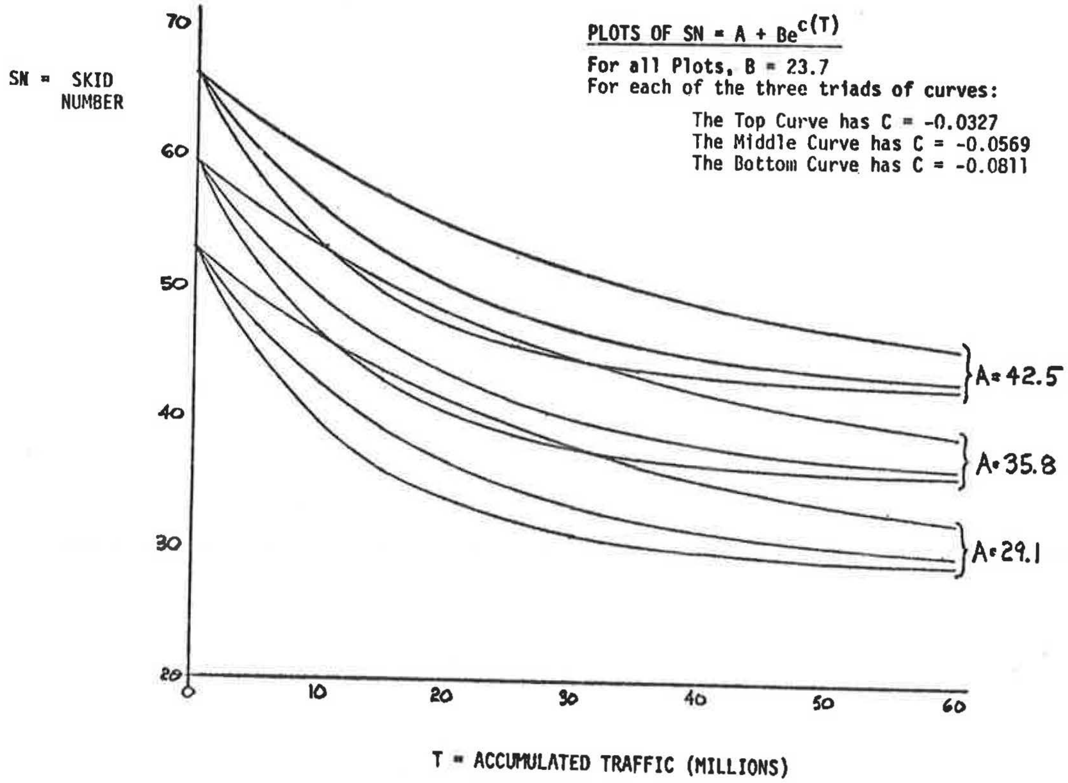


Figure 11. Model of wet pavement accident frequency as function of skid number.



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RATING SYSTEM FOR NEW MEXICO'S MAINTENANCE MANAGEMENT PROGRAM

Charles H. Barbee, New Mexico State Highway Department

The New Mexico State Highway Department developed a method to rate the use of its Maintenance Management System. This paper describes the reasons for developing the system, defines the system, explains what is rated and how the system was developed, gives an overview of how the rating can and has been used, and describes problem areas associated with the use of this rating.

During the final stages of implementation of the Maintenance Management System, the New Mexico State Highway Department developed a method to rate the use of that system.

Our discussions of this rating system will attempt to:

+ outline the reasons for developing the system,
+ define the system,
+ explain what is rated and how the system was developed,
+ give an overview of how the rating has been used,
+ cover additional areas where the rating could be used, and
+ describe the problem areas associated with the rating as experienced by the New Mexico State Highway Department.

Why was the Rating System Developed

The rating system was developed at the request of the Chief Highway Administrator. He wanted an objective indicator that would show how field managers were using the new management system.

What is the Rating System

The management rating system is an analytical performance index for maintenance managers. Each management unit is rated quarterly. The rating scheme ranges from 0 to a maximum score of 10. As originally developed, it was anticipated that the ranges of scores shown in Figure 1 would indicate how a manager is performing.

Figure 1. Interpretation of Rating

Range of Scores	Rating
10 to 8.5	Excellent-deserves special recognization,
8.4 to 7.0	Good-deserves recognization,
6.9 to 5.5	Acceptable-shows reasonable management capability,
5.4 to 4.0	Fair-needs additional attention, and
3.9 to 0.0	Poor-unacceptable, requires immediate management attention.

What is rated and how was the System Developed

Two separate ratings are computed to form the management index--plan compliance and use of standard crew sizes.

The plan compliance portion of the management index is based on how well maintenance managers are able to perform work on their work plan. This rating uses routine work activities---those activities which the manager has been told should be done regardless of staffing. By limiting the rating to these activities, over or under staffing should not penalize a manager. Only work activities which require significant resource commitment are used in this analysis.

The numerical value is computed in the following manner:

Step 1 - Select routine work activities to be used for plan compliance rating. These activities may vary from season to season.

Step 2 - Compute ratings at the crew level for each percent of plan range using the following formula:

(Percent of Evaluated Activities within specific Percentage Range of Plan) X Weighted Value = Rating

Percent of Plan Ranges	Weighted Value By Range
90-110%	10
80-90% and 110-120%	7
70-80% and 120-130%	5
More than 30% away from plan	0*

Step 3 - Compute the average rating for the ranges using the following formula:

(Ratings for each Percent Range) = Average Rating

Step 4 - Calculate average plan compliance rating for higher management levels by averaging the ratings for all subordinate managers. For example, the average plan compliance rating for all foremen reporting to an assistant superintendent becomes the plan compliance rating for the assistant superintendent.

*(Not computed-only to ensure 100% of activities are considered)

The second part of the management index is based on how often maintenance managers assign the recommended number of workers to do a specific work activity. This rating uses only those activities for which productivity is measured in units other than man-hours and which have a recognized optimum crew size. By limiting the rating to these activities, crews which do betterment, special projects and/or other maintenance (for which standard crew size is not meaningful) are not penalized.

The numerical value is computed in the following manner:

Step 1 - Select work activities to be used for standard crew size rating. These activities may vary from season to season.

Step 2 - Compute ratings at the individual crew level for each crew size range using the following formula:

(Percent of Evaluated Activities within Crew Size Range) X Weighted Value = Rating

Crew Size Range	Weighted Value
Standard Crew Size	10
Standard Crew Size ±1	7
Standard Crew Size ±2	5
Standard Crew Size ± More than 2	0*

Step 3 - Compute the average rating for the ranges using the following formula:

(Rating for each Crew Size Range) = Average Rating

Step 4 - Calculate average crew size rating for higher management levels by averaging the ratings for all subordinate managers.

*(Not computed-used only to ensure 100% of selected activities are considered).

The final management index is computed by averaging the ratings computed for plan compliance and use of standard crew sizes. A sample work sheet used to derive a crew's rating is shown in Figure 2.

The rating was originally computed manually and required approximately three man-days to complete for all management units. It was programmed to run directly from the management system reports during the last year substantially simplifying the procedure.

How has the System been used

The rating system has been used as an indicator to locate areas of the departments' maintenance operation where in-depth analysis will provide a better understanding of how work is being accomplished. Analysis of very high rated or very low rated crews provides insight to problems that can effect plan compliance and/or use of standard crew sizes. The factors that cause low ratings can often be controlled or improved by first-line managers. It must be realized, however, that some lower ratings can result from conditions that a foreman has little or no control over.

The rating has been used to identify areas where the work plan does not meet the needs of a group of management units or a particular management unit. Analysis of low plan compliance in several instances resulted in a determination that the procedures used in developing the work plan did not provide for an acceptable level of service for particular management units.

An important area where the rating can focus on needs is in training. Reporting problems have been highlighted by exceptionally low or high ratings. Areas have also been identified where managers need additional support in the scheduling process. Emphasis in the area of improving scheduling procedures and improving communication between first and second line managers have resulted in improved plan compliance ratings. A few isolated cases of slightly lower ratings have resulted when emphasis was placed on identifying work that needed to be done that was not included in the work plan. This information has also been used in evaluating the work plan for future improvements. Very low ratings in use of standard crew sizes have isolated a few cases where incorrect reporting was a problem.

A statewide average has been monitored since the base year of 1977-78 to determine if our crews are raising the rating or if we are moving further away from plan compliance/use of standard crew sizes.

Figure 3 shows the average crew rating for 1977-78, 1978-79 and the current rating for this fiscal year as of March 7, 1980. The lower rating for 1979-80 has been effected partially by a required reduction in the work program due to a short fall in revenues beginning last October. Critical work on routine activities was delayed because our department had a cash flow problem and reduced materials purchases to provide only for emergency work. The cash flow problem improved late this spring and our crews have been completing routine work that had to be delayed and it is expected that the overall rating will improve slightly.

To date, our use of the management rating system has been as an indicator to direct us to areas that need more analysis and field review. The rating is used to supplement the more detailed reports that are part of the management system. The rating by itself does not answer questions, but it can indicate where we should be looking to determine a cause and effect that will help us better understand how, why, and where we are using our maintenance resources.

What additional uses can be made of the rating

Several additional items have been discussed for possible use of the rating including:

+ evaluation for merit or extra merit raises,
+ as part of a performance rating, and
+ to provide special recognization to managers that maintain high standards of plan com-

Figure 2. Management System Rating Worksheet

INDIVIDUAL MMS MANAGEMENT SCORECARD

MANAGEMENT LEVEL ________________

DISTRICT ________ MGT UNIT ______

I. PLAN COMPLIANCE

	THIS PERIOD							
Percent of Plan	Number of Activities	x	Percent of Activities	x	Value	=	Rating	Rating Last Period
90 - 110%	______	x	______	x	10	=	______	______
80 - 120%	______	x	______	x	7	=	______	______
70 - 130%	______	x	______	x	5	=	______	______
<70 >130%	______	x	______	x	0	=	0	______
Overall Rating							______	______

II. USE OF STANDARD CREW SIZE

	THIS PERIOD					
	Percent of Activities	x	Value	=	Rating	Rating Last Period
Standard Crew Size	______	x	10	=	______	______
Standard Crew Size ±1	______	x	7	=	______	______
Standard Crew Size ±2	______	x	5	=	______	______
Standard Crew Size ±>2	______	x	0	=	0	______
Overall Rating					______	______

III. MANAGEMENT INDEX

Index This Period	Index Last Period
______	______

pliance and standard crew size usage.

What problems have been associated with the rating

The major problem the New Mexico State Highway Department had with the rating system was the controversy that developed at most levels of management when the rating was originally introduced.

Many maintenance supervisors look upon the rating as a report card and will still identify it as the major item that caused many people to resist the changes required to utilize the new management system. There has been concern that the rating system will encourage field managers to report planned work rather than actual accomplishment.

The information generated by an effective maintenance management system makes all levels of management more accountable as to why, where, when, and how work is being performed. Our field managers were in the early stages of adjusting to this new accountability when they became aware of the rating system. Apparently this was a case of moving too rapidly in a sensitive area and a very definite negative reaction erupted. As a result, the rating has not been widely distributed and has basically been used by the maintenance management staff as discussed earlier in this paper.

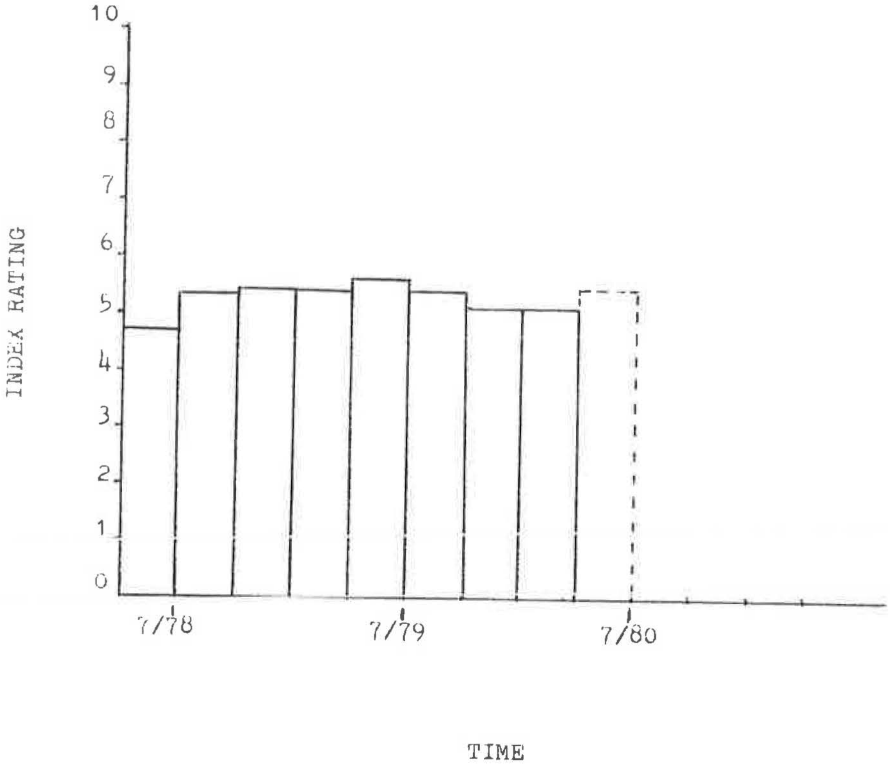
We learned how this type of system should not be introduced to our maintenance personnel. I do not believe I can give any expert advice on methods that would provide for successful implementation. Conditions probably vary greatly depending on agency and how the rating system is presented.

We have discussed why and how this rating system was developed, what it measures, how it has and can be used, and problems that have been associated with its use.

In conclusion, this type of performance index is an additional tool that maintenance managers can use as an indicator to focus on areas that need in-depth analysis. It provides an objective measure of two of the basic elements of any successful maintenance management system--plan compliance and use of standard crew sizes.

The most effective use of any maintenance management tool usually results from acceptance and utilization by all levels of management. It can

Figure 3. Management System Rating/Statewide Average



be expected that an effective selling job will be required in many situations to get first line managers to accept and use this type of information.

Implementation of a rating system in an environment where there is resistance to changes required for systems management can result in strong negative reactions and increase the overall resistance encountered.

It is anticipated that the New Mexico State Highway Department will continue to use this management rating system as discussed. In addition, we hope to find ways to provide the information in a format that is acceptable to and usable by field managers. It is believed that the information provided by the rating system is viable and useful if an agency can use it effectively.

COMPONENTS OF A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM

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Engineering Research Laboratory

This paper discusses the important components of a rational pavement maintenance management system: (1) pavement network identification, (2) pavement inspection and rating, (3) pavement condition evaluation and determination of maintenance and rehabilitation (M&R) requirements, (4) M&R priorities, (5) M&R consequence models, (6) life cycle costing, and (7) data management and report generation. Each component is illustrated by examples from a working system developed for the U.S. Air Force and Army for pavement maintenance management of airfields and roads. The paper is intended to serve as a guideline for those pavement agencies that want to develop or improve their pavement maintenance management system.

Most of the in-service pavements in the United States were built many years ago, and only very limited amounts of new pavements are being constructed now. These older pavements, which deteriorate more quickly than new roads, increase user costs through vehicle deterioration, delay in travel time, and energy consumption, and necessitate the unplanned spending of taxpayers' money for their repair. Unfortunately, the availability of maintenance and rehabilitation (M&R) funds is not keeping pace with the rate of pavement deterioration. The national backlog of needed M&R for state highways is estimated to be in the billions of dollars. A great deal of money is spent annually on emergency repair, such as filling of potholes. Since many emergency repairs are temporary and must be repeated periodically, much more money is spent over the pavement life than is necessary. Therefore, there is an urgent need for pavement agencies to adopt rational pavement maintenance management systems. The objectives and/or benefits to be derived include:

1. Knowledge of the existing pavement and of the condition and health of the pavement system.
2. Rational determination of M&R needs by setting performance standards.
3. The ability to generate or develop a list of priority M&R needs on demand.
4. Availability of information, including maintenance cost data.
5. Ability to answer "what if" questions dealing with the consequences of implementing various M&R alternatives.
6. Ability to perform life cycle costing and to determine the consequences of various M&R alternatives.
7. Ability to develop long-range M&R plans.
8. Ability to optimize a given M&R budget.
9. Establishment of or improvement of communications among the various management levels dealing with M&R.

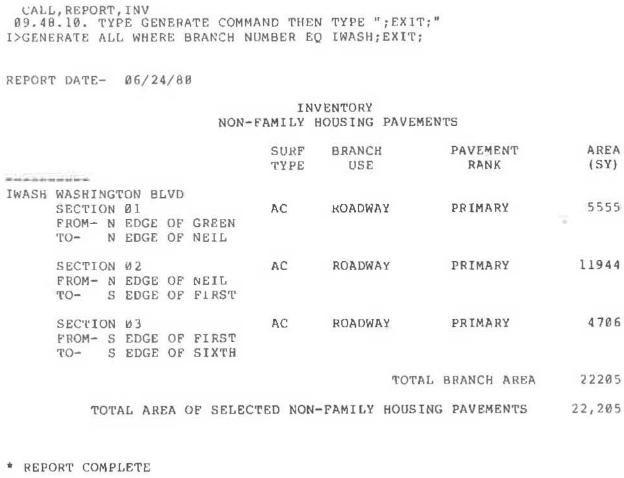
This paper presents components of a comprehensive pavement maintenance management system; these components are described through the pavement maintenance management system for airfields and roads developed for the U.S. Air Force and Army. The system components include (1) identifying the pavement network, (2) inspecting and rating pavements, (3) evaluating pavement condition and determining M&R requirements, (4) establishing M&R priorities, (5) determining the consequences of various M&R alternatives, (6) performing life cycle costing for selection of cost-effective M&R strategies, and (7) managing data and generating reports. The following sections describe each component.

Network Identification

Network identification is the process of dividing the pavement network into manageable sections (also called segments or features) for inspection and for determining M&R needs and priorities. Each pavement section should be uniform in structural composition, construction history, functional classification, traffic, and condition. A pavement "branch" (also called a "facility," e.g., a given runway or highway) may consist of one or more sections.

Each section is given an identification number within its branch. The location of a section (beginning and end) can be identified on a map, for example, by arrows. On computer output, section locations can be identified by mileposts, existing physical features such as rivers or bridges, or intersection with other pavements. For example, in Figure 1 (1) the location of section number 3 of Washington Blvd. is defined from the south end of

Figure 1. Example output of Inventory Report of the Army system.



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  CALL,REPORT,INV
 09.48.10. TYPE GENERATE COMMAND THEN TYPE ";EXIT;"
I>GENERATE ALL WHERE BRANCH NUMBER EQ IWASH;EXIT;


REPORT DATE-  06/24/80

                               INVENTORY
                     NON-FAMILY HOUSING PAVEMENTS

                                SURF    BRANCH        PAVEMENT        AREA
                                TYPE     USE            RANK          (SY)
----------
IWASH WASHINGTON BLVD
      SECTION 01                AC      ROADWAY        PRIMARY         5555
      FROM- N EDGE OF GREEN
      TO-   N EDGE OF NEIL

      SECTION 02                AC      ROADWAY        PRIMARY        11944
      FROM- N EDGE OF NEIL
      TO-   S EDGE OF FIRST

      SECTION 03                AC      ROADWAY        PRIMARY         4706
      FROM- S EDGE OF FIRST
      TO-   S EDGE OF SIXTH

                                             TOTAL BRANCH AREA        22205

             TOTAL AREA OF SELECTED NON-FAMILY HOUSING PAVEMENTS     22,205


* REPORT COMPLETE
```

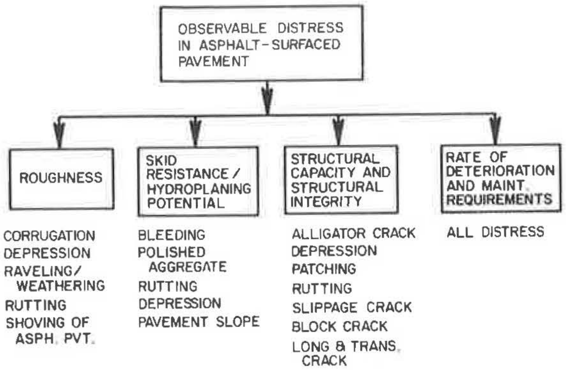
First Street to the south end of Sixth Street. This figure is an example output of a branch inventory obtained from the Army system.

Pavement Inspection and Rating

It is commonly recognized (2, 3, 4) that a rational pavement evaluation requires analysis of pavement roughness (ride), skid, structural capacity, and distress. Different agencies use different equipments, methods, and frequencies to measure these indicators. For example, the U.S. Air Force uses a Laser Profilometer to measure roughness and the Diagonal Braked Vehicle and Mu-Meter to measure skid. In addition, several structural capacity evaluation teams core pavements, determine thicknesses, and determine allowable aircraft loads for each pavement section. Other highway agencies use the Mays Ride Meter to measure ride, a towing vehicle to measure skid, and a Road Rater or Dynaflect to measure structural capacity.

However, more than ever before, the importance of distress measurement and analysis is being emphasized by many Federal and state agencies which are leaders in pavement maintenance management, e.g., the U.S. Air Force (5), California (6), Arizona (7), Washington (8), Ontario (9), and Texas (10). The degree of pavement distress relates directly to needed maintenance, and indirectly measures the other pavement functional indicators, as illustrated for asphalt pavements in Figure 2 (11). Some agencies rely only on the analysis of individual distresses, such as alligator cracking and raveling, to determine the primary cause of pavement deterioration, e.g., load, climate, materials, construction quality control. Other agencies use an index based on weighted distress to serve as a composite pavement condition index. One of the earliest indices used was the State of Washington's Pavement Final Rating; the most recent development in this area has been the U.S. Air Force and Army Pavement Condition Index (PCI). The PCI has been formally adopted worldwide by the Air Force and other agencies, such as the Federal Aviation Administration, and various state aeronautic departments are now evaluating and adopting it. The U.S. Army is currently evaluating the PCI for roads, which was developed after the one for airfields, for implementation.

Figure 2. Relationship of observable distress in asphalt-surfaced pavements to various pavement condition indicators.



The PCI agrees closely with the collective judgment of experienced pavement maintenance engineers. It provides (1) a standard method for rating the structural integrity and operational surface condition of pavement sections, (2) a method for determining M&R needs and priorities by comparing the condition of different pavement sections, and (3) a method of determining pavement performance from accumulated data. The PCI, which measures pavement structural integrity and surface operational condition on a scale from 0 to 100 (Figure 3) (5), is based on measured pavement distress types, severity, and amount of distress obtained during pavement inspection.

To determine the PCI, a pavement section is first divided into inspection units called sample units. For example, for asphalt roads, a sample unit is approximately 230 m^2 (2500 sq ft) (e.g., 7.6 m [25 ft] wide x 30 m [100 ft] long). The number of sample units to be inspected (n) is determined from Figure 4 (11) as a function of the total number of units in the section (N) and the standard deviation of the PCI (σ) between sample units in the section. The location of units to be inspected is determined using either the "stratified-random" or "systematic-random" techniques (12).

The PCI method uses weighted (deduct) values that are functions of the types, severities, and densities of visible distress. The current PCI of a given sample unit is determined by adding the deduct values for observed distresses in a given sample unit, adjusting the sum, and then subtracting the sum from a maximum possible PCI.

Figure 3 summarizes the steps for computing the PCI for a pavement section. It should be emphasized that inspection procedures closely follow methods outlined in distress manuals (5, 11, 13) developed over several years of continuous field evaluation, revision, and improvement.

Pavement Condition Evaluation and Determination of M&R Requirements

Figure 5 is a flow chart summarizing the process for determining M&R requirements. This process is greatly expedited in an automated pavement maintenance management environment. Following is a brief description of the logical steps of this process:

Figure 3. Steps for determining PCI of a pavement section.

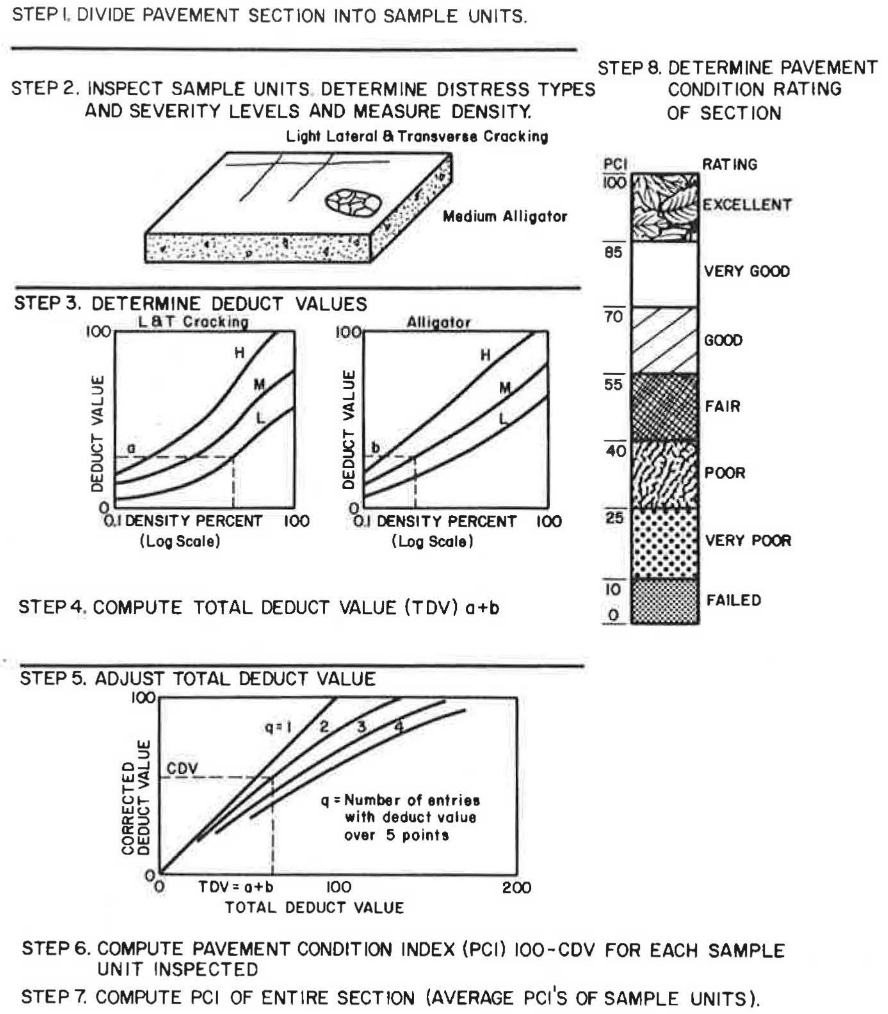


Figure 4. Determination of minimum number of sample units to be surveyed for 95 percent confidence that the error in PCI of section is within ±5 points.

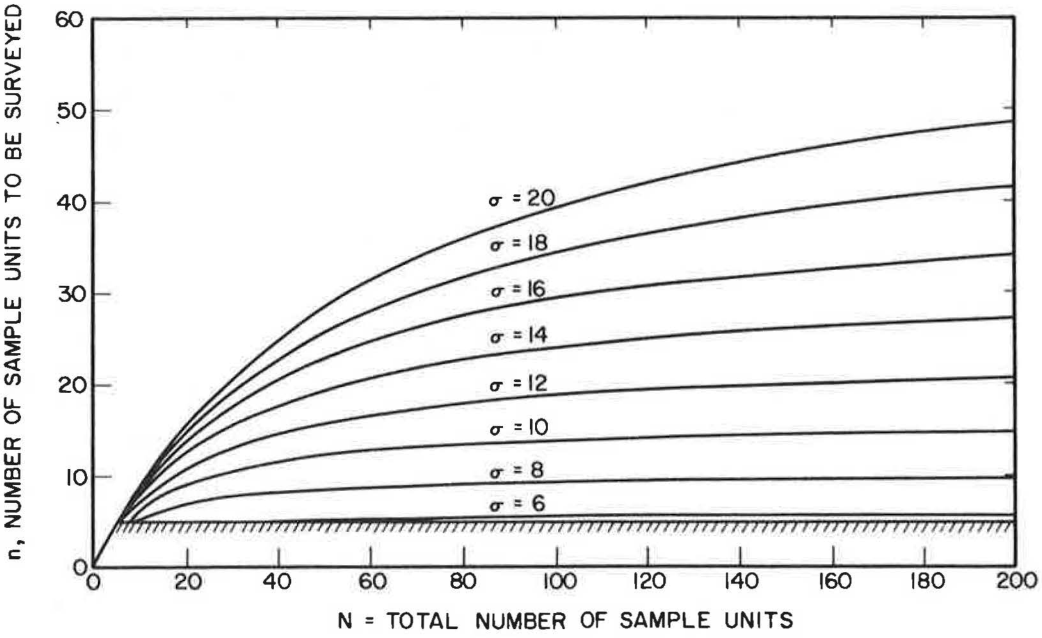
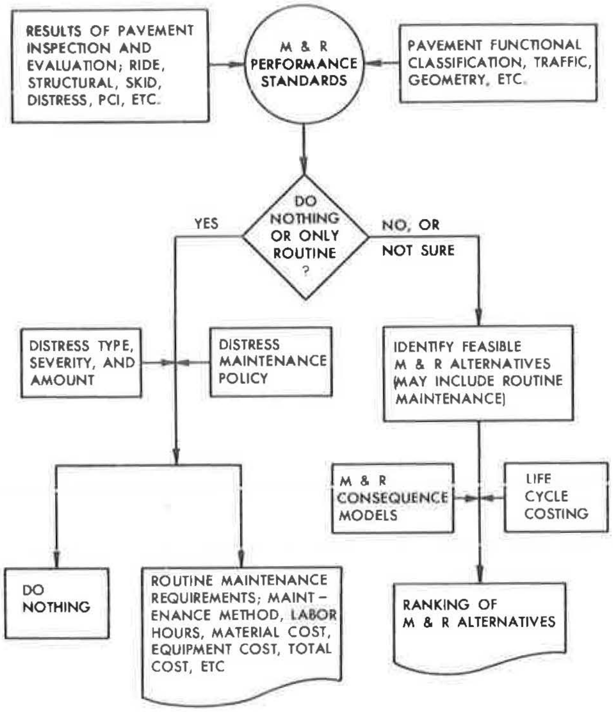


Figure 5. Flow chart summary of the process of determining M&R requirements.



Decision to "Do Nothing" or to Perform "Only Routine" Maintenance Within 1 to 2 Years

The inputs needed to make this decision are taken from the most recent pavement inspection and evaluation, and from other relevant pavement information, such as functional classification and traffic. The decision is based on the agency's performance standards. Performance standards may consist of limits on ride, skid number, and individual distress densities (% area) or composite pavement condition. Figure 6 (14) shows an example of the PCI-based portion of the performance standards used by the Air Force. Other parts of the performance standards include the results of pavement evaluation shown in Figure 7 (12).

Determination of Routine (Including Preventive) Maintenance Requirements

The healthier the pavement network, the more pavement sections would be treated under this step, rather than considering major or overall rehabilitation. The primary input for this step is the type, severity, and amount of distress. Tables such as Table 1 (12), which summarizes recommended maintenance methods for various asphalt road distresses, have been useful to field maintenance engineers. For pavement agencies with automated systems, a distress maintenance policy, as shown in Table 2, can be stored in the computer. At the user's request, a specially designed computer program combines the maintenance policy with distress information for selected pavement sections; routine maintenance requirements are then generated, as shown in Figure 8 (1).

Figure 6. Correlation of M&R zones with PCI and condition rating.

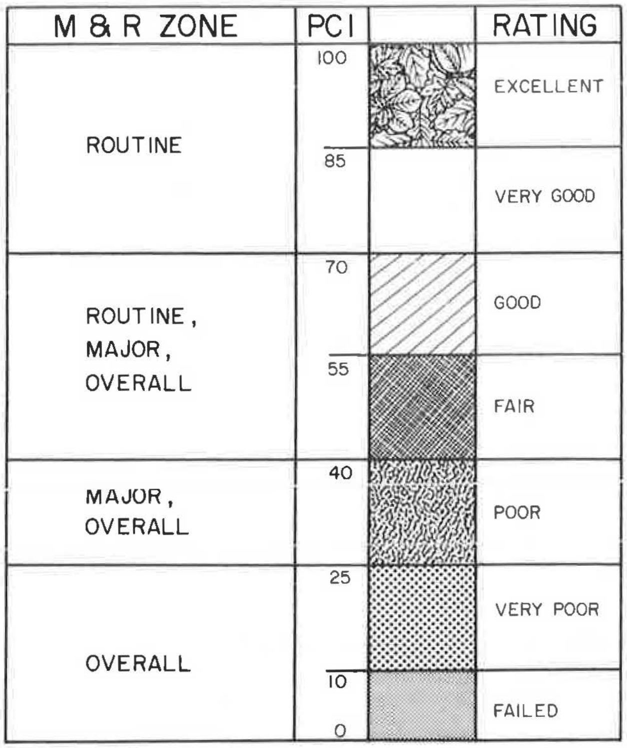


Figure 7. Pavement section condition evaluation summary.

PAVEMENT EVALUATION SUMMARY

1. PCI : ______ RATING : ______ M&R ZONE : ______
2. PCI VARIATION : UNIFORM LOCALIZED SYSTEMATIC
3. PCI RATE OF DETERIORATION
   a. LONG-TERM : LOW NORMAL HIGH
   b. SHORT-TERM : LOW NORMAL HIGH
4. DISTRESS EVAL. : CAUSE PERCENT DEDUCT

CAUSE	PERCENT DEDUCT
LOAD	______
CLIMATE	______
OTHER	______

5. STRUCTURAL CAPACITY DEFICIENCY : NO YES
6. SURFACE ROUGHNESS : MINOR MODERATE MAJOR
7. SKID POTENTIAL : NONE NOT DEFINED EXISTS HIGH
8. PREVIOUS MAINT : LOW NORMAL HIGH
9. EFFECT ON MISSION : ______

Table 1. Asphalt concrete pavement distress types and M&R alternatives.

	Distress Type \ M&R Method	Do Nothing	Crack Seal	Partial Depth Patch	Full Depth Patch	Skin Patch	Pothole Filling	Apply Heat & Roll Sand	Apply Surface Seal Emulsion	Apply Rejuvenation	Apply Aggregate Seal Coat	Notes
1	Alligator Cracking			M,H	M,H				L	L		
2	Bleeding	L						L,M,H				
3	Block Cracking	L	L,M,H							L	L,M	
4	Bumps & Sags	L		M,H	M,H	M,H						
5	Corrugation	L		M,H	M,H							
6	Depression	L		M,H	M,H	M,H						
7	Edge Cracking	L	L,M	M,H*	M,H*							*apply shoulder seal, e.g., agg. seal coat
8	Joint Reflective Cracking	L	L,M,H	H								
9	Lane/ Shoulder Drop-Off	L									M,H*	*level off shoulder and apply agg. seal coat
10	Longitudinal Transverse Cracking	L	L,M,H	H					L	L	L,M	
11	Patching & Utility Cut	L	M	H*	H*							*replace patch
12	Polished Aggregate	A									A	
13	Potholes			L	L,M,H		L,M,H					
14	Railroad Crossing	L				L,M,H						
15	Rutting	L		L,M,H	M,H	L,M,H						
16	Shoving	L		M,H								
17	Slippage Cracking	L	L	M,H								
18	Swell	L			M,H							
19	Weathering & Raveling	L		H					L,M	L	M,H	

Note: L = low severity; M = medium severity; H = high severity.

Table 2. Example distress maintenance policy output.

```
REPORT DATE-  06/25/80

                              MAINTENANCE POLICY

DISTRESS          REPAIR         MTL  REPAIR LABOR    ********UNIT COSTS($)********
 TYPE     SEV     TYPE          CODE  UNIT  HR/UNIT  LABOR    MTL     EQUIP   TOTAL

CORNER SPALLING
            H SHALLOW PATCH      110 SF      .300    4.790    .860   1.010    6.660
            M SHALLOW PATCH      110 SF      .300    4.790    .860   1.010    6.660

DURABILITY CR
            H SLAB REPLACING     110 SY                                      60.000
            M DEEP PATCH         110 SF      .600    9.580   1.720   2.020   13.330

FAULTING
            H GRINDING               SF                                       2.000
            M GRINDING               SF                                       2.000

JOINT SPALLING
            H SHALLOW PATCH      110 SF      .300    4.790    .860   1.010    6.660
            M SHALLOW PATCH      110 SF      .300    4.790    .860   1.010    6.660

JT SEAL DAMAGE
            H JOINT FILLING      171 LF      .030     .580    .070    .100     .750

LG PATCH/UTIL
            H DEEP PATCH         110 SF      .600    9.580   1.720   2.020   13.330
            M DEEP PATCH         110 SF      .600    9.580   1.720   2.020   13.330

PUNCHOUT
            H DEEP PATCH         110 SF      .600    9.580   1.720   2.020   13.330
            M DEEP PATCH         110 SF      .600    9.580   1.720   2.020   13.330

SMALL PATCH
            H SHALLOW PATCH      110 SF      .300    4.790    .860   1.010    6.660

* REPORT COMPLETE
* PAVER READY.....
C>CALL,REPORT,POLICY
 07.14.44. TYPE GENERATE COMMAND THEN TYPE ";EXIT;"
I>GENERATE ALL WHERE DIST CODE LT 20;EXIT;
```

Note: 1 SF - .0920 m^2; 1 LF = .3048 m.

Figure 8. Report listing local maintenance requirements of sections.

```
                    MAINTENANCE AND REPAIR GUIDELINES

BRANCH NAME -   CENTER AVE                          SLAB LENGTH     -    20  LF
BRANCH NMBR  -  ICENT                               SLAB WIDTH      -    11  LF
SECTION NMBR  - 01                                  NMBR. OF SLABS -     76

INSPECTION DATE - 06/18/79                          SECTION PCI     -    36

DISTRESS        DIS  DIST-QTY  WORK              MAT'L LABOR LABOR MAT'L EQUIP TOTAL
TYPE            SEV  WORK-QTY  TYPE              CODE  HOURS COST$ COST$ COST$ COST$
----------------------------------------------------------------------------------
DURABILITY CR   L       3 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
DURABILITY CR   M      10 SLAB
                      250 SF   DEEP PATCH        110   150.0  2394   429   504  3332
FAULTING        L       2 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
FAULTING        M       1 SLAB
                       11 SF   GRINDING          ***     0.0     0     0     0    22
FAULTING        H       1 SLAB
                       11 SF   GRINDING          ***     0.0     0     0     0    22
JT SEAL DAMAGE  H      76 SLAB
                     3116 LF   JOINT FILLING     171    93.5  1807   218   311  2337
LG PATCH/UTIL   L       3 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
LG PATCH/UTIL   M       1 SLAB
                       55 SF   DEEP PATCH        110    33.0   526    94   111   733
LG PATCH/UTIL   H       7 SLAB
                      385 SF   DEEP PATCH        110   231.0  3688   662   777  5132
SMALL PATCH     L       6 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
SMALL PATCH     M       7 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
SMALL PATCH     H      19 SLAB
                       76 SF   SHALLOW PATCH     110    22.8   364    65    76   506
POLISHED AGG    N       / SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
PUNCHOUT        M       1 SLAB
                       44 SF   DEEP PATCH        110    26.4   421    75    88   586
PUNCHOUT        H       1 SLAB
                       44 SF   DEEP PATCH        110    26.4   421    75    88   586
SHRINKAGE CR    N       9 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
CORNER SPALLING M       6 SLAB
                        6 SF   SHALLOW PATCH     110     1.8    28     5     6    39
CORNER SPALLING H       6 SLAB
                        9 SF   SHALLOW PATCH     110     2.7    43     7     9    59
JOINT SPALLING  L       4 SLAB
                               --- NO MAINTENANCE POLICY AVAILABLE ---
JOINT SPALLING  M      15 SLAB
                       90 SF   SHALLOW PATCH     110    27.0   431    77    90   599
 JOINT SPALLING  H      29 SLAB
                      478 SF    SHALLOW PATCH     110  143.6  2292   411   403  3186
 POPOUTS         N      11 SLAB
                                --- NO MAINTENANCE POLICY AVAILABLE ---
----------------------------------------------------------------------------------
                                         TOTAL  750.1 12415  2118  2543 17139
```

Determination of Feasible M&R Alternatives

If the decision about whether to perform only routine maintenance is not clear, then other feasible M&R should be identified. Feasible M&R alternatives are determined based on the results of the evaluation shown in Figure 7. In this figure, the PCI is used to determine whether there are localized or systematic variations in the pavement, and to determine the pavement's long- and short-term deterioration rates. The distress information is used to compute the different percentage effects of loads, climate, and other factors on pavement condition. Other variables included in the procedure are load capacity, roughness, skid-hydroplaning potential, and previous maintenance.

For example, if none of the evaluation items in Figure 7 is exceeded (e.g., rate of deterioration is low, load-carrying capacity is adequate), then only routine maintenance should be considered. On the other hand, if skid is the only item that is deficient, then feasible alternatives may include surface grooving, recycling, overlay, or application of a surface friction course.

Ranking of M&R Alternatives for a Given Pavement Section

The ranking of feasible M&R alternatives for any pavement section is based on how each alternative will affect future pavement performance and associated cost. Consequence models and life cycle costing are described in subsequent sections of this paper.

M&R Priorities

Establishment of an M&R priority list is usually the first specific payoff that managers expect from a pavement maintenance management system. The criteria for establishing priorities for pavement sections requiring routine maintenance are different from those used for sections needing major or overall M&R.

M&R priorities for sections requiring routine maintenance are functions of individual distress types and severities. Distresses having a large negative effect on the pavement's operational condition are given the highest priority, e.g., medium- and high-severity joint spalling, potholes, bumps, cracking. Priorities for sections requiring major or overall M&R are usually based on pavement condition and functional class; the PCI is very useful for determining these criteria. Figure 9 (1), an example output from the Army PCI system, lists primary roads with PCIs of less than 70 in increasing order of the PCI. This system can generate a separate list for other functional classes, such as secondary or tertiary pavements.

M&R Consequence (Prediction) Models

Prediction models are a series of equations with the overall objective of predicting pavement performance for various M&R alternatives, including a "do nothing" alternative. Equation 1 shows the general mathematical functional relationship of such models. Pavement condition indicators (the left-hand side of equation 1) predicted by the models include ride, skid, cost, deflection, expected life of specific maintenance activities such as joint seal, individual distress types such as cracking and

Figure 9. Report listing sections in order of increasing PCI.

```
  CALL,REPORT,PCI
 09.32.06. TYPE GENERATE COMMAND THEN TYPE ";EXIT;"
I>GENERATE ALL WHERE PAVEMENT RANK EQ PRIMARY AND PCI LT 90;EXIT;


REPORT DATE-  06/24/80                         PCI REPORT

BRANCH         BRANCH    SECTION                          SURFACE     SECTION   PAVEMENT
NUMBER          USE      NUMBER    PCI      RATING         TYPE       AREA/SY     RANK

ICENT         ROADWAY       01     36        POOR          PCC          1858    PRIMARY
T8A           TAXIWAY       01     78     VERY GOOD        PCC          8542    PRIMARY
55512         ROADWAY       04     80     VERY GOOD        PCC          5333    PRIMARY
55512         ROADWAY       01     81     VERY GOOD        AC           4533    PRIMARY
55512         ROADWAY       02     85     VERY GOOD        AC           3466    PRIMARY
T14A          TAXIWAY       01     86     EXCELLENT        PCC         25139    PRIMARY
T9A           TAXIWAY       01     88     EXCELLENT        PCC         34722    PRIMARY
AIB           APRON         01     89     EXCELLENT        PCC        166667    PRIMARY

* REPORT COMPLETE
C>
```

Figure 10. Example output of the PCI consequence models.

```
 ENTER PAVEMENT ID
I>RUNWAY 5/23
 ENTER PAVEMENT TYPE. AC OR PCC (A/P)
I>AC
 HAS PCI BEEN PREVIOUSLY DETERMINED? (Y/N)
I>N
 ENTER TIME IN YEARS BETWEEN ORIGINAL CONSTRUCTION [AGECOL]
 AND LAST OVERLAY (0 IF NO OVERLAY)
I>0
 ENTER TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS [TB]
I>4
 ENTER TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE [TSG]
I>16
 ENTER CBR OF BASE [CBR-B]
I>60
 ENTER CBR OF SUBGRADE [CBR-SG]
I>10
 ENTER AIRCRAFT ID (OR "HELP") [ID]
I>HELP
 T38 F4 C130 DC9 B737/200 B727/200 B707/320B C141 B747F C5A B52
I>B727/200

 ACCEPT,CHANGE,DISPLAY? (A/C/D)
I>A
 ENTER PREDICTION AGES SEPARATED BY COMMAS
I>0,10,25



   RUNWAY 5/23

   B727/200 AIRCRAFT ID
        0.0 AGE BETWEEN CONSTRUCTION/OVERLAY OF PAVEMENT AND LAST OVERLAY
        4.0 TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS
       16.0 TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE
       60.0 CBR OF BASE
       10.0 CBR OF SUBGRADE


    AGE          PCI
    ---          ---
    0.0         100.0
   10.0          67.0
   25.0          17.5



 DO YOU WISH TO DETERMINE THE CONSEQUENCE ON PCI OF CHANGE IN
 AIRCRAFT, OVERLAY, OR NONE? (A/O/N)
I>O
 ENTER AGE TO OVERLAY
I>10
 ENTER OVERLAY THICKNESS
I>3
 ENTER PREDICTION AGES SEPARATED BY COMMAS
I>0,9,10,25



   RUNWAY 5/23

   B727/200 AIRCRAFT ID
        0.0 AGE BETWEEN CONSTRUCTION/OVERLAY OF PAVEMENT AND LAST OVERLAY
        4.0 TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS
       16.0 TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE
       60.0 CBR OF BASE
       10.0 CBR OF SUBGRADE

       10.0 AGE OF OVERLAY
        3.0 THICKNESS OF OVERLAY


    AGE          PCI
    ---          ---
    0.0         100.0
    9.0          70.3
   10.0         100.0
   25.0          50.8
```

rutting, and composite pavement condition such as the PCI. Techniques used to develop the models include regression based on in-service data, mechanistic, probabilistic, or any combination of these.

$$\text{Pavement Condition Indicator} = \text{function of [age, pavement structural composition, construction history, traffic, climate, material properties, geometry, and maintenance]} \quad (1)$$

In addition to predicting pavement performance for various M&R alternatives, consequence models provide valuable input to life cycle costing, budgeting, and planning. Also, the predictions can be used to identify the pavement sections that should be scheduled for inspection, and this will reduce inspection costs.

Figure 10 (15) provides example output from the PCI consequence models which are part of the U.S. Air Force's overall pavement maintenance management system; these models have been designed and programmed for interactive use. Figure 11 (1) is an example output of the interactive individual distress prediction model.

Life Cycle Costing

Life cycle costing is useful when comparing various M&R alternatives for a given pavement section. Figure 12 (1) is example output from an interactive life cycle costing program designed for the U.S. Army and Air Force. Factors included in the life cycle costing are initial cost, future M&R costs, interest and inflation rates, analysis period, and salvage value.

Salvage value, as used in this program, is defined as the difference between building a new pavement and the cost of rehabilitation at the end of the analysis period. Alternately, the salvage value is assumed to be zero; however, the M&R cost for the last year in the analysis period should be the cost of the rehabilitation necessary to upgrade the pavement so that its quality is equivalent to that of a new pavement.

Data Management and Report Generation

To use a pavement maintenance management system efficiently, one must be able to store and retrieve data expediently. The U.S. Army and Air Force systems are operated via a disk-sized computer terminal. Data may be added, changed, or deleted by having it keypunched and read in through a card reader or interactively by using the disk-sized terminal. Figure 13 is an example of interactive data update. Information and two types of reports (writer reports and computation reports) are generated through the same terminal.

Writer Reports

These are preformatted reports generated by the data base manager feature called the report writer. The report writer has a built-in capability for sorting through stored information to meet specific user requirements. Such reports include inspection results, lists of pavement sections in an increasing order of the PCI (Figure 9), pavement inventory (Figure 1), pavement structure, work required, and work history. The formats of these reports can be modified or new reports developed in just a few days.

Figure 11. Example output of individual distress prediction program.

```
                       DISTRESS INPUT DATA

          DISTRESS TYPE =        8.
          AGE         =    10.00  YEARS
          L           =     2.05
          M           =     3.40
          H           =      .81
          EARLIEST DISTRESS STARTING TIME =        0.0  YEARS
          LATEST DISTRESS STARTING TIME   =        5.0  YEARS
          DISTRESS AT INITIAL TIME =   .0100
          EARLIEST TIME FROM L TO M       =        0.0  YEARS
          LATEST TIME FROM L TO M         =        5.0  YEARS
          EARLIEST TIME FROM M TO H       =        0.0  YEARS
          LATEST TIME FROM M TO H         =        5.0  YEARS
          MAXIMUM PREDICTION AGE          =       20.0  YEARS


     OPTIMUM VALUES
          INITIAL TIME       =          0.0  YEARS
          TIME FROM L TO M =              1  YEARS
          TIME FROM M TO H =              3  YEARS
                MEAN                  =    16.8417  YEARS
                STANDARD DEVIATION =        4.4615  YEARS

YEAR          L+M+H            L             M              H
  0             .01           .01          0.00           0.00
  1             .02           .01           .01           0.00
  2             .05           .02           .02           0.00
  3             .10           .05           .05           0.00
  4             .20           .10           .09            .01
  5             .40           .20           .18            .02
  6             .76           .36           .35            .05
  7            1.37           .61           .66            .10
  8            2.38          1.01          1.17            .20
  9            3.94          1.56          1.98            .40
 10            6.26          2.32          3.19            .76
 11            9.52          3.26          4.89           1.37
 12           13.89          4.37          7.15           2.38
 13           19.46          5.57          9.95           3.94
 14           26.21          6.75         13.20           6.26
 15           33.99          7.78         16.69           9.52
 16           42.52          8.53         20.10          13.89
 17           51.41          8.89         23.06          19.46
 18           60.24          8.83         25.20          26.21
 19           68.57          8.33         26.25          33.99
 20           76.05          7.48         26.05          42.52
```

Computation Reports

These are special reports that use computer calculations based on data stored in the system and/or data provided by the user. Such reports include M&R requirements (Figure 7), M&R consequence (Figure 10), individual distress prediction (Figure 11), and life cycle costing (Figure 12). Other computation reports can be developed and interfaced with the system as needed.

Figure 12. Example output of the life cycle cost program.

```
                   COMPARISON OF M&R ALTERNATIVES
                             GREEN ST
                            SECTION 04

                                              INFLATION RATE 13.00 PERCENT
ANALYSIS PERIOD - 20 YEARS                    INTEREST RATE  11.00 PERCENT

ALTERNATIVE       DESCRIPTION                         NET PRESENT COST
          B       COLD MILL&OVERLAY                             47341.
          C       RECONSTRUCT                                   65575.
          A       2 IN OVERLAY                                 115424.


                 DETAILED COMPARISON OF M&R ALTERNATIVES

           *     ALT A        *     ALT B        *     ALT C        *
           *           PRES   *            PRES  *            PRES  *
YEAR       *   COST    COST   *    COST    COST  *    COST    COST  *
           *                  *                  *                  *
 0 (FY80)  *  15900   15900   *   22350   22350  *   36000   36000  *
 1 (FY81)  *      0       0   *       0       0  *       0       0  *
 2 (FY82)  *      0       0   *       0       0  *       0       0  *
 3 (FY83)  *      0       0   *       0       0  *       0       0  *
 4 (FY84)  *      0       0   *       0       0  *       0       0  *
 5 (FY85)  *      0       0   *       0       0  *       0       0  *
 6 (FY86)  *      0       0   *       0       0  *       0       0  *
 7 (FY87)  *  39900   45212   *    2000    2266  *    1000    1133  *
 8 (FY88)  *      0       0   *       0       0  *       0       0  *
 9 (FY89)  *      0       0   *       0       0  *       0       0  *
10 (FY90)  *      0       0   *       0       0  *       0       0  *
11 (FY91)  *      0       0   *       0       0  *       0       0  *
12 (FY92)  *      0       0   *       0       0  *       0       0  *
13 (FY93)  *      0       0   *       0       0  *       0       0  *
14 (FY94)  *      0       0   *       0       0  *       0       0  *
15 (FY95)  *      0       0   *       0       0  *       0       0  *
16 (FY96)  *      0       0   *       0       0  *       0       0  *
17 (FY97)  *      0       0   *       0       0  *       0       0  *
18 (FY98)  *      0       0   *       0       0  *       0       0  *
19 (FY99)  *      0       0   *       0       0  *       0       0  *
20 (FY00)  *  38000   54311   *   15900   22725  *   19900   28442  *
           *                  *                  *                  *
 TOTAL     *  93800  115424   *   40250   47341  *   56900   65575  *
           *                  *                  *                  *
 SALVAGE   *      0       0   *       0       0  *       0       0  *
           *                  *                  *                  *
PRES WORTH *         115424   *           47341  *           65575  *

 DO YOU WISH TO MAKE SAME ANALYSIS
 WITH DIFFERENT INTEREST AND INFLATION RATES?(YES/NO)
I>YES
 ENTER INTEREST RATE (PERCENT):
I>6
 ENTER INFLATION RATE (PERCENT):
I>17
 PRINT DETAIL ANALYSIS? (YES/NO)
I>NO
 REPORT DATE -  80/06/24.

                   COMPARISON OF M&R ALTERNATIVES
                             GREEN ST
                            SECTION 04

                                              INFLATION RATE 17.00 PERCENT
ANALYSIS PERIOD - 20 YEARS                    INTEREST RATE   6.00 PERCENT

ALTERNATIVE       DESCRIPTION                         NET PRESENT COST
          B       COLD MILL&OVERLAY                            140893.
          C       RECONSTRUCT                                  181364.
          A       2 IN OVERLAY                                 369309.
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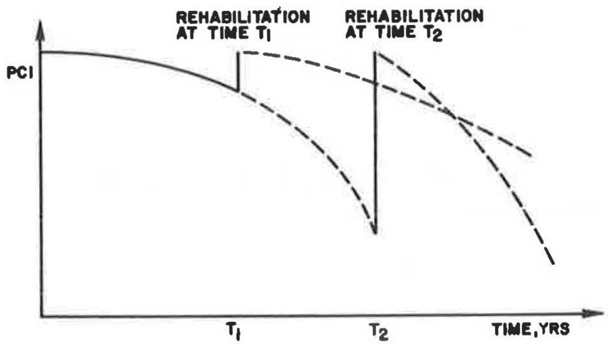
Figure 13. Example consequence of differing rehabilitation.



Conclusions

The components of a comprehensive pavement maintenance management system have been described through an example working system. Pavement maintenance management is an idea which is most timely. At a time when pavements are deteriorating very quickly and maintenance budgets are limited, the benefits of adopting a pavement maintenance management system are numerous. One benefit is having a consistent, rational method of pavement condition rating such as the PCI. Such a rating is an invaluable tool for communication, particularly when justifying M&R requirements to decision-making personnel. In addition, having the capability to perform a comprehensive pavement evaluation that considers condition rating, deterioration rate, structural capacity, and previous maintenance allows rational determination of M&R requirements and avoids over- or under-maintenance of a pavement. An important payoff related to these advantages is the ability to establish an M&R priority list. Such a payoff can be realized during the early years of pavement maintenance management implementation.

Probably the greatest benefit of this system is its contribution to the development of M&R consequence models that are based on all available data. With such models, previous M&R decisions and policies can be assessed and future ones improved. Important "what if" questions can be answered. For example, what is the consequence of delaying any project or combination of projects for any period of time in terms of cost and further pavement deterioration (Figure 13)? What is the consequence of allowing heavier traffic to use a specific pavement section (Figure 14)? What is the consequence of applying an asphalt surface treatment instead of overlay or reconstruction (Figure 15)? Another payoff of the consequence models and life cycle costing procedures is the ability to predict and plan future M&R needs and budgets, as well as the ability to optimize a given budget and still obtain maximum benefits.

Although the benefits are overwhelming, the pace of implementing a pavement maintenance management system depends on available money and manpower. However, it should also be realized that overcoming initial obstacles (e.g., resource availability, data credibility, system residence, documentation, interdepartmental communications, training) in implementing such a system is the most difficult step.

Figure 14. Example consequence of change in traffic volume and/or load intensity.

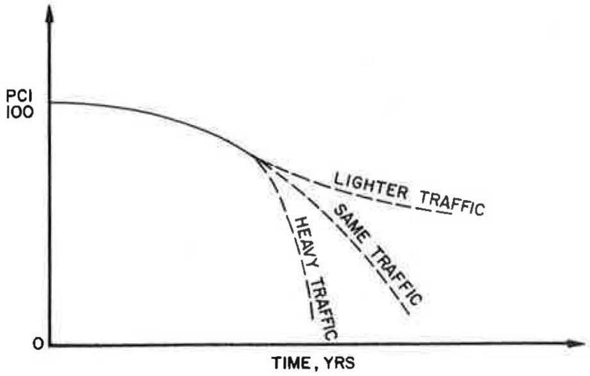
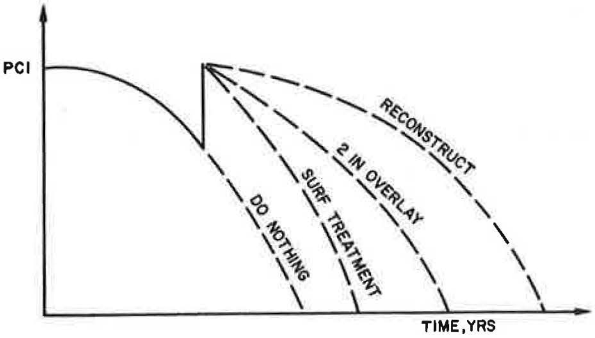


Figure 15. Example consequence of various maintenance and rehabilitation alternatives.



Acknowledgements

The U.S. Air Force and Army pavement maintenance management systems discussed in this paper were developed by the U.S. Army Construction Engineering Research Laboratory, Champaign, IL, under projects funded by the Air Force and Army.

The views of the author do not purport to reflect the position of the Department of the Army or the Department of Defense.

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PHOTOLOGGING - A MAINTENANCE MANAGEMENT TOOL

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Connecticut Department of Transportation

Use of the photolog system as an aid in the decisionmaking process involving the management of Connecticut highway-maintenance operations is outlined. Areas where the photolog system is highly useful, moderately useful and of limited use are denoted. Annual savings in man-hours and fuel consumption as a result of photolog usage are presented. Second generation photolog equipment and its capabilities are discussed.

In the United States, the various administrations responsible for transportation have invested vast sums of capital in their highway, rail, and airport systems. In Connecticut alone, our overall investment in transportation systems has been estimated at several billion dollars. In this connection, there is every justification to document them and maintain them in the best possible condition to ensure an adequate rate of return on invested capital.

In 1973, the Office of Research, Department of Transportation (ConnDOT), in cooperation with the Federal Highway Administration (FHWA), undertook the development of a photolog system to provide a pictorial documentation of our 6440-Km (4,000-mile) State-maintained highway system. The project was completed in 1976 at an estimated cost of $130,000. At that time, the entire photolog system, including a completed library of positive prints documenting the 6440-Km (4,000-mile) system in both directions, was turned over to our newly created Engineering Data and Inventory Photolog Unit.

The Photolog Unit is currently housed in the Rocky Hill Laboratory from which required field filming and editing tasks are performed. Since 1976, the initial library has been located in the highway engineering complex in Newington. A second library was placed in service at the Main Administration Building in Wethersfield in 1979, and a third is planned for the Division of Traffic in Hartford. The latter is scheduled for service in the fall of this year. These libraries are readily accessable to all engineering and management personnel, with the exception of personnel in our four district offices.

Our system is composed of a 35-mm Flight Research Model 4C camera and control unit installed in a 1973 Ford Econoline Van. We normally operate the system at a rate of one frame every .0161 Km (1/100-mile) traveled, but vary this increment for special purposes. The camera is oriented at 5° to the right and 6° down for two-lane roads, and at 2° right, 3° down for multiple-lane roadways /1/.

The film used is 35-mm color negative from which an appropriate number of positive prints can be processed. The format of each frame includes space for data entered via light-emitting diodes (direction traveled and cumulative mileage) and via a mylar data slate (handwritten information such as date, route filmed, and camera angles). Appendix 1 shows photos of this system, which were gleaned from available reports /1,2/.

The system is being maintained such that 1/3 of the highway network is updated each year. In addition, routes that have been reconstructed or relocated are given a priority status for refilming. Thus, the libraries will ideally contain film that is no older than three years.

As previously stated, our photolog was turned over to operating personnel in 1976. Since that time, log-type usage records have been maintained and periodically provided to the FHWA. Annual savings due to reduced man-days required in field trips have increased steadily to an estimated $65,500 in 1979 (Fig. 1). This figure is thought to be somewhat conservative, because of the indifference shown by certain employees in the matter of signing the usage log. This so-to-speak "apathetic" behavior could account for a 25-50 percent increase in savings over and above the figures listed. Figure 2 shows the estimated miles of travel saved by personnel in state-owned vehicles through use of the photolog. Conversion of these mileages to cost savings based on a $ .20 per mile operating cost would result in annual figures ranging from $11,600 to $15,000 or 13,110 to 19,000 liters (3,450 to 4,000 gallons) of gasoline conserved annually depending on your method of analysis. These savings are, of course, the result of use by the entire Department, and not by Maintenance personnel alone.

In maintenance activities, primary use of the photolog is made in spot checks of locations exhibiting high-accident frequencies. Geometrics, signing, fixed objects, and other possible contributing factors can be viewed within the office by both operations and administrative personnel.

Figure 1.

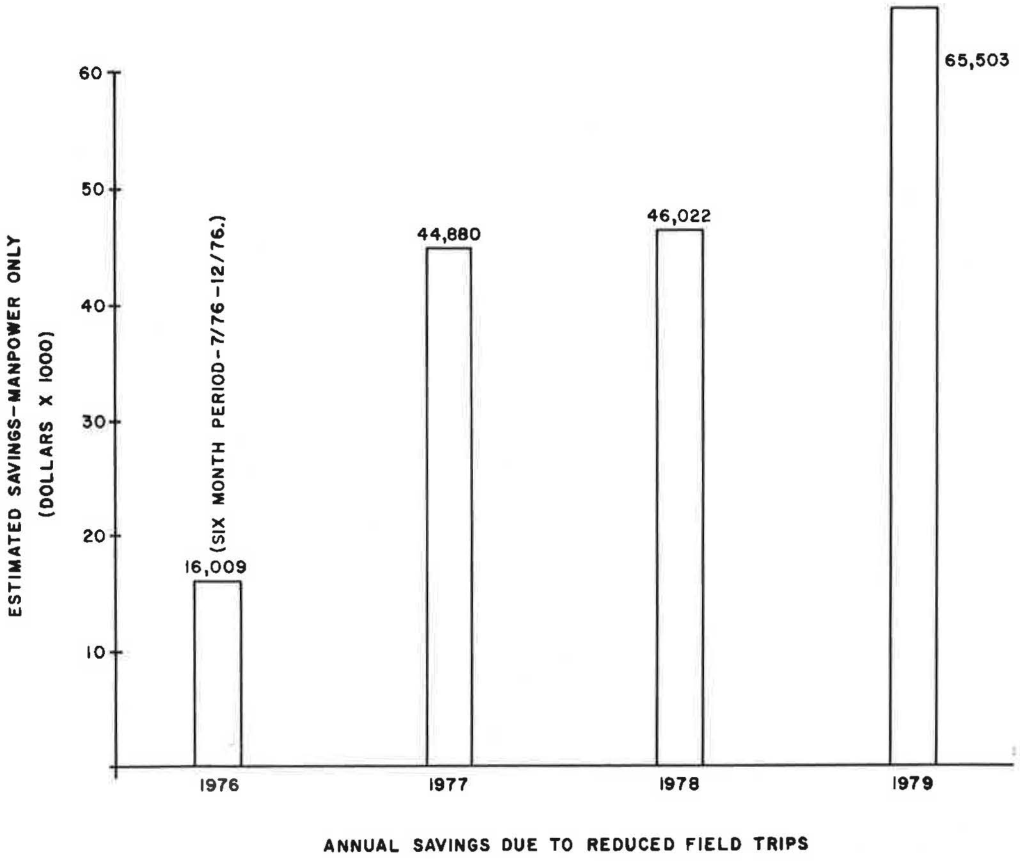
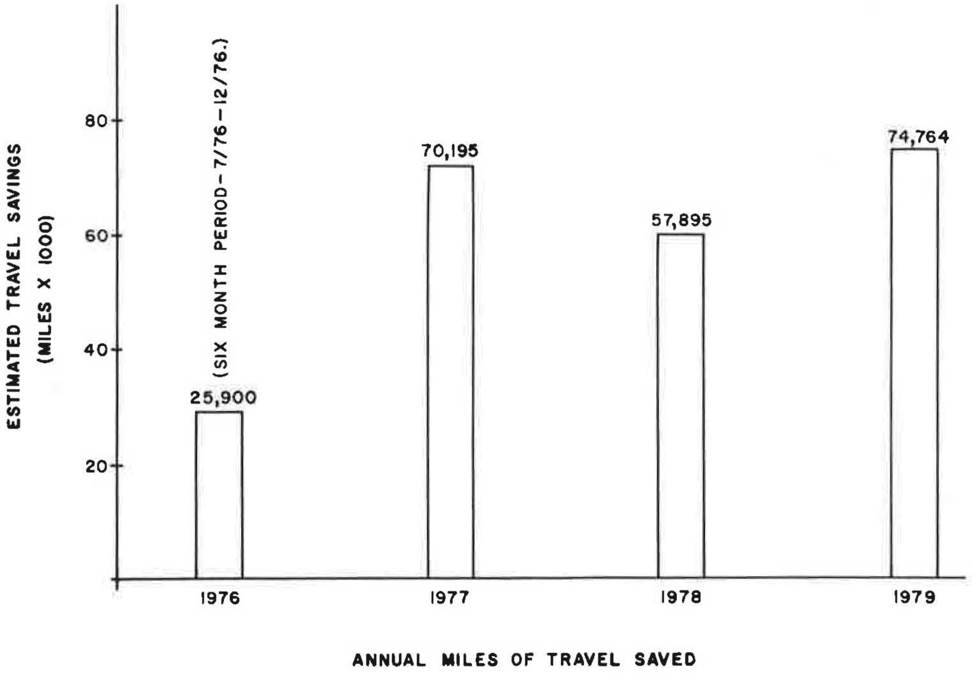


Figure 2.



Lateral distances are estimated from the film by using grids overlaid on the viewing screen. The grids were developed for each camera orientation used and we have measured the accuracy of this method to 15.24 cm (6") in 9.15 m (30'). We are now developing the grids required to obtain vertical dimensions which will expand our anlytical capability.

Another area of high use is the development of future projects or project programming and scheduling. A needs survey is conducted twice a year in this connection. Here, use is restricted to recently updated routes, since obviously a three-year old film would not suffice for this type of work. Specific uses include the application of a Jersey-type barrier to portions of the Connecticut Turnpike. In this case, we were able to determine quite accurately the areas that would accomodate the barrier and those that would present difficulty in the application.

The photolog is ideal for before-and-after studies of projects involving pavement surfaces. We are currently using the photolog to evaluate new emulsified asphalt surface treatments. By filming the section in question prior to application of a treatment, we can easily determine the trouble areas and thus have a base on which to attribute any failures that might develop in the new surface.

Also along these same lines, we have used the photolog to document the condition of the road surface prior to the application of an experimental crack-inhibiting material. Transverse and longitudinal reflection cracks were located from the film. The effectiveness of the crack-inhibiting material beneath the overlay can then be determined from later films of the same area. As applied to crack surveys conducted on continuously reinforced concrete pavements, the photolog is approximately 80 percent effective. The fineness of the transverse cracks makes it difficult to discern them from the film, even when the camera is tilted 11° down and the filming interval reduced to 1.55 m (5 ft).

ConnDOT has also employed the photolog concept to determine the effects of various salt and sand applications on pavement surfaces during snowstorms. Various road sections were given applications of different proportions of deicing chemicals at set time intervals. The effect of these chemicals was monitored by driving the photolog van over the same section at preset time intervals. The outcome was not as fruitful as we had expected, however, because of the low-light levels and heavy snow that occurred during the runs. Subsequent analysis of the film revealed an inability to discern between similar meteorological conditions on the roadway. Specifically, the physical state of the pavement surface moisture (frozen, liquid, or a combination thereof) could not be determined.

The Department has recently installed raised pavement markers at various locations on the state's expressway and interstate systems. Subsequent to these installations, the need arose to devise an effective means of monitoring these sites in order to develop criteria for the repair and replacement of damaged markers. The most effective method of surveying the large number of these markers requires dark-hour observation of actual reflectance characteristics. To reduce the risk of accident generated by a slow-moving observation vehicle or an inspection team walking the shoulder, it was suggested that the photolog van be run at 40 mph over the areas in question during nighttime hours. This would obviously minimize the danger to both the inspection team and passing traffic, and also greatly accelerate the survey process.

The resulting film could then be studied in the safety of an office. Specific marker failures could be pinpointed from the film and odometer readings associated with each exposed frame.

Analysis of the film revealed that the best combination of conditions were: normal headlamps and an additional pair of quartz-halogen lamps; a standard photolog film (Eastman Kodak 5247); a driving speed of not more than 64.4 Kmh (40 mph); and, a shutter speed not faster than 1/60th of a second.

Connecticut's present photolog system will be augmented shortly through the acquisition of a new dual purpose photolog vehicle from Techwest Research. This vehicle, in addition to possessing a sophisticated second-generation data-gathering system, is "high-rail" equipped, thereby affording the capability of monitoring both rail and highway systems. Along with the pictorial aspect, this second generation system will digitally present on the film and magnetic tape the following data: grade; curvature; cross slope; side friction; and, roughness. The acquisition of these quantitative data in the past was generally a time-consuming and potentially hazardous task. Photos of this system are shown in Appendix 2.

The ability to visually review various pavements with a concurrent display of roughness should prove to be an effective device in determining overlayment priorities.

In Connecticut we were encouraged by the efforts of others to embark on a photolog program. Our savings support the fact that our system continues to be a productive and useful management tool. With our continued deployment, new uses for the photolog continue to evolve. Somewhat hesitant and/or reluctant personnel have been shown that we now possess another tool to use in managing our transportation system.

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APPENDIX 1
Photos of Highway Photolog Unit
First generation

Fig. 1A Photolog Van with Camera mounted in filming position.

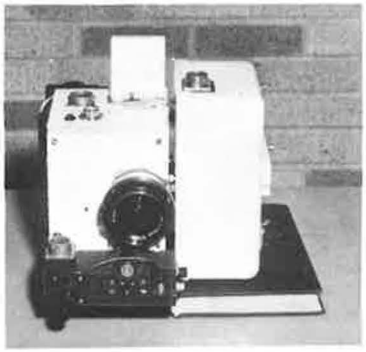


Fig. 1B Front View of camera showing lens, light-sensing element and data chamber.

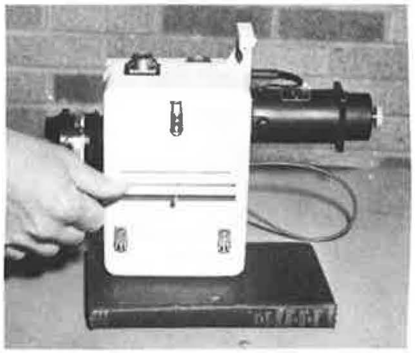


Fig.1C Side view of camera showing attached data chamber with trap door open.

Fig. 1D Distance Measuring Instrument (DMI) and Distance Event Marker (DEM) mounted in dash.

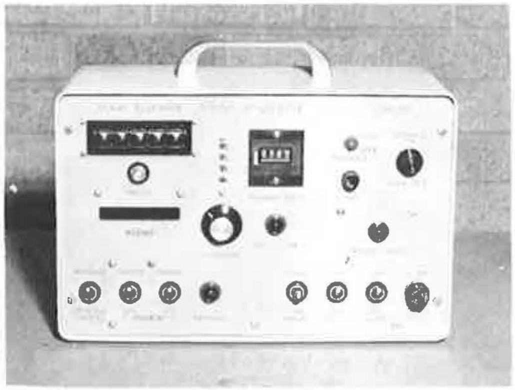


Fig. 1E Front view of control console.

Fig.1F Mylar data slate showing position of data with respect to clipped corners.

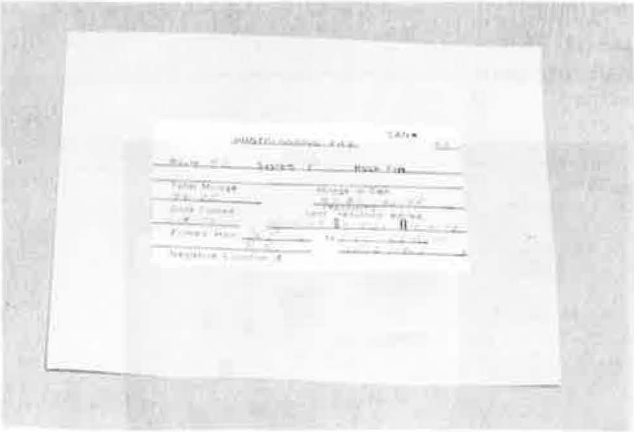


Fig. 1G Reference card for route file.

APPENDIX 2
Rail Photolog Unit
Second Generation

Fig. 2A Front view of rail photolog van, Chevrolet Chassis, High-rail equipped.

Fig. 2C Track viewed from inside of van. Camera is mounted immediately to left of passenger's seat.

Fig. 2B Close-up of high-rail assembly engaged on track.

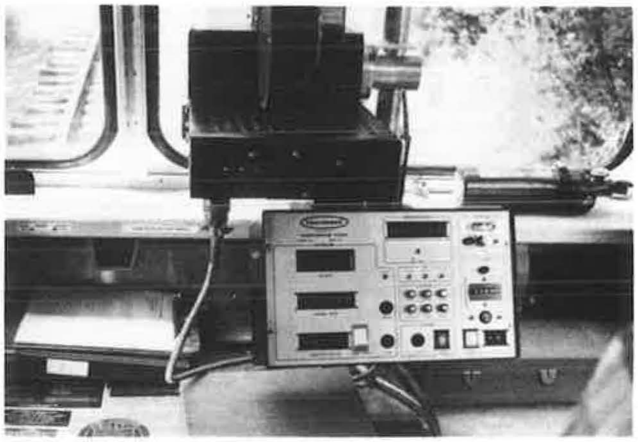


Fig. 2D Data chamber in van.

THE PENNSYLVANIA DOT TRAINED OBSERVER SURVEY: DESIGN AND PRELIMINARY RESULTS

Theodore H. Poister, Pennsylvania State University
William R. Moyer, Pennsylvania Department of Transportion

This paper discusses the design and initial findings of a trained observer survey developed for the Pennsylvania Department of Transportation. With a shift in priorities from construction to maintenance it became clear that some systematic, objective basis for assessing the condition of the state's 45,000 miles of highway was needed for analyzing needs and monitoring program performance over time. The trained observer approach was chosen because it could be tailored to fit the varied concerns of the maintenance program, and the instrument was designed to provide an intensive examination of surface, foundation, shoulders, drainage and appurtenances. Preliminary findings show that there is widespread variation in conditions among road sections across the state with high percentages of deficient roads on many items. To some extent this variation is attributable to systematic differences by Maintenance Functional Code, pavement type, and district and county. Sample reliability with the initial 3 percent sample is fairly weak and sample size will have to be expanded on subsequent cycles of data collection; however, the survey's reportable condition variables appear to be more reliable than PSI measures in discriminating good roads from bad roads.

This paper discusses the development of a Trained Observer Survey of road conditions for the Pennsylvania Department of Transportation and presents some initial findings from the first round of data collection. The survey was designed by university researchers, working in conjunction with staff from the Bureau of Maintenance and Operations Review Group, as part of a more comprehensive effort to develop systems for monitoring the performance of the Department's highway programs.

As a result of a worsening fiscal crisis which made it impossible to carry on a large new construction program and adequately maintain the existing system in the face of a growing backlog of resurfacing projects, the Department's priorities were shifted away from construction to maintenance of the 45,000 mile system. (1) Concurrently, a new administration came into office determined to economize where possible, use resources more effectively and upgrade a highway system which had become a shambles. (2) Part of the approach of this new management-control oriented administration rested on the concept of developing performance indicators to monitor trends in activities, outputs and effects on a continuing basis. With the heavy priority on maintenance, monitoring the efficiency of maintenance activities and the results of these efforts was essential.

Early on in the performance indicator project, it became apparent that this system had to include a means of periodically assessing the condition of state owned roads across the state. While the preferred approach was to utilize existing reporting systems as much as possible--such as using the Highway Maintenance Management System for efficiency analysis--the Department simply did not have any systematic, comprehensive road condition survey in use. Thus, a major part of the project has been devoted to developing and testing such a survey, to be conducted on an ongoing basis. The trained observer approach was chosen because it could be tailored to fit the varied concerns of the maintenance program and because it could be geared up fairly quickly with no major capital outlay. This paper describes how the survey works and illustrates the kinds of analysis for which it can be used.

Trained Observer Survey

The trained observer survey entails the use of trained professionals to physically inspect a number of conditions on a sample of highway sections in each of the state's 67 counties on a periodic basis. Each sample section is also run with a Mays Meter to obtain an indication of roughness. As with the system currently in use in Ohio, the number of "reportable conditions" of deficiencies in surface, foundation, drainage, shoulders, and other safety features which are observed can be used to obtain an overall rating of the "as built" maintenance condition of the roads in each county and district. (3,4)

The data generated by this system are intended to serve two purposes relating to needs assessment and performance monitoring. First, analysis of the numbers of reportable conditions and overall maintenance ratings should provide an improved basis for allocating funds for maintenance activities. The results should show where the greatest needs are for maintenance efforts and permit a better allocation of resources among counties or districts and a more efficient targeting of funds within counties or districts by type of highway and by maintenance cost function.

Secondly, the trained observer system will provide the Department with a means of tracking the effectiveness of the maintenance program. Since highways in each county will be sampled for observation on a periodic basis, this system will accumulate time series data which can be examined to determine whether the number of certain types of reportable conditions is being decreased or the overall maintenance ratings improved over time. Such measures of change over time can also be correlated with the amount of selected maintenance activities conducted and their associated costs to examine the effectiveness and efficiency of these activities.

Instrument Design

In determining what kinds of deficiencies would be included in the trained observer survey and defining the reportable conditions to be noted, three criteria were taken into account:

1. The system should be comprehensive in terms of highway maintenance concerns and should include measures representing conditions of major structural characteristics and major safety features.
2. The list of reportable conditions should include those which relate to the Department's high cost maintenance activities (excluding winter maintenance) and should only include deficiencies to which the Department responds. For example, the condition of surface flushing would not be included because the Department does not take action intended to directly counteract this problem.
3. The measuring instrument itself must be reliable, based on observable, tangible characteristics or conditions rather than impressions. To assure inter-observer reliability, the system must be based on clearly defined reportable conditions which would be observed and counted the same by different individuals.

Offsetting these criteria for valid measurement is the need for an instrument which is not too cumbersome to use. The system needs to be workable in the field, and an unduly complicated set of measures will make the observers' work too tedious and time-consuming. During pre-testing, the instrument was simplified and streablined to make the fieldwork smoother and quicker.

Figure 1 shows the set of deficiencies included in the survey. They reflect the major structural and safety concerns of highway maintenance as grouped in the general categories of roadways (surface and foundation), shoulders, drainage and appurtenances. Figure 1 also shows the individual reportable conditions which are counted as indicating given types of deficiencies. For example, surface deterioration may be indicated by dust layering, slopes of greater than ½ inch per foot, depressions, minor cracking or "mapcracking", and gaps in transverse or longitudinal joints. Specific definitions of each type of deficiency have been established as illustrated in Figure 2 and the observers have been drilled and trained in applying them before beginning actual fieldwork.

An attempt has been made to minimize problems of inter-observer reliability by establishing limits on the amount of each type of deficiency which counts as a reportable condition. The prevalence of each type of reportable condition is to be measured by the frequency with which the observers see that condition along the sample stretch of highway they are inspecting. The definition of each type of reportable condition specifies a minimum--how much of that condition must be observed in order to be counted. For instance, minor cracking must cover at least one square foot in order to count.

In addition, a unit count is specified for each specific type of reportable condition. If a given deficiency extends for more than this unit count, it counts as more than one reportable condition. For example, the unit count for minor cracking is every 25 lineal feet. Thus, if the observers encounter mapcracking of one square foot or more which extends 12 lineal feet, this counts as one reportable condition. However, if the mapcracking were more extensive and found to cover 60 lineal feet, this would be counted as three reportable conditions. With this system, the observers have less responsibility for determining the severity of the problems they come across.

It should also be noted that some degree of continuity among the different reportable conditions is built into the system. For instance, small depressions or holes less than 2 inches deep count as surface deterioration while potholes 2 inches or more in depth count as surface obstructions as long as they are not bigger in area than 2 square yards. Large potholes or depressions covering 2 square yards or more count as areas that are broken up or have mud surfacing through units of foundation failure.

In addition to visually inspecting the sample highway segments and recording the observed reportable conditions, crews are riding each segment in a vehicle equipped with a May's Ride Meter to obtain an indication of roughness. The resulting roughness is converted into a Present Serviceability Index (PSI) which can be thought of as an indicator of rideability and service as opposed to a structural or safety indicator. The Department has been using May's Meters on selected roadways and relying primarily on PSI measures to determine the need for resurfacing. Rideability is only one aspect of road condition, however, and the trained observer counts on a variety of conditions should greatly improve the ability to discriminate good roads from bad roads.

Sample Selection

The trained observer survey is to be conducted twice each year, once in the spring and once in the fall, with a "floating" sample; in other words a new random sample of road segments will be selected for observation each time. While the sampling fraction must be low--given time and cost considerations and the fact that the total system contains some 45,000 miles--over time data will build up on most of the system. The use of floating samples is advisable in order to obtain more complete coverage over the span of a few observation periods and to avoid possible problems arising from the targeting of maintenance activities on those few segments known to be included in a stationary sample.

Given the purposes of the trained observer system as aiding in the allocation of maintenance funds and monitoring the progress of the maintenance program across time, the development of a sample selection procedure was based on the following criteria:

1. The overall sample should be approximately representative of the statewide highway network in

Figure 1. Reportable conditions - trained observer survey.

Components	Deficiencies	Reportable Conditions	Unit Counts
ROADWAYS	Surface Deterioration	Dust Layering	25 LF
		Slope - ½"/ft.	25 LF
		Depressions	25 LF
		Minor Cracking	25 LF
		Joints	25 LF
	Surface Obstructions	Potholes	Each
		Foreign Objects	Each
		Blowups	Each
		Virginia Joints	Each
	Foundation Failure	Soft Spots	25 LF
		Major Cracking	25 LF
		Broken up or Mud	25 LF
		Bituminous Patch	25 LF
SHOULDERS	Deterioration	Slope - ½"/ft.	25 LF
		Depressions	25 LF
		Minor Cracking	25 LF
		Raveling	25 LF
		Buildup	25 LF
	Obstructions	Potholes	Each
		Foreign Objects	Each
		Washouts or Slides	Each
		Bad Drives	Each
	Failure	Major Cracking	25 LF
		Rutted	25 LF
		Broken up or Mud	25 LF
	Drop Off	Edge Pavement 2"	100 LF
		Edge Pavement 4"	
DRAINAGE	Obstruction	Non-functional Ditch	100 LF
		Non-functional Inlet	Each
		Pipe ½ Inlet	Each
	Failure	Bad Pipe	Each
		Broken Inlets	Each
		Non-functional Endwalls	Each
APPURTENANCES	Guard Rails and Median Barriers	Bad Stripping	500 LF
		Rotted Posts	Each
		Non-functional Elems.	100 LF
		Median Barrier	100 LF
	Signs	Regular Signs	Each
		Delineators	Each
		L.R. or Station Markers	Each
	Litter	Litter	25 LF

terms of the distribution across the 67 counties and the 11 Engineering Districts.

2. Within individual counties the samples should provide for fairly precise estimates of the number of reportable conditions for the county as a whole.

3. While the samples will not be very reliable for a given type of road for any given county, the overall sample should provide reliability for a given maintenance functional code on a district basis.

Given these criteria it was decided that the most appropriate type of sample would be a random sample of the approximately 2,600 observable segments stratified by county and Maintenance Functional Code (MFC). Thus a separate sample is selected from each county, and within each county care is taken to include sufficient examples of each road type. Since there are relatively fewer miles of the higher classes of highways, they have to be sampled more heavily in order to have good sample reliability on a district basis. Therefore, while collectors and local roads were sampled at 2% for cycle 1 of the survey, the sampling fraction for Interstates was 15%.

On the average, the length of the highway sections that are inspected is approximately one half mile. To generate the sample, the highway sections entered in the road log were combined or subdivided where necessary to form segments from .3 to .7 miles in length. In combining small sections care was taken not to mix very dissimilar roads in the segments which would be used to draw the sample. Thus, entries in the road log could be combined only if they were part of the same legislative route, had the same urban/rural status, were classified the same according to the maintenance functional code, and fell within the same general range of average daily traffic (ADT). The ranges of ADT which were established by Bureau of Maintenance personnel were 1 - 1,499 vehicles, 1,500 - 2,999 vehicles, 3,000 - 4,999 vehicles, and 5,000 vehicles and above. Highway sections with ADT's of more than 5,000 vehicles

Figure 2. Sample definitions of reportable conditions.

Rigid Base Roads - Include all highways with a base course of plain or reinforced cement concrete and a wearing course of bituminous concrete, brick, or block.

Surface Deterioration

<u>Minor cracking</u> - The presence of irregular cracks, less than 1/8 inches wide, often referred to as map-cracking, covering at least one square foot of area. Unit count - every 25 lineal feet.

<u>Depression</u> - Any depression hole or corrugation which is greater than ½ inch and less than 2 inches deep and at least one square foot in area. Unit count - every 25 lineal feet.

<u>Joints</u> - Any gap in a transverse or longitudinal joint at least one foot long which needs to be filled. Also, any crack greater than ¼ inch wide and more than one foot long, which need to be filled. Unit count - every 25 lineal feet.

could be combined only if the difference in ADT did not exceed 10,000 vehicles.

From the resulting file of these .3 to .7 mile segments, then, roads were randomly selected for a sample which is stratified proportionally by county and disproportionally by MFC. The total mileage and number of sections sampled for each MFC is shown in Figure 3.

Figure 3. Sample selection statistics.

MFC	Total Mileage	Sampling Fraction	Sections Observed
Interstate	1,060	15%	339
Principal Arterials	4,060	8%	633
Minor Arterials	8,460	2.5%	399
Collectors	17,700	2.0%	728
Local	12,780	2.0%	482
Total	44,060	3.0%	2,581

This overall 3% sample clearly contains a substantial number of highway segments to be observed; yet if there is wide variation in the rate of reportable conditions, a larger sample may be needed to draw valid conclusions on a district by MFC basis. On the basis of the results of Cycle 1 of the survey it may well be determined that the sample size must be expanded and/or reallocated among MFC classes for subsequent cycles.

Conduct of the Field Work

The definitions of reportable conditions were field tested by piloting the program in Lycoming County with two Engineers from Operations Review Group. Lycoming County is a rural County in North Central Pennsylvania with one major city, Williamsport, and 869 miles of State highway. It was felt that this was a representative County; even though it has no Interstate it has several major four lane roads. On two lane roads only one direction was walked and observations extended only to the center line. On three and four lane roads, both directions were walked and the data combined for one section. Upon completion of the pilot representatives from the Bureau of Highway Maintenance, Penn State, and the Operations Review Group reviewed the results and made numerous changes. First, several definitions were revised to reflect actual conditions and make reporting easier, and unit counts were standardized for ease in observing and reporting. Directions of walk were also set to alternate to provide greater randomness and actual representation.

A two-man team procedure for performing observations and recording data was established for the following reasons: (1) Use of a two-man team with two vehicles and parking one at each end of the section saved considerable time lost by walking back to the vehicle at the original starting point. (2) Many of the reportable conditions are based on frequencies or occurrences within a 25 or 100 foot length. Through experimentation the easiest method of tracking the distances was found to be with the use of a measuring wheel. This requires one member of the team to use the wheel and note distances and conditions while the other member records the counts on the chart and is observing the conditions. A set of standard packages was developed for each county for use by the trained Observers including: (1) Straight line diagrams for each section of roadway to be examined to help team members in locating roads in counties lacking station and/or legislative route markers, (2) County maps with all sections plotted in color to identify approximate locations of sections as an aid to the team in planning a days work with the minimal amount of travel time between sections, and (3) Copy of tabulation of sections by MFC, starting and stopping station, length in feet and miles. Finally, it was decided to inspect bridges up to a 20 foot span length because this was the actual cut-off length of the Bridge Inspection Team.

It was anticipated that a minimum of five two-man teams would be needed to complete the work before the Winter. New employees worked with the two engineers who did the pretesting until they were proficient and then as we hired new employees they were placed with experienced employees. One of the engineers who performed the pilot in Lycoming County worked with the program as the coordinator during the entire cycle. He or his supervisor was available to answer any questions concerning interpretations, definitions, etc., via phone and periodically visited crews in the Counties.

An attempt was made to overcome weather problems by starting with the Counties in the Northern and Western part of the State and working generally toward the Southeast corner. Whenever possible team members were rotated to eliminate the same two people working together constantly. This helped to ensure uniform interpretation and application. At the completion of the cycle and prior to release of the temporaries, a two-day seminar was held to discuss each of the definitions and conditions and identify any potential problem areas that required attention before the next cycle.

The cost for the first cycle of field operations was approximately $200,000. For the second cycle efficiency has been increased by plotting all counties prior to starting field work and dividing the State into five geographical areas. At the start of the cycle each team was provided all the packages for their assigned counties. This permits them to reduce wasted time and perform isolated sections with adjacent counties or perform a complete days work on Interstates. Furthermore, data processing has been streamlined. The tally sheets for the current and subsequent cycle have been computerized to reduce handwork and transpose information. All headings and pertinent information is now printed when the computer selects the sample.

Results

The preliminary findings from the trained observer survey presented here concern ratings of existing road conditions as well as estimates of total needs for maintenance work. The results pertain to statewide conditions and also show comparisons across districts and counties. While most of the data are purely descriptive, some attempt is made here to apply statistical tests and evaluate sample reliability.

Overall Conditions

Figure 4 shows aggregate statewide frequency distributions for four illustrative reportable conditions: surface depressions, minor cracking on the surface, nonfunctional ditches and nonfunctioning guardrail elements. The incidence of all conditions is reported on a count per mile basis. The most striking feature of these distributions is that they reflect widespread variation and are highly skewed to the right. While some of the 2,581 road sections that were inspected had no surface depressions, for example, some had a moderate-to-heavy incidence of depressions and a few had the maximum possible, 211-220. On these highways depressions were encountered in every 25 foot stretch that was observed.

That these reportable conditions are highly variable--and this characterizes almost all the items included in the survey--is further evidenced by the fact that the standard deviations exceed their respective mean averages by a considerable margin. The high degree of dispersion weakens sample reliability and makes it more difficult to compare means of obtaining precise interval estimates. This is a strong indication that sample sizes should be expanded to future cycles of the survey.

The one-sidedness of these distributions along with the skews toward extremely high values also makes the mean average less reliable as an indicator of central tendency. Median averages are preferable as a more accurate indication of what values the more typical roads take on for various conditions. It is also the case that on many of the indicators a significant number of roads have zero counts. Thus, the percentage of road sections with some counts, the percent deficient roads, is also a measure which is worthwhile to look at. To concentrate on the extremely high values on the basis that in some respects the worst roads in a county or district are of greatest concern, the eightieth or ninetieth percentile might also be useful.

As can be seen in Figure 4, then, surface depressions and minor cracking have similar distributions ranging from zero to the maximum, although a substantially higher percentage of all roads evidenced depressions (small potholes) than minor cracking. Comparing the two medians also indicate that depressions were observed more than minor cracking. Figure 4 shows that only 18.4% of the highway sections that were inspected had nonfunctional guardrail elements and that the median was only slightly above .1 observed count per mile. The drainage condition of a pipe being half-full or more was encountered in nearly 40% of all the sections, and the median was .33 counts per mile. The overall range of this condition is much less than many others because along many stretches of highway there are simply no pipes to observe.

The wide variability in the condition of Pennsylvania's road network is not surprising considering the inadequacy of funding of the maintenance program over the past decade and the wide range of roads included in the system. Unlike most states, whose responsibility covers only trunk-line highway systems, the Pennsylvania DOT system also incorporates many lower order collectors and farm-to-market and small borough "local use" roads which are not likely to stack up as well in terms of many reportable conditions. Given this context, the distributions seen in Figure 4 are what would be expected as a profile of the condition of the state's roads. Now that this profile is known, it raises questions about the preferred strategy of an improved maintenance program: should the Department seek to steepen the skew by upgrading the good and moderately good roads to zero deficiency roads or should it concentrate on trying to eliminate roads in the worst possible condition?

Maintenance Classification Comparisons

Since programming and work planning are geared in part to functional class of highway, it is worthwhile to make initial comparisons of reportable conditions by MFC. Figure 5 shows the percentage of deficient roads on selected surface conditions as well as median averages. On Interstates and some other higher order roads the percent deficient will be overstated relative to lower MFC classes because lane highways were walked in both directions. There is little systematic variation in percent deficient in depressions except that local roads have more deficient roads than the higher categories. However, looking at medians it is apparent that the typical Interstate has fewer depressions per mile than other roads and that this indicator increases with the lower order MFC's. This pattern holds for "all potholes" which includes depressions, potholes, and broken up areas with mud surfacing through. Minor cracking and major cracking are more prevalent on the lower order roads than on interstates and principal arterials as would be expected given maintenance priorities. However, the incidence of joint deterioration varies in the other direction, from 44 counts per mile on the interstates and 33 per mile on principal arterials to almost nonexistent on collectors and 6% on local roads, largely because joints are only observed on rigid base and rigid pavement roads. Yet the 92% deficient on interstates and 73% on principal arterials would have to be considered unacceptable.

As seen in Figure 6, insufficient shoulder slopes are mainly a problem on collectors and local roads, largely because this condition occurs much less frequently with paved shoulders. Shoulder buildup varies in the opposite direction, perhaps reflecting the greater use of antiskid material on the higher order roads. It is interesting to note that although some shoulder buildup is encountered on a fairly high percentage of roads, the problem is not severe in that on the average there is substantially less than one count per mile. Surprisingly, washouts have their lowest incidence on local roads and Interstates and are more prevalent on arterials although overall the counts are low. Edge of pavement dropoffs greater than 4 inches have the lowest incidence on interstates, as expected, and do not vary substantially by MFC otherwise. The percent of roads with major cracking on the shoulders is substantially higher for Interstates--at 6 counts per mile--than for other roads which have fewer concrete and bituminous shoulders.

With the exception of interstates, the percent of roads with nonfunctioning ditches is greater with the lower order roads, as shown in Figure 7. On the other hand, the percent of roads with nonfunctioning inlets as well as median averages tend to decrease with the lower order roads, as they have fewer pipes.

Figure 4. Frequency distribution.

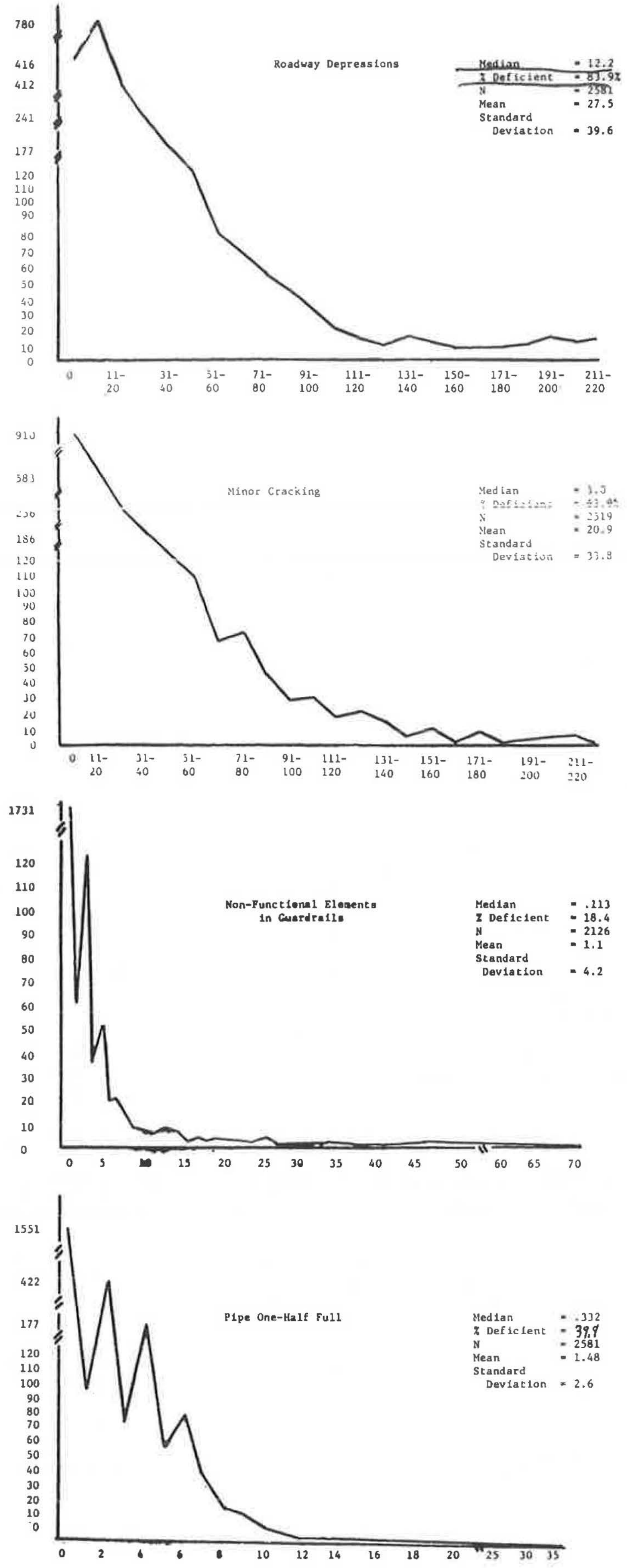


Figure 5. Median average counts and percentage of sections with reportable conditions--selected surface items.

MFC	Surface Depressions	Minor Cracking	Joint Deterioration	Major Cracking	All Potholes
Interstate	5.1	0.5	44.0	1.2	5.7
	83.5%	49.8%	92.0%	57.8%	85.2%
Principal Arterial	10.6	2.5	33.1	2.8	11.7
	81.8%	59.7%	73.2%	59.4%	82.7%
Minor Arterial	8.3	7.7	0.5	10.9	9.4
	78.4%	71.4%	49.6%	69.2%	81.4%
Collectors	16.7	9.2	0.1	8.5	19.0
	83.6%	66.2%	16.9%	64.0%	85.9%
Local	27.4	13.0	0.0	12.1	35.6
	91.7%	70.1%	5.6%	64.7%	93.2%

Figure 6. Median average counts and percentage of sections with reportable conditions--selected shoulder items.

MFC	Shoulder Slope	Shoulder Buildup	Washouts	Major Cracking	Edge Pavement 4"
Interstate	0.1	0.5	0.2	6.3	0.0
	8.3%	48.5%	26.2%	60.5%	8.9%
Principle Arterial	0.3	0.3	0.3	0.4	0.1
	34.2%	38.8%	33.5%	41.3%	16.6%
Minor Arterial	0.5	0.3	0.2	0.4	0.1
	48.9%	34.7%	31.5%	45.1%	17.3%
Collectors	14.9	0.2	0.2	0.3	0.1
	65.1%	26.6%	24.3%	37.3%	20.2%
Local	22.2	0.2	0.1	0.5	0.1
	69.7%	27.3%	20.4%	59.3%	16.6%

Figure 7. Median average counts and percentage of sections with reportable conditions--selected drainage items.

MFC	Nonfunctional Ditches	Nonfunctional Inlet	Pipe 1/2 Full
Interstate	0.1	0.1	0.1
	22.4%	21.2%	20.9%
Principal Arterial	0.1	0.2	0.3
	15.3%	23.7%	40.9%
Minor Arterial	0.1	0.1	0.3
	19.5%	12.0%	37.8%
Collectors	0.2	0.1	0.4
	25.1%	8.6%	45.3%
Local	0.2	0.0	0.4
	25.9%	5.8%	45.4%

Principal arterials are at the same level as interstates on this indicator, reflecting the fact that they have as many inlets but perhaps receive a little less maintenance effort. The prevalence of roads with cross-pipes which are one-half full or more is lowest for Interstates, higher for arterials, and still higher for collectors and local roads, even though they have fewer pipes. This would indicate less maintenance attention to pipes on these roads. Because the incidence of drainage problems is so heavily dependent upon the actual numbers of ditches and structures, in Cycle 2 these totals will also be tabulated and the deficiencies will be analyzed on a percentage basis.

Figure 8 shows median averages the percent deficient on selected appurtenance conditions by MFC. Striping is good on the interstates and evidences only a minor problem on lower order roads, except local roads. While many local roads do not have striping, the level of maintenance is less on those that do as compared with higher MFC's as would be expected. The reportable conditions concerning both nonfunctioning guardrail elements and missing or damaged regular signs are more frequent on the higher order roads, largely because such roads have more of these appurtenances in place. Missing or damaged delineators are the greatest problem on local roads and, surprisingly, on the Interstates; the lowest count is on principal arterials. The percentage of roads with some litter count is almost uniformly high except for local roads, but the median count decreases dramatically with the lower

Figure 8. Median average counts and percentage of sections with reportable conditions--selected appurtenances.

MFC	Bad Striping	Nonfunctional Guardrail Elements	Regular Signs	Missing Delineators	Litter	(N)
Interstate	0.0	0.1	0.1	2.9	81.5	
	0.0%	21.4%	22.4%	76.9%	100.0%	339
Principal Arterials	0.0	0.2	0.1	0.4	64.7	
	4.4%	25.3%	19.6%	46.9%	97.8%	633
Minor Arterials	0.0	0.1	0.1	1.1	45.4	
	4.4%	21.8%	13.3%	59.9%	95.5%	399
Collectors	0.0	0.1	0.1	2.3	32.0	
	7.1%	16.5%	13.3%	63.9%	95.9%	728
Local	0.2	0.0	0.1	2.5	14.8	
	2.4%	7.7%	9.7%	67.6%	89.2%	482

MFC's mainly a function of their lower levels of usage. This reportable condition may need to be redefined in order to provide a more discriminating indicator.

Because some of the variation by MFC presented above seems to be explicable in part by pavement type, it will be interesting to make some comparisons on this basis as illustrated by Figure 9. Median values and the percentage of roads exhibiting some potholes are highest for unpaved roads and lowest for rigid pavement roads, as might be expected given their respective design standards and maintenance priorities. Yet the most stark impression conveyed here is that the overall incidence of potholes is so high. Cracking--major and minor cracking combined--vary in the same direction although in a lower order of magnitude. While cracking is not applicable to unpaved roads, it was found in 64% of the flexible base roads observed and in only 24% of the rigid pavement roads.

Figure 9. Median average and percent roads deficient by pavement type--potholes and cracking.

	All Potholes		All Cracking		
Pavement Type	Md	%	Md	%	N
Unpaved	33.2	95.2	-	-	63
Flexible Base	20.1	87.2	36.4	63.7	1,419
Rigid Base	11.6	83.3	35.4	60.7	493
Rigid Pavement	6.8	80.0	3.2	24.4	601
					2,576

District and County Comparisons

Figure 10 shows the percentage of road sections with deficient shoulder slopes broken down by Engineering district and MFC. In general, the pattern of shoulder slope problems increasing with lower order MFC's is replicated in the 11 districts with some exceptions. In districts 4 and 5 there is less incidence of this problem on minor arterials than on Interstates and major arterials. Overall, the percentage deficient ranges from 38% in District 5 to 61% in District 10. From a macro level management perspective, this level of information should be of primary importance in evaluating maintenance efforts, particularly over time. District engineers can then be called upon to explain poor performance and to deal with problems in problem counties internally.

Following a hierarchical approach to data display, district engineers can be given results in the format of Figure 11, showing the incidence of minor cracking by district and counties within districts. The districts range from 53% to 75% roads with some deficiency and from a median of 1.8 to 13.2 counts per mile. While there is some degree of homogeneity within districts on this indicator, there is clearly substantial variation within. District 3, for example, is in relatively good shape in terms of minor cracking with the exception of Northumberland county which pulls the overall median up.

Figures 12 and 13 show geographic distributions of the percent deficient roads with major cracking and nonfunctional guardrail elements respectively. Major cracking problems do not coincide with district boundaries to any substantial degree. District 10 including Jefferson and Armstrong counties and District 4 including Luzerne, Bradford and Wayne counties both contain the upper and lower extremes. Most of the other districts include some near zero deficient counties as well as counties with a high percentage of deficient roads.

By contrast, the variation in the percentage of roads with nonfunctional guardrail elements coincides with district boundaries to a much greater degree. Districts 8 and 9 in the middle of the southern tier counties along with District 3 to the north have almost uniformly low percentages of deficient roads. Districts with concentrations of counties in the highest ranges of percent roads with nonfunctional guardrail elements include District 6 around Philadelphia, District 4 in the northeast corner, and District 12 in the southwest. This kind of clustering facilitates delegating responsibilities to correct problems to the District level.

Needs Assessment

A second major purpose of the trained observer survey is to project maintenance needs on the basis of the estimated total amount of each deficiency in a district or county or particular MFC. This is done by applying the overall mean count per mile and the percentage of deficient roads to the total mileage of a particular MFC in a district or county. While the ratings discussed above are based only on roads that are applicable--for a certain condition--counts of nonfunctioning guardrail elements are recorded only for road segments that have guardrails, for example--for the purposes of estimating the total magnitude of a condition rates and percentages from the complete subsample (including "not applicables")

Figure 10. Percentage of roads with deficient shoulder slope by district and MFC.

District	Interstate	Principal Arterial	Minor Arterial	Collectors	Local Roads	Row Total
1	17%	48%	54%	72%	67%	53%
2	0%	10%	52%	57%	83%	40%
3	0%	10%	35%	59%	62%	43%
4	11%	57%	30%	60%	68%	45%
5	6%	33%	24%	57%	63%	38%
6	0%	50%	70%	52%	45%	49%
8	8%	23%	38%	62%	66%	45%
9	0%	31%	32%	68%	70%	52%
10	8%	27%	64%	77%	90%	61%
11	7%	45%	74%	88%	82%	59%
12	14%	37%	77%	73%	76%	59%
	9%	34%	49%	65%	70%	49%

Figure 11. Incidence of Minor Cracking by district and county.

	Md	%
District 1	2.1	56%
Crawford	4.4	68
Erie	12.2	77
Forest	56.0	78
Mercer	.19	27
Venango	.32	39
Warren	2.0	58
Lawrence	7.0	60
District 2	6.8	69%
Centre	26.0	84
Clearfield	4.3	64
Clinton	10.7	67
Cameron	13.5	100
McKean	6.8	73
Potter	9.5	72
Mifflin	4.0	65
Elk	.23	31
District 3	13.2	75%
Columbia	18.0	90
Lycoming	3.7	64
Montour	.25	33
Northumberland	44.0	94
Snyder	1.0	50
Sullivan	24.0	90
Tioga	17.0	70
Union	14.0	94
District 4	4.9	61%
Bradford	16.5	79
Lackawanna	.31	38
Luzerne	.41	45
Pike	.37	42
Susquehanna	27.0	86
Wayne	21.0	85
Wyoming	.50	50
District 5	9.7	72%
Berks	1.50	53
Carbon	15.5	79
Lehigh	28.0	86
Monroe	2.5	58
Northampton	44.0	94
Schuylkill	8.0	81

	Md	%
District 6	1.9	57%
Bucks	.45	47
Chester	3.0	63
Delaware	2.3	62
Montgomery	12.0	72
Philadelphia	.21	30
District 8	7.9	73%
Cumberland	1.67	55
Franklin	2.1	62
York	22.0	74
Dauphin	8.5	84
Juniata	25.0	63
Lancaster	23.0	79
Lebanon	13.2	86
Perry	10.5	81
District 9	2.0	54%
Bedford	12.0	79
Blair	12.2	83
Cambria	.25	33
Fulton	.15	13
Huntingdon	.36	42
Somerset	4.5	60
District 10	3.9	62%
Armstrong	26.5	82
Butler	.46	48
Clarion	8.5	81
Indiana	4.0	65
Jefferson	.25	33
District 11	12.0	70%
Allegheny	16.0	77
Beaver	2.0	54
District 12	1.8	53%
Fayette	13.0	65
Greene	10.0	67
Washington	.21	29
Westmoreland	3.7	64

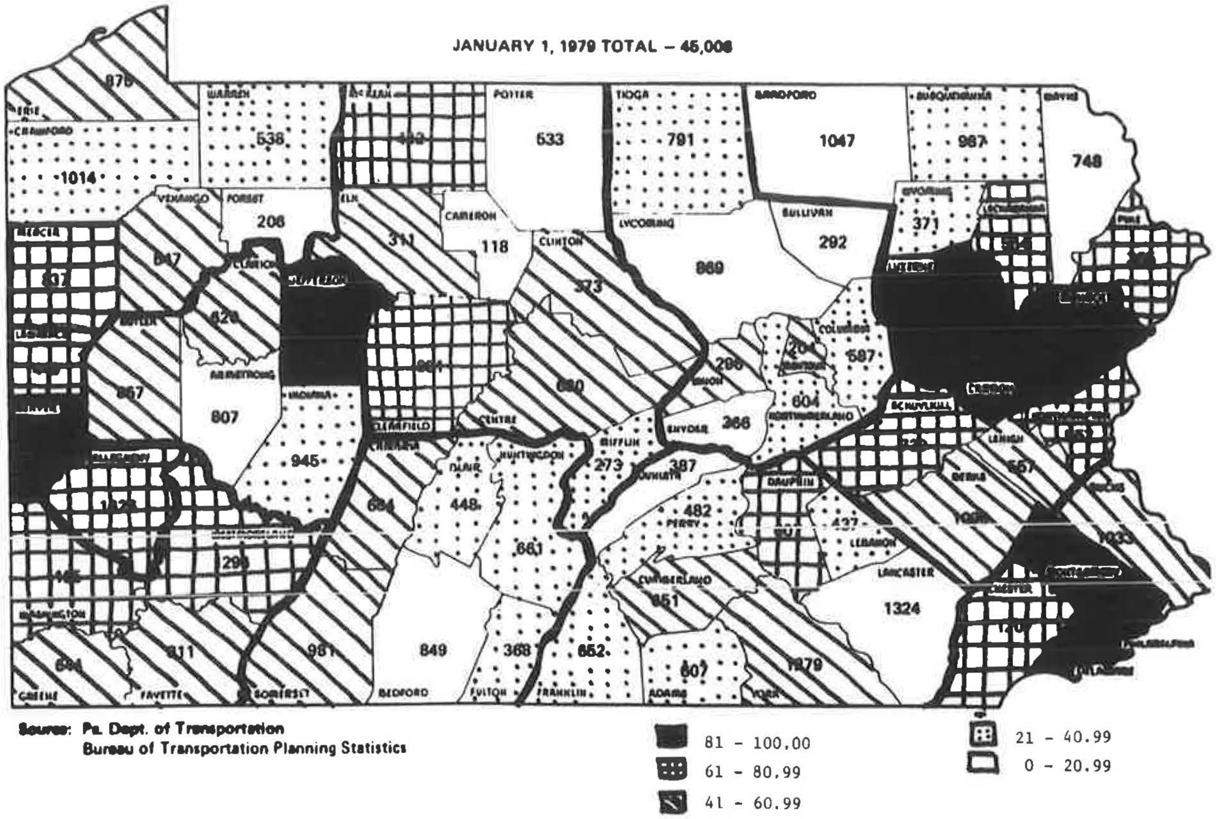
are appropriate. Thus the issue for a given district is, how many counts of nonfunctioning guardrail elements on principal arterials are there, taking into account the fact that many road segments, have no guardrail?

Figure 14 illustrates these findings with respect to all potholes (depressions + potholes + broken up areas) by district and MFC. Looking at the totals it shows that the overall sample is being expanded to 44,209 miles by applying the original sampling fractions. Of this total mileage it is estimated that 38,324 miles have at least one pothole per mile. In addition, the number of 25 foot sections with one or more potholes is projected to be 1,808,640; this would be the total estimated number of pothole clusters in the state system. Stated another way, if these 25 foot sections containing potholes were placed end to end, they would amount to 8,563 miles of highway, roughly 20% of the entire state system.

This kind of output should be most useful for programming because instead of showing the average condition on roads with certain design characteristics, it indicates the magnitude of deficiency across all highways in a given district. Depending on the size of the network of highways in different districts, their relative magnitudes of needs may or may not conform to their ranking in terms of average condition. For instance, District 4 has a lower rate of potholes per mile than does District 12, but the total projected pothole count is nevertheless higher in District 12. Districts 11 and 12 have the same rate of potholes per mile while District 12 has twice the total magnitude of deficiency. Similarly, Districts 5 and 8 have roughly equivalent ratings on potholes per mile, but District 8 has a much greater total need.

The output in Figure 14 can also be examined to make comparisons across MFC's. Although District 3 has a somewhat larger highway system than District 2, for example, it has substantially lower projected total pothole counts on Interstates, principal arterials, minor arterials and collectors, reflecting in general a higher level of maintenance on arterials and collectors. Yet, District 3 has a much higher projected pothole count on local roads than does District 2, due to the fact that there are many more local roads in District 3 than District 2. When this kind of analysis is conducted for all reportable

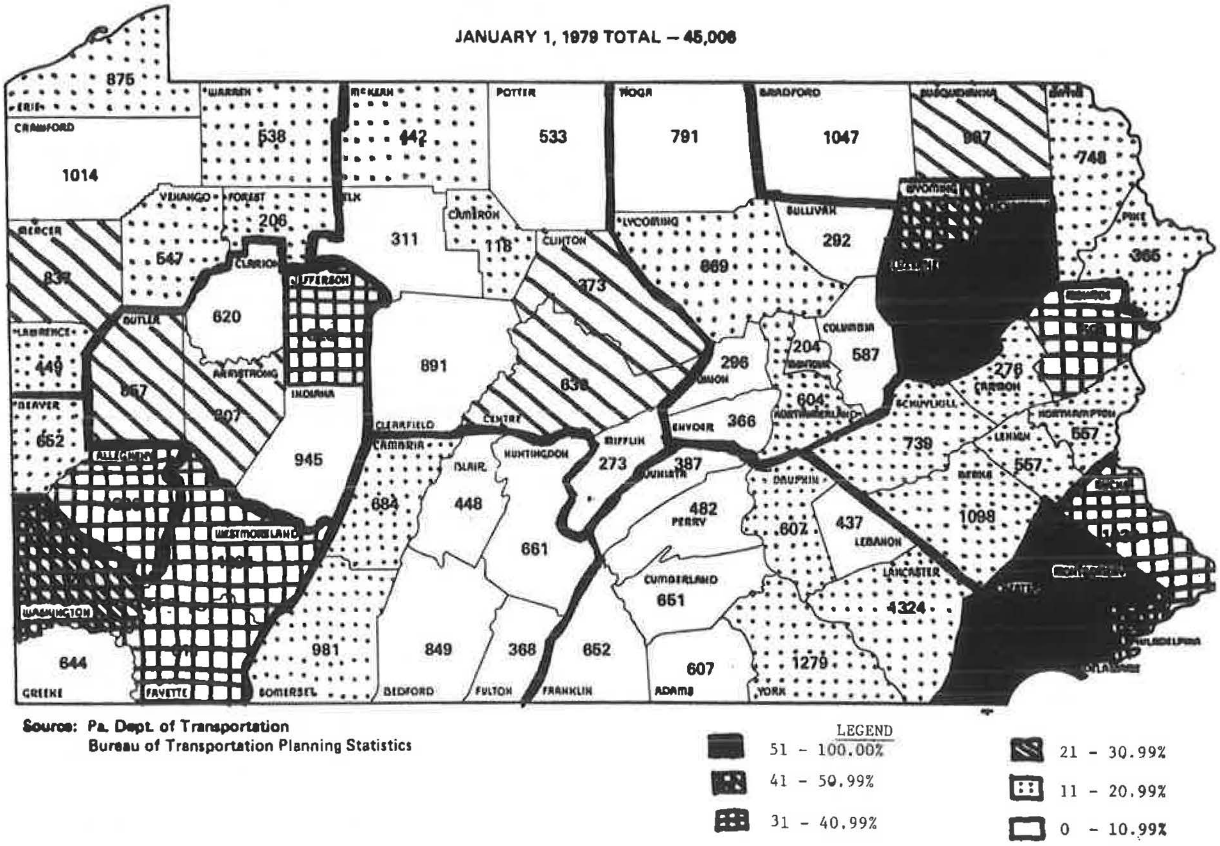
Figure 12. Percentage of roadway segments with major cracking on roadway surface.


JANUARY 1, 1979 TOTAL — 45,006

Source: Pa. Dept. of Transportation
Bureau of Transportation Planning Statistics

■ 81 - 100.00
▦ 61 - 80.99
▨ 41 - 60.99
⊡ 21 - 40.99
□ 0 - 20.99

Figure 13. Percentage of roadway segments with nonfunctional elements in guardrails.


JANUARY 1, 1979 TOTAL — 45,006

Source: Pa. Dept. of Transportation
Bureau of Transportation Planning Statistics

LEGEND

■ 51 - 100.00%
▦ 41 - 50.99%
▦ 31 - 40.99%
▨ 21 - 30.99%
⊡ 11 - 20.99%
□ 0 - 10.99%

Figure 14. Projected total pothole counts by district and MFC.

District		Interstate	Principal Arterial	Minor Arterial	Collectors	Local Roads	Total
1	Total Mileage	166	191	1,027	1,980	1,057	4,421
	Deficient Mileage	149	154.3	859.2	1,809	1,031	4,003
	Total Count	1,433	4,613	33,828	107,433	55,351	202,659
2	Total Mileate	99	279	870	1,545	737	3,530
	Deficient Mileage	92.6	163.3	692.1	1,283	737	2,968
	Total Count	984	3,845	19,100	55,542	38,029	117,500
3	Total Mileage	52	223	629	1,695	1,369	3,968
	Deficient Mileage	48.9	128.4	426.8	1,464	1,269	3,337
	Total Count	471	2,710	11,906	47,203	70,167	132,458
4	Total Mileage	178	161	860	1,877	1,897	4,973
	Deficient Mileage	155.7	140	650	1,642	1,872	4,460
	Total Count	2,352	5,943	16,613	68,276	134,238	227,421
5	Total Mileage	163	415	648	1,607	872	3,705
	Deficient Mileage	138.7	381	543.5	1,428	797	3,289
	Total Count	1,581	9,491	14,340	38,900	29,249	93,561
6	Total Mileage	63	1,053	736	1,327	629	3,803
	Deficient Mileage	51.8	962	715.5	1,106	524	3,359
	Total Count	1,201	29,641	17,337	40,891	36,010	125,080
8	Total Mileage	161	593	998	2,748	1,783	6,283
	Deficient Mileage	120	452	825.3	2,146	1,612	5,155
	Total Count	1,744	9,003	15,181	73,071	70,563	169,561
9	Total Mileage	24	387	556	1,649	1,342	3,958
	Deficient Mileage	20.6	317.9	402.6	1,374	1,165	3,280
	Total Count	391	8,818	21,646	48,146	73,202	152,203
10	Total Mileage	81	197	699	1,649	1,177	3,803
	Deficient Mileage	81	163	555.1	1,446	1,126	3,371
	Total Count	864	3,397	17,167	136,842	115,704	273,973
11	Total Mileage	51	453	463	664	268	1,899
	Deficient Mileage	37.4	411	442.9	638	268	1,797
	Total Count	346	16,145	17,675	42,726	26,776	103,667
12	Total Mileage	101	349	673	1,790	948	3,861
	Deficient Mileage	69.7	280.6	525.8	1,563	848	3,287
	Total Count	1,073	6,583	21,578	79,264	101,186	209,684
Total State							
	Total Mileage	1,139	4,301	8,159	18,531	12,079	44,209
	Total Deficient	968	3,553	6,646	15,909	11,252	38,324
	Total Count	12,411	100,051	206,429	740,527	749,224	1,808,640

conditions, such comparisons should facilitate a more objective basis for programming maintenance activities. Staff should be cognizant of differences between districts on total projects count of a given deficiency broken down by MFC, as well as differences in the projected magnitudes of various kinds of reportable conditions across districts.

Sensitivity Analysis

One concern with this trained observer survey is making comparisons between districts and counties which are statistically significant, concluding from the comparison of three percent samples that the incidence of some reportable condition in one area's entire road system is higher or lower than that of another area. Figure 15 shows the results of two-tailed difference of means tests (2 sample t tests) across the range of deficiencies for selected pairs of counties. These findings indicate a few important points regarding sample reliability for drawing conclusions about differences between counties. First, among the trained observer deficiencies, the surface foundation and shoulder items tend more to show significant differences than do the drainage and appurtenance items. Secondly, the former set of items also tend to indicate more significant differences than do the PSI measures. Although the PSI measures have compact frequency distributions with low standard deviations, the trained observer variables tend to discriminate better and worse counties than does PSI.

A final point about these comparisons highlights a problem. Although many of the pairs of counties shown in Figure 15 are seen to have statistically significant mean average counts, they represent some of the extreme pairings of counties. Many other pairs of counties with sample differences that are of practical significance do not turn out to have statistically significant differences. Even looking at Figure 15, shoulder deterioration is not statistically significant between Erie and Adams counties although the mean count for Erie is more than double that for Adams, a difference of more than 50 points. This is due to the extreme variation and resulting large standard deviations in most of these measures.

This indicates that larger sample sizes are required for future cycles of the survey. Using one-tailed tests with the present sampling fraction, differences in foundation failure means with a difference of 28 points are significant at the .05 level.

Figure 15. Two tailed difference in means test results for selected pairs of counties.

Variable	Susquehanna		Lycoming	Lycoming		Erie	Erie		Adams	Adams		York
Surface Deterioration	156.0	*	32.3	32.3	*	80.7	80.7	*	50.1	50.1	*	112.4
Surface Obstruction	3.7	*	0.4	0.4		3.9	3.9		0.6	0.6	*	1.6
Foundation Failure	72.0	*	17.1	17.1	*	81.8	81.8	*	7.6	7.6	*	40.7
Shoulder Deterioration	132.8	*	28.2	28.2		99.9	99.9		46.4	46.4	*	111.8
Shoulder Obstruction	9.2		2.5	2.5	*	8.1	8.1	*	2.4	2.4	*	12.7
Shoulder Failure	10.6		5.8	5.8	*	30.6	30.6		14.5	14.5		15.5
Shoulder Dropoff	16.5	*	3.2	3.2		7.0	7.0	*	0.9	0.9	*	12.8
Drainage Obstruction	3.8		2.1	2.1		3.6	3.6		1.3	1.3	*	3.9
Drainage Failure	0.9		0.2	0.2		0.3	0.3		0.1	0.1		0.2
Bad Striping	0.0		0.0	0.0		0.3	0.3		0.0	0.0	*	0.8
Guardrail Deterioration	1.4	*	0.5	0.5		1.0	1.0	*	0.0	0.0	*	2.7
Median Barrier Deterioration	0.0		0.0	0.0		2.0	2.0		0.0	0.0		0.0
Sign Deterioration	6.4		4.0	3.0		4.6	4.6	*	1.1	1.1	*	3.0
Litter	55.8		37.6	37.6		53.6	53.6		39.9	39.9		43.6
PSI LOW	2.5		2.6	2.6		2.9	2.9		2.7	2.7	*	2.3
PSI AVE	2.8		2.9	2.9		3.2	3.2		2.9	2.9		2.6
N =	47		41	41		57	57		32	32		69

* t test results statistically significant at the .05 level.

For districts the required difference is cut down to roughly 12 counts. Confidence interval estimates for the mean counts of foundation failure at the 95% level would run from 2.6 to 12.6, from 59.8 to 112.3 and from 30.3 to 50.6 for Adams, Erie and York counties respectively. Sample reliability seems a little more useful when looking at differences in the percentage of deficient roads. Initial tests conducted on surface depressions, minor cracking, major cracking and all potholes, for instance, indicates that differences of 60 to 10 percentage points between districts are statistically significant.

Further Analysis

The kind of descriptive analysis discussed in this paper, refined and conducted in a thorough fashion, will be beneficial to the Department in terms of both programming and monitoring performance over time. Beyond this, however, there are a number of subsequent types of analysis which can further improve the usefulness of the survey. These include:

1. The development of a weighting scheme for computing indexes of roadways, shoulders, drainage and appurtenances for ranking counties in the aggregate and inclusion in an allocation formula for maintenance funds.
2. Incorporation of ADT to build in a use factor in analyzing variation in condition and projecting total needs.
3. Conducting sampling experiments with data collected on 100% samples of major and minor arterials in Berks County to obtain a feel for increasing sample reliability.
4. Correlating the trained observer roadway items with PSI data to determine the degree of complementarity or redundancy.
5. Analyzing the road condition data in conjunction with maintenance expenditure data to assess the responsiveness of the program and, over time, sensitivity of road condition to maintenance efforts.

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WORKING WITH A HIGHWAY MAINTENANCE SIMULATION MODEL ... USING AN INTERACTIVE INPUT MODULE

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The functions related to highway maintenance are often conceptually simple (repair the highway) and administratively complex (alternatives related to priorities, approaches, resources, and many others). Highway maintenance administrators are often faced with questions about which little or no definitive information exists and asked to make the proper decision. For example, if some amount of money is available for equipment which type of equipment should be purchased? How many such equipment units? Where should they be placed and so forth? The dilemma of wanting to do the job well (i.e., make the best decision) and not having sufficient data with which to work is disconcerting at best. The highway maintenance simulation model and accompanying input module described in this paper are intended to help alleviate the highway maintenance administrator's problem by providing an easy to use, flexible highway-maintenance-decision-laboratory in which alternative courses of action may be tested. At the January, 1979 Transportation Research Board meeting, the research required to perform the initial phase and several follow-up phases in the development of the model was presented in the paper "The Systematic Development of a Highway Maintenance Simulation Model." At that time, the model included several simplifying assumptions which made actual considerations regarding highway maintenance operations unrealistic (e.g., one manpower type, one equipment type, etc.). At the January, 1980 Transportation Research Board meeting, the complete simulation model was discussed and presented in the paper entitled "A Highway Maintenance Simulation Model." A description of the model's construction, typical input and output, and some interpreted results (based on an example) were given. This paper includes some of that same information, plus a discussion of the interactive input module. The input module has been added in order to simplify the process of examining different alternatives.

Introduction

Highway maintenance is an important function which is administratively complex. Virtually everything related to highways requires maintenance. There are many types of maintenance activities. There are multiple highway surface types; numerous types of defects, often optional approaches available for defect repair; a spectrum of weather conditions; an infinite number of terrain variations; a divided land work area with often overlapping assignments of responsibility; an ever present element of danger; a variety of equipment types, quantities, and breakdown rates; and, various numbers, levels, and types of manpower and abilities. This sampling of variations does not even mention the human considerations of personalities, interests, absentee levels, and interpersonal relationships. Also omitted from this discussion have been the unique and demanding tasks of planning, priority assignment, scheduling, monitoring, and controlling the maintenance activities. In addition, it should be mentioned that these tasks are all performed in a political arena, supported by the taxpayers' money. There is little question, after even cursory assessment, that administration of highway maintenance activities is a difficult and challenging task.

This paper describes an analytical tool capable of lending order, to some degree, to a number of the dilemmas which are frequently faced by highway maintenance administrators. A highway maintenance simulation model is described which considers many of the interrelated factors already mentioned and provides quantitative output that allows orderly analysis of the situation. In addition, a description of a computer interactive input module is given. The input module was included in order to simplify the input process and, therefore, make it easier to examine alternative decision possibilities.

Model Overview

Model Objectives and Usage

The purpose of the simulation model is to aid users in better understanding the response and behavior of the highway maintenance system under different conditions. That is, to provide highway maintenance engineers with a computer-aided simulation laboratory in which to test and evaluate various alternative courses of action. The input module is intended to simplify the input process, keep users from entering erroneous data (whenever possible), force users to consider all interrelated data values, and to speed the evaluation procedure.

Before discussing the input module, however, a closer look at the idea of how a simulation model may be used is given. Suppose a particular highway maintenance district requests two (5 ton) dump trucks. How might such a request be evaluated? How much would these two trucks really help? Would they cause additional manpower shortages? Would they sit idle too much of the time (and how much is too much?)? The example presented later in this paper deals with this very problem in some detail, but a brief analysis is warranted here.

The district in question would be evaluated thoroughly enough to define the input values required for the model. Such items as the quantity of each equipment type and manpower type available, the absenteeism and equipment breakdown rates, evaluation of work activities (frequency, severity, and location) and travel distances throughout the district are obviously needed if any reasonable analysis is to be made. After these and other values are entered into the model, the current situation can be simulated. Model output should be reasonably close to actual records for some test period (e.g., the last fiscal year), if the model input provided is fairly good and if the district's productivity is near the work standards used for prediction.

Next, the input may be changed to reflect two additional dump trucks and the model rerun. Again, a close look at output values may reveal any number of ideas. For instance, it is possible that the dump trucks were vastly underutilized because of one or more of several possibilities. It may be that insufficient material was available, or qualified equipment operators were unavailable, or that the particular work activities which were to be performed did not require usage of the trucks, or extremely bad weather happened to occur. Each of these possible reasons could be found through evaluation of the output provided. Subsequently, other related situations could be simulated, further enhancing user understanding of the situation.

For example, suppose the previous run of the model indicated that a shortage of equipment operators of type I negated much of the productivity possible by the inclusion of the two additional dump trucks. A third run of the model could be quickly executed with some reasonable increase in the number of type I operators available (e.g., maybe three more). Similar evaluation of performance reports for the district might indicate that the increase in operators (along with the addition of the dump trucks) was precisely the action needed. At this point, administrators charged with evaluating requests from maintenance districts would have a realistic (though certainly not exact) view of the probable results of the possible actions they might take with regard to the district's request for equipment.

It is important to understand that the simulation model is not expected to find the optimum solution for any particular problem, but rather is intended to provide sufficient statistical results to adequately describe the state of the system over a period of time during which a particular course of action was followed.

This simulation model was developed using the FORTRAN based simulation language known as GASP IV (General Application Simulation Program IV). The language was chosen because of its flexibility (and because it was known from the project's outset that the model would probably be modified on numerous occasions) and because FORTRAN compilers are widely available on virtually all large computers.

The Model's Logic

The model's logic (which follows the macro flowchart logic of Figure 1) is described next in an attempt to provide insight into the modeling approach and into the inner workings of the model itself. The simulation is begun by entering the necessary input values. This part of the model is extremely important since it provides the user an opportunity to specify the particular conditions which are to be examined, as well as the values which establish the boundaries of the simulation. An example of the first type of input is the specifying of the number of dump trucks to be used in the simulation, while an example of the second type of input is the value indicating the number of work periods that are to be simulated. Table 1 provides an abbreviated list of the model's input. Once these values are established, the actual simulation process may begin. Because of the crucial nature of this state of the process, the interactive input module was developed. It is discussed later in the paper.

Based on the work activity probability distributions entered as input to the model, a list of work activities which are to be accomplished is generated. Next, calling on probability distributions read into the model in step one (for items such as location and severity of the activity to be performed), a number of identifying parameters are specified for each work activity in the list. These activities are then stored to be called upon when actual scheduling begins.

Emergency activities, if any happen to occur, are generated next. These are not part of the normal sequence of work activities since emergencies occur at unexpected points in time. As such, emergency activities are considered for scheduling during that particular period prior to considering any regular activities.

Weather conditions for the week are generated next. Since the increment of time chosen for use in the model is a half day, ten different weather conditions (one for each period of the week) are generated. These are stored and referred to later.

A special set of weather dependent activities is generated next. On reflection, the reason for such an activity type is apparent. That is, some activities are worked only in specific weather conditions. For example, snow removal is necessary only when it snows. This type of activity is similar to an emergency activity in that its occurrence cannot be anticipated. It is different from an emergency activity, however, in that it is dependent directly on the weather. Once generated, these activities are stored with top priority consideration in the period in which they are to occur.

At this point, the simulation's clock is changed from zero to one. This means that period one is now to be considered for scheduling of work activities. The work activities list for period one is checked. If any work activities exist, the activity with the highest priority is considered first for possible scheduling. This activity may be an emergency activity, a weather dependent activity, or some type of regular activity. Regardless of the activity type, a search of the resources available is made to see if the activity can be worked. This is quite an involved procedure. The reason for the complication is the large number of possible resource combinations capable of satisfying the work activity (i.e., job) requirements. Several factors must be considered. For example, it may be that the work activity can be accomplished through the efforts of more than one crew arrangement (and the most preferred one available should be chosen) and that more than one resource base location may be required to provide the necessary resources. Also, since the resources for an entire work activity must be accounted for, each type of manpower, equipment, and material need must be considered individually against the corresponding resource availabilities, with the existing possibility of resource substitution included in the consideration. If consideration of the work activity is successful and acceptable resources are available to perform the task, the activity is scheduled and each of the resource availability files are updated.

Statistics are collected for the activity and control of the simulation process returns to the question,"Are any more activities to be worked this period?" This question emphasizes the fact that the modeling process discussed so far has dealt with only one activity. Each activity in the work activity list must go through the same process each period during the simulation.

Eventually, after all the possible work activities have been considered, the work period ends. At this point, some of the activities may have been completed, while others are still in progress. The completed activities are removed from the possible work activity list, some statistics are collected, and consideration is given to the question,"Is the week complete?".

If the week is not complete, the period number is increased by one and the activities currently on the work activity list are again considered one at a time. If the week is complete, it is necessary to carry forward all the unfinished activities as part of next week's work activity list. The activities already begun have a higher priority than those which have not yet been started.

Since the week has been completed, the simulation model next asks whether or not the entire simulation process is complete. If it is (and, eventually, of course, it will be), all the final simulation statistics are computed. If the simulation process is not complete, this means that another work week is to begin and the processes of activity generation, emergency generation, weather generation, and so forth are performed again.

The simulation model was designed and developed with the idea of being able to address a wide variety of frequently occurring highway maintenance situations. As such, a large number of statistics are collected during the model's execution and are printed at the conclusion of each simulation run.

Interactive Input Module

Introduction

It became apparent during the development of the model that the most difficult part of the simulation process for the user would be the steps related to developing and entering the model's input. There are several reasons for this. One, the process can be lengthy. The model requires a significant amount of input in order to perform a simulation run. Two, some of the input values must (by necessity) be estimated, if no actual data exists. Poor estimates or errors in the entry of the input could easily lead to erroneous results. Three, modifications to already existing data sets must be made with extreme care so that all remaining interrelated data values are correctly entered and properly sequenced. For example, removal of a dump truck from the equipment availability file must be accompanied by the removal of the truck's characteristics from the data set. Four, changes made in the data necessitate some type of "hands on" (i.e., either via cards or computer terminal) interaction with the computer and with a largely unlabeled set of data values. All of these reasons contribute to a high probability that the user might erroneously modify the data sets in some way. While some mistakes could lead to stoppage of the simulation run (i.e., premature program termination, accompanied by no useable output), other mistakes might easily go undetected, produce erroneous output, and lead to incorrect evaluation and decision making. The interactive input module was developed to circumvent these difficulties.

The Approach

The interactive input module was developed around several important ideas. These ideas were aimed at overcoming the input difficulties which had been encountered and which were described in the previous section.

The first two difficulties (i.e., lengthy input and estimated values) were overcome by presenting the user with an already existing data set (prepared with the aid of Louisiana Department of Transportation and Development highway engineers) to change from. The reason for this approach is quite simple. First, work activities performed by Louisiana highway maintenance personnel are sure to be quite similar to work activities performed by highway maintenance personnel in other states, so that new users would need only to make modifications unique to their situation. Second, it is generally regarded as easier to modify something which already exists than to begin from "scratch." Therefore, the idea of creating a "base data set" and working from it was step one in the process.

Difficulty number three, the problem related to the cascading effect of data changes and proper data sequencing, was not so easily dealt with. In fact, the problem has several aspects to it. One, data value entries cannot be accepted blindly. Values entered must be checked against actual or reasonable limiting values before being accepted. Two, the user must not be expected to be extremely familiar with the data set and must, therefore, be made aware of all related variables which must be given consideration when a particular, single change (e.g., to an equipment unit) is being made. Mainly, it is important that the user not forget any related modifications. Three, once a change has been incorporated, the process of updating all files and sequencing of data values must be performed successfully. These important considerations heavily influenced the organization of the interactive input module.

Difficulty number four, the fact that user-computer interaction is required, led to further consideration of the organization of the input module. Several factors had an influence on the module's design at this point. First, the approach had to be logical - logical in the sense that the user should not be asked to significantly change his thinking pattern in order to use the module. Two, closely related to comment one, the approach had to be useable by non-computer types of people. Three, the module had to have the capability of providing definitions and descriptions for the user.

Beginning with these ideas, the module evolved to include another goal. It must be streamlined enough for the frequent user, but descriptive enough for the novice user. This realization led to the current design format - a statement-alternative approach, with the capability of providing more complete descriptive information about the topic (or variables) being considered.

The Arrangement

The input module is subdivided into seven major input groups: equipment, manpower, material, work activities, base locations, weather, and emergencies. The module permits data changes within each group separately, but allows the user to access each group as frequently as he wishes. For example, if an equipment change of some type is desired (but no other data modifications are warranted), the user may go to the "equipment" section and be led through the data change process. However, if the user later decides to change the way a particular work activity is staffed, he may then go to the "work activity" section and be led through it, as well. The simulation program may be run after each modification.

The interactive input module is appended to the front of the simulation model. Figure 2 describes the relationship between the input module and the simulation model itself. In general, modifications may be made to the existing data set, the simulation program run (or not), and the data modifications retained (or not).

Figure 3 shows a portion of the prompting-response (i.e., interactive) sequence in the equipment section of the input module. User responses are clearly marked.

The next section (EXAMPLE) describes the manner in which the simulation model may be used to aid the decision process. A variety of output values are referenced. None of the statistics claim to be "the" answer. The simulation results must be taken as a whole and examined in light of the particular situation being considered. Table 2 presents a list of statistics provided by the model.

Example

Situation

The situation selected for this example is a fairly typical highway maintenance district. It consists of 30 men and 28 pieces of equipment. The district is currently recognized as producing at a less than acceptable level. There are many reasons for the poor productivity, some of the reasons are external (exceptionally large work load, poor weather conditions) and some are internal (insufficient resources). Highway maintenance engineers are asked to assess the district's activities and current status and to make recommendations for rectifying steps.

Input

The first step is to determine the district's present condition and to collect the necessary input values to allow the simulation model to be run. This step is of extreme importance, since it is on the foundation created by the input values that all future decisions are based.

Some of the input required is readily available and factual (e.g., the number of equipment operators of type 1), while some of it requires research (e.g., weather parameters for each season of the year), and much of it requires good judgment (e.g., the effect that a particular poor weather condition has on an activity). The amount and detail required in the form of input is significant, but the process is simplified considerably by the interactive input module. After the input quantities are entered and the program is run, a close look at the output is warranted.

Output - Initial Run

The initial run is meant primarily to reflect current conditions. In this case, the output was sufficiently close to that expected to be used as the basis for change. Of course, it might be that further fine tuning of input values is necessary before the user can feel comfortable with the output values generated.

The output provided a number of clues concerning the reasons for low productivity. Some of these are listed below:

(1) Unutilized manpower ... The manpower units initially available of the five manpower types specified (foremen, equipment, operator type 1, equipment operator type 2, equipment operator type 3, and labor utility) were 3,9,4,1, and 13, respectively. Significant percentages of each manpower type were not used for productive tasks each period.

(2) Unutilized equipment ... Results similar to those mentioned regarding manpower were found for equipment as well.

(3) Stockouts ... A number of inventory shortages were noted.

(4) Time loss reasons ... Twenty-five activities were defined and some of each were generated. It is expected that not all jobs could be worked, but it is hoped that the higher priority jobs are worked consistently and that only lower priority tasks are held up.

The initial run showed that of the top six priority jobs, manpower was never a problem, but that the main causes for the job not being worked were lack of equipment, inclement weather, and insufficient material, in that order.

The insufficient equipment problem may be further investigated by determining (at least among the highest priority activities) which equipment units are being required. A brief look at the top six priority jobs from the activity characteristics file shows the following needs (only the first crew option is shown):

	EQUIPMENT TYPE									
Job	1	2	3	4	5	6	7	8	9	10
1	0	3	1	1	1	0	0	0	0	0
2	0	1	0	1	0	0	0	0	0	0
3	1	2	0	1	0	0	1	0	0	0
4	0	3	1	1	1	0	0	1	0	0
5	0	4	0	1	1	1	0	0	0	0
6	0	3	1	1	1	1	0	0	0	0

Each job (work activity) requires at least one equipment unit type 2 and exactly one equipment unit type 4. No other equipment type has as much demand. The difference between equipment types 2 and 4 lies in their availabilities. There are eight equipment type 2 units available, but only one equipment unit type 4. This means that only one of the top six priority jobs can be worked at any one time. An obvious alternative (although certainly not necessarily the best) is to obtain at least one more equipment unit type 4. Since the tool of simulation is being used, a unit of equipment type 4 may be added immediately and the situation revisited.

Output - Run 2

The results of the second run of the model were also quite revealing. Slightly more money was spent on maintenance activities (as expected with one additional piece of equipment), productive manpower utilization was up, productive use of equipment was increased (in fact, the addition of one equipment type 4 unit increased the utilization for all the other equipment units as well), material usage was increased, and successful scheduling of the higher priority jobs increased significantly. So, as a first step, the addition of a single unit of equipment type 4 to the resources of the district appears to be a step in the right direction.

There are more deficiencies, however. There is still significantly more demand for work (i.e., planned work activities) than there are resources to accomplish it. Unavailable equipment is still the primary reason for work stoppage. Manpower and material shortages still exist at a relatively high level. So, what next?

Subsequent Steps

Before considering other possible resource alternatives, a more thorough analysis of the work environment may be warranted. It has been noted that weather conditions contributed heavily to problems of scheduling work activities. A run in which weather parameters are slackened (i.e., statistically improved weather) might be performed to see what effect better weather might have on the situation.

If there is little or no change in the basic problems encountered, the next logical step is to return to those factors which highway maintenance engineers can influence - primarily, those factors associated with scheduling policies and resource levels. An example of effecting scheduling policies may be described by considering a typical work activity's characteristics. Suppose that the work standard for the task of patching the road base specifies that a foreman, two equipment operators of type 1, one equipment operator type 2, one equipment operator type 3, and one laborer are required. If, however, it is common practice for operators to work out of class (e.g., a type 2 operator might perform the work of a type 1 operator), it would not be unreasonable for highway maintenance engineers to group resources (i.e., combine operator types), which might improve scheduling success.

Another similar alternative also deserves mention. Experience has shown that even though the standard work crew may not be available, work may still be successfully accomplished at a rate approximating the standard rate. Such alternative work crew arrangements could be entered as second and third crew options.

The most obvious actions which might be tried by highway maintenance engineers are, of course, those related to varying resource levels. The next step for this particular example would probably deal with an increase in manpower availability, but more detailed analysis might lead the analyst to try any of a number of alternatives.

Simulation performed in this manner does not yield instantaneous results. It is apparent that the analyst is still very much responsible for the alternatives tried and the decisions made. In fact, the process is much like that of actually making the changes in reality, but the time, cost, and hassle factors are reduced to a minimum.

Summary

The highway maintenance simulation model is an attempt to provide highway maintenance management personnel with a laboratory in which various decisions may be tested. As in all laboratory experiments, the results are not exact replicas of real world activity. However, it is apparent that the model is of sufficient detail to provide output values which are reasonable approximations to reality and valuable aids to decision making.

The simulation model is currently operative on the Louisiana Department of Transportation and Development's computer facility. To that extent, it has already been successfully applied. The work currently being done is directed solely toward further development and implementation of the input module and fine tuning of the simulation model. Louisiana DOTD highway engineers are working closely with the researchers to assure appropriate model validation.

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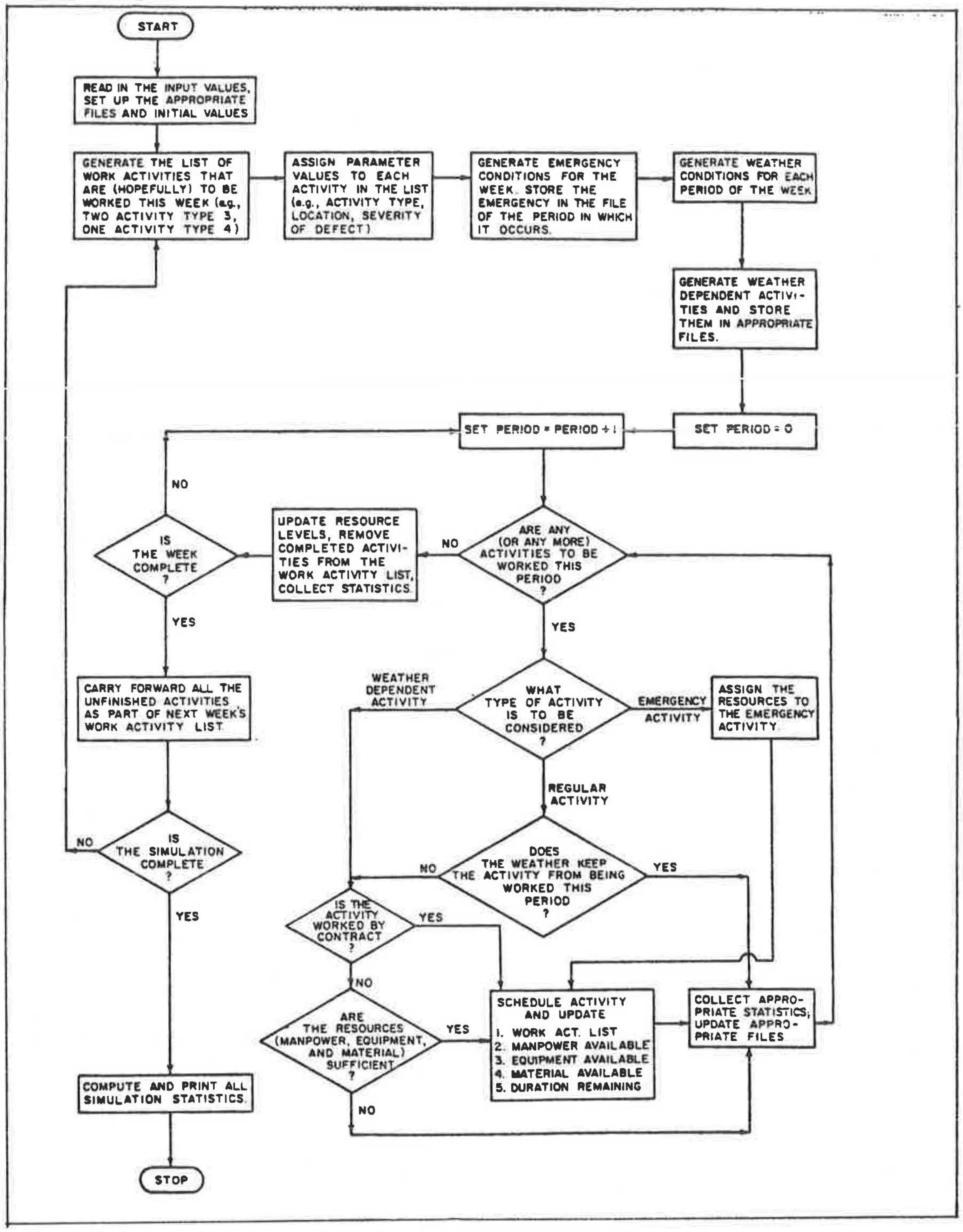


FIGURE 1. MACRO FLOWCHART FOR HIGHWAY MAINTENANCE SIMULATION MODEL

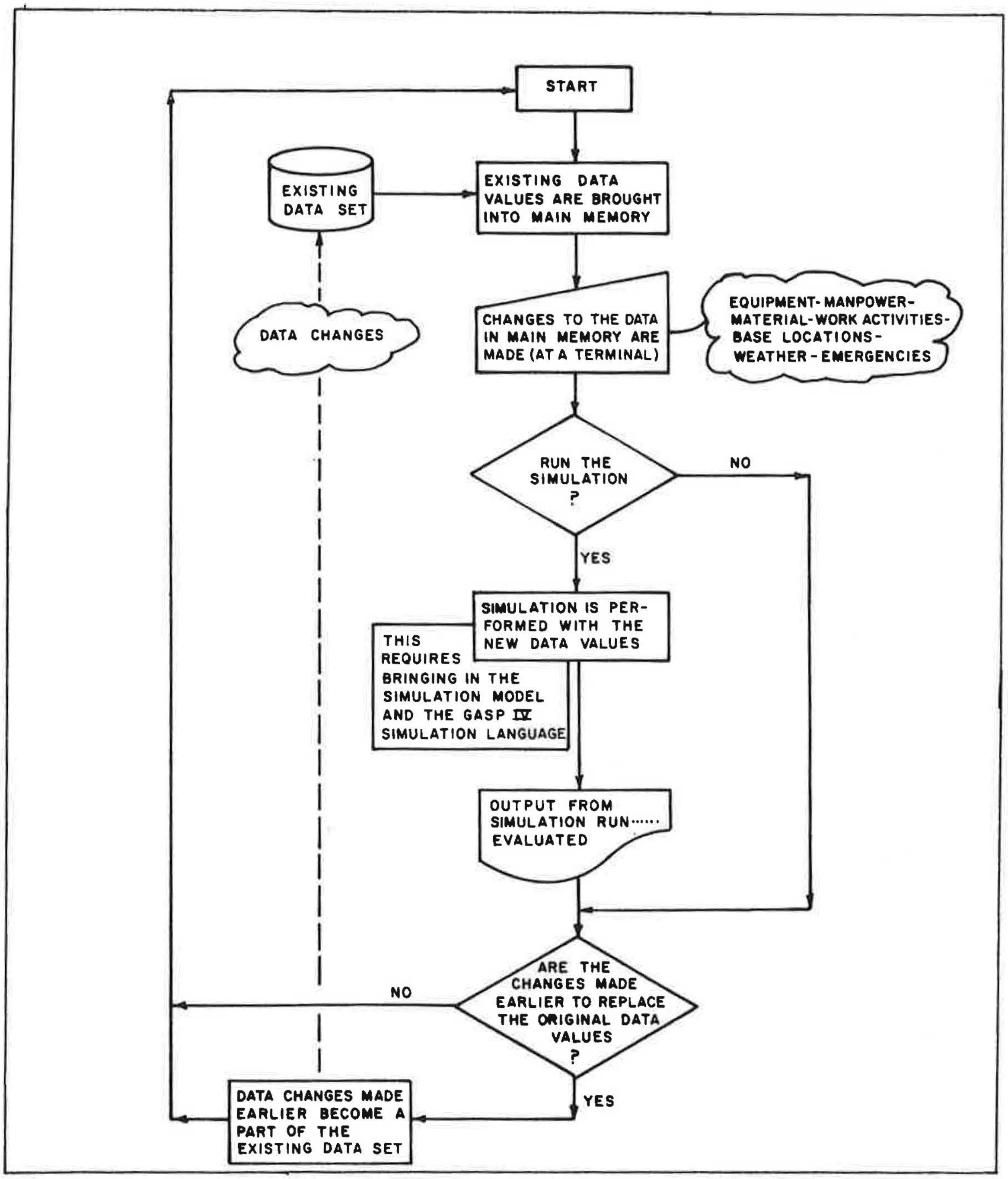
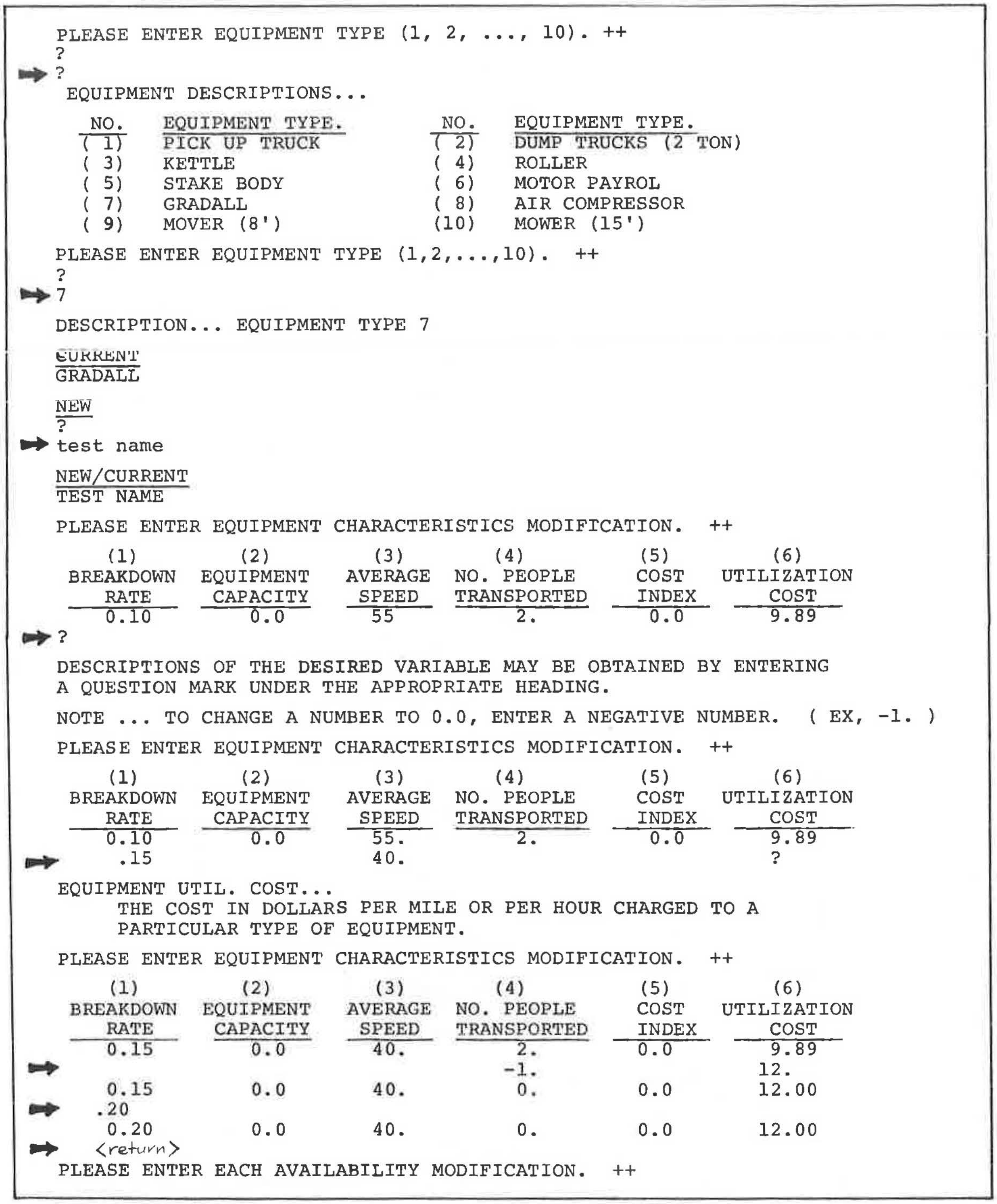


FIGURE 2.
RELATIONSHIP BETWEEN INPUT MODULE AND SIMULATION MODEL



```
   PLEASE ENTER EQUIPMENT TYPE (1, 2, ..., 10). ++
   ?
➡  ?
    EQUIPMENT DESCRIPTIONS...
      NO.    EQUIPMENT TYPE.             NO.    EQUIPMENT TYPE.
     ( 1)    PICK UP TRUCK              ( 2)    DUMP TRUCKS (2 TON)
     ( 3)    KETTLE                     ( 4)    ROLLER
     ( 5)    STAKE BODY                 ( 6)    MOTOR PAYROL
     ( 7)    GRADALL                    ( 8)    AIR COMPRESSOR
     ( 9)    MOVER (8')                 (10)    MOWER (15')
   PLEASE ENTER EQUIPMENT TYPE (1,2,...,10).  ++
   ?
➡  7
   DESCRIPTION... EQUIPMENT TYPE 7
   CURRENT
   GRADALL
   NEW
   ?
➡  test name
   NEW/CURRENT
   TEST NAME
   PLEASE ENTER EQUIPMENT CHARACTERISTICS MODIFICATION.  ++
       (1)         (2)        (3)        (4)          (5)        (6)
    BREAKDOWN   EQUIPMENT   AVERAGE  NO. PEOPLE       COST   UTILIZATION
      RATE      CAPACITY     SPEED   TRANSPORTED     INDEX       COST
      0.10        0.0         55         2.           0.0        9.89
➡  ?
   DESCRIPTIONS OF THE DESIRED VARIABLE MAY BE OBTAINED BY ENTERING
   A QUESTION MARK UNDER THE APPROPRIATE HEADING.
   NOTE ... TO CHANGE A NUMBER TO 0.0, ENTER A NEGATIVE NUMBER.  ( EX, -1. )
   PLEASE ENTER EQUIPMENT CHARACTERISTICS MODIFICATION.  ++
       (1)         (2)        (3)        (4)          (5)        (6)
    BREAKDOWN   EQUIPMENT   AVERAGE  NO. PEOPLE       COST   UTILIZATION
      RATE      CAPACITY     SPEED   TRANSPORTED     INDEX       COST
      0.10        0.0         55.        2.           0.0        9.89
➡      .15                    40.                                ?
   EQUIPMENT UTIL. COST...
        THE COST IN DOLLARS PER MILE OR PER HOUR CHARGED TO A
        PARTICULAR TYPE OF EQUIPMENT.
   PLEASE ENTER EQUIPMENT CHARACTERISTICS MODIFICATION.  ++
       (1)         (2)        (3)        (4)          (5)        (6)
    BREAKDOWN   EQUIPMENT   AVERAGE  NO. PEOPLE       COST   UTILIZATION
      RATE      CAPACITY     SPEED   TRANSPORTED     INDEX       COST
      0.15        0.0         40.        2.           0.0        9.89
➡                                       -1.                     12.
      0.15        0.0         40.        0.           0.0       12.00
➡   .20
      0.20        0.0         40.        0.           0.0       12.00
➡   <return>
   PLEASE ENTER EACH AVAILABILITY MODIFICATION.  ++
```

Figure 3. Prompting Sequence from Interactive Input Module
(Note: ➡ denotes user response)

Table 1. Summary List of Model Input

1. Single-value constants which provide limiting values for the simulation (e.g., number of work activity types, number of years to be simulated)
2. Description of activity types, equipment types, manpower types, and range of weather conditions
3. Distribution parameters for absenteeism and breakdowns of equipment
4. Manpower, equipment, and material costs
5. Resource availability files (manpower, equipment, and material)
6. Equipment characteristic file
7. Point-to-point travel times
8. Work activity characteristic file (specification by activity type for each crew option, equipment, and manpower needs, material needed, performance rate, indicators of effect of various weather types on work activity, etc.)
9. Probabilistic description of weather by season
10. Information regarding preferences of base locations for manpower, equipment, and material ordered by location within the district (or parish).
11. Work activity parameter sets for use in work activity occurrence distributions
12. Parameter sets for weather dependent activities
13. Parameter set for emergency activity duration and time between occurrence specification
14. Simulation specifications - length of simulation, number of files, etc.

Table 2. Summary List of Model Output

1. Input Listing - A complete listing of all model input.
2. Quarterly Performance Report - Report by activity type which includes planned and actual quantities for material and labor hours used, total cost, cost per unit, and hours per unit.

   The Performance Report also includes (for each activity type) labor cost, material cost, overtime labor cost, travel cost, fringe benefits and operational service (contract) costs.
3. Activity Frequency Table - The number of occurrences of each type of work activity in each section of the district (or parish).
4. Manpower Characteristics Table - A summary for each resource base location which lists by equipment type the number of periods worked, the number of absentee hours, the number of overtime hours worked, the average number of manpower units not assigned each period, the absenteeism cost, and stand by cost.
5. Equipment Characteristics Table - A summary for each resource base location which lists by equipment type the number of periods the equipment was in use, the number of hours the equipment spent in transit, the capacity of the equipment, the number of times breakdowns of the equipment occurred, and the average number of each equipment unit not assigned (leftover) to an activity each period.
6. Material Chracteristics Table - A summary for each material base location which lists by material type the average number of times each material was required, the average demand for each material type per period, the number of times an activity could not be worked because of lack of material, and total material demand per year.
7. Time Loss Table - A summary by activity number of the frequency and percentage of the reasons for time loss. Reasons categorized are insufficient manpower, unavailable equipment, insufficient material, and bad weather.
8. Time Loss Breakdown by Resource Type - A more detailed version of the Time Loss Table described in number 7. The table summarizes for each activity, the number of times that each equipment and manpower type caused a delay.
9. Manpower Substitutions - A summary of the manpower substitutions performed during the period simulated. The number of times (work periods) that equipment operators of type i were used when less qualified operators (type j) would have been adequate.
10. Overall Work Activity Statistics - Summary statistical values for each activity regarding its overall time in the system, including the number of occurrences, the average time length of occurrence, longest and shortest activity time span, and others.

IDENTIFYING MAINTENANCE NEEDS

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This paper describes an ongoing project initiated for the purpose of improving Virginia's maintenance management system. It is directed at helping maintenance area superintendents (1) identify maintenance needs, (2) prioritize the needs, and (3) plan and perform the work necessary to satisfy the needs. Virginia's present maintenance management system is based on a performance budgeting concept designed by Roy Jorgensen and Associates in the early 1960's. The present project is designed to supplement the performance budgeting concept with detailed planning by the state's 232 area superintendents. In the project, the following activities are being pursued.

1. Each area superintendent is preparing a detailed graphic log of all maintainable items on all of the approximately 250 miles of roadway in his area.
2. Using the graphic logs, six of the area superintendents are identifying all roadway deficiencies to form a list of assessed needs.
3. These six superintendents are developing long-range (1-month) and short-range (1-week) work plans by combining men, equipment, and materials into work crews by activity at specific locations for the purpose of satisfying the assessed needs.

There is high hope of improving the state's system for identifying and prioritizing maintenance needs and in planning and accomplishing the work necessary to meet the needs in an economical and efficient manner.

This paper discusses a project initiated in an attempt to find means of improving Virginia's maintenance management system. It is concerned primarily with improving first line management's ability to identify maintenance needs, prioritize the needs, and plan and perform the work necessary to satisfy the needs.

The Virginia Department of Highways and Transportation's maintenance management system is based upon recommendations resulting from a review of the state's maintenance program by Roy Jorgensen and Associates in the early sixties. The basic ingredient of the system is a performance budgeting concept linked to productivity standards. In essence, budgeting and planning are based upon performance records. Jorgensen did not intend for planning to be based entirely upon performance but rather that performance records be used as a guide for budgeting. In addition to recommending the use of performance as a budgeting and planning tool, Jorgensen emphasized certain types of planning for every level of management. This paper discusses the planning required of the maintenance area superintendent.

AREA SUPERINTENDENT'S RESPONSIBILITIES

Germane to the present study are four of the area superintendent's responsibilities set forth by Jorgensen. He noted that the superintendent should —

1. assist the residency maintenance supervisor in the preparation of area maintenance plans;
2. determine the needs for routine maintenance by patrolling roads and observing conditions on all systems;
3. prepare short-term work accomplishment schedules within general plans that show actual crew patterns planned and days of work anticipated to meet performance standards; and
4. inspect roads within his area for maintenance replacement and incidental construction needs, and make recommendations to the residency maintenance supervisor.

It should not be inferred that the area superintendents do not meet these responsibilities; however, it is true that the tasks are performed at different levels of quality.

The Department has 232 area headquarters, each headed by a superintendent and each responsible for about 250 miles of roadway. It was decided that to bring the performance of all these people up to a high level of quality, a program should be initiated to reemphasize and strengthen their role and responsibility in assessing needs, and planning and performing the functions necessary for the efficient and economical maintenance of the state's highway system.

The modified system that has been developed and is being experimented with in ten area headquarters is referred to as the "assessed needs approach". It differs from the performance approach that is based on centerline mileage and on accomplishments reported in terms of the total effort expended on each type of maintenance activity. Rather, it places emphasis on surveys of the quantities of each activity needed and the physical condition of all the maintenance items within the total roadway mileage. It provides a more structured approach to both budgeting and planning, and facilitates evaluations of how well the maintenance function is being performed. If at the end of the study the assessed needs approach warrants implementation, it will not replace the performance approach; it will supplement the present system by strengthening some of the management features Jorgensen recommended.

The ingredients the research team felt to be essential in any maintenance program are as follows:

1. Capable superintendents.
2. An awareness on the part of superintendents of the importance and responsibility their job carries as well as an awareness of the high regard the Department holds for their position.
3. An organized record of all items that need to be maintained.
4. Standards setting forth the condition in which all items are to be maintained.
5. An assessment of the present and anticipated condition of all of the maintainable items, and a listing of the order in which items should be given attention.
6. An extended plan of the maintenance work effort based on the productivity standards, the quality standards, and the available resources (1-month in this project).
7. A plan of the work effort for each week, based on the 1-month plan and developed each Friday for the ensuing week.
8. A record of each month's accomplishments for comparison with the 1-month work plan.

The remainder of this paper discusses the attempt to improve the maintenance program in terms of these eight items.

1. Capable Superintendents

When Virginia implemented the maintenance management system in the sixties it was not deemed appropriate to replace any of the people in the key position of area superintendent who did not meet the newly written job description for that position. However, through attrition this position has, in most cases, now been filled with highly qualified people. Therefore, at present the people are qualified not only to accept the responsibility of seeing that the needed maintenance is accomplished, but also to assess and plan maintenance needs.

2. Awareness of Importance and Responsibility

There is some question, at least in the mind of the writers, as to whether the superintendents have a total appreciation of the importance of their position. They know that they have a great deal of responsibility, but it appears that more direct communication with management is needed to assure them of the importance of their position. Communication between the superintendents and the residency are good; but those between them and higher management could be improved. This does not imply that management doesn't have an appreciation for the key role of the area superintendent, but it does mean that management should adopt an effective means of letting its appreciation be known. In defense of management, it is the nature of most people to take the obvious for granted and overlook the value of close personal communications. The writers believe that a simple reminder to management will improve this situation.

3. Organized Record of All Maintenance Items

The reader is reminded that the Virginia Department of Highways & Transportation is responsible for not only the interstate and primary road systems, but also for the secondary or county system. The total state highway system comprises more than 52,000 centerline miles of roads of which the interstate, primary, and 7,000 of the 43,000 miles on the secondary system are logged. The graphic logs for these systems by no means show all of the maintainable roadway items. Therefore, the first step in the project discussed here was the development of a graphic method for identifying and locating all of the maintainable items.

The method devised is a modified concept developed by Roy Jorgensen and Associates for the Federal Highway Administration in 1973, and is explained in detail in Appendix A. With this method, all of the needed information for a maintenance area is recorded by highway type as shown in Appendix B. A summary is then prepared for all of the roads in the area for each of the three systems — interstate, primary and secondary — as shown in Appendix C.

When the experimental use of the modified maintenance system was initiated, the superintendents saw little need for the logging of the maintainable items; they thought that they already knew the items in their areas. However, after completing a log, they changed their attitude, and several have commented that they have found multiple uses for this information when it is available at their fingertips. Further, they admit to a better understanding of the magnitudes of the quantities of the various maintainable items. This was especially true for drainage items such as the numbers of pipes under the roadway and at entrances.

In the maintenance areas included in the experimental program this logging has been completed, and top management has found the results helpful to the degree that the procedure will be implemented statewide.

4. Quality Standards

Just prior to the inception of this project, new maintenance quality standards were developed within the Department for the majority of the maintainable items. As an example, one of the standards is shown in Appendix D. The process used in developing the standards, which as yet haven't been completed for all items, was to obtain a consensus of a limited number of all levels of maintenance personnel. These standards have been adopted with the understanding that they might have to be modified as additional knowledge is gained through experience. Experience gained in the present project will be helpful in this respect.

5. Assessment of Condition of Maintainable Items

Step 5 requires the superintendent to again survey all of the roads in his area. In this survey, he records all of the work required to make the maintainable items meet quality standards for the next year, including what needs to be done at the time of the survey as well as what needs to be done during the year. For instance, if a stabilized road is surveyed right after it has been improved by blading or adding stone and it needs no further work at present, the superintendent will still record the number of times he anticipates this particular road will need blading during the next twelve months and the quantity of stone that will be required over the same time period.

The summary resulting from this survey provides the superintendent the quantity of work that needs to be done in each activity during the next year. It is likely that much more work needs to be done than the available resources will permit. At this point the planning task becomes difficult. The superintendent, with the residency supervisor's help, is expected to set priorities for the types of activities to be performed and to justify these priorities to higher management. Of course, if there is a frequent and widespread inability to perform all of the work that should be done with the available resources, then the Department should consider lower quality standards, at least in some activities. In such cases, consideration should be given to revising the quality standards for selected activities. It should also be remembered that although the available resources appear adequate for accomplishing the required work, it may be difficult to bring them together in the ideal combinations necessary for getting the job done. Six of the ten areas using the modified system are presently working on this phase.

6. Formulation of 1-Month Work Plan

In this step the superintendent forms crews and assigns equipment to accomplish the required maintenance activities in the most effective manner (see Appendix E). The most important unit of time is one day, and emphasis is placed on the importance of planning combined activities on any given day in such a manner that will achieve maximum use of the available equipment and men. Frequently, one or maybe even two men cannot be effectively matched to the equipment available for the planned activity. On other days, a truck may go unassigned. The superintendent should try to avoid these situations, but should not add a man or a truck to a crew if the productivity rate of the crew will be diminished. The crews should be maintained at their ideal size with respect to both men and equipment. Any man not assigned to a crew for a given day should be used where practicable to catch up any backlog of work around the headquarters. On days that the trucks cannot be effectively used, they should be left idle or be scheduled for any needed repairs or preventive maintenance.

In the planning of the units of work to be accomplished in each day of the 1-month work plan, the days are not considered to be in calendar sequence. Rather, the 22 days of work are planned so that they can be performed in any order the superintendent feels will best meet the most pressing needs. When planning the 22 days, the superintendent should take into account the need to plan for some foul weather days. Six of the ten areas are presently working on this phase.

7. Work Plan for Ensuing Week

By Friday afternoon, the superintendent can plan activities for the coming week with (1) a fair idea of what the weather will be, (2) the condition of his equipment, (3) the probable number of men to be available, and (4) the most urgent maintenance needs. Therefore, he selects five of the days from his 1-month work plan and arranges them in the most appropriate sequence. A specially devised four-by-eight foot weekly planning board is used to post this plan by days, crews, and activities as shown in Appendix F. In addition to the space provided for the 1-week plan, room is available for several inclement weather days and for the storage of the remaining work units from the 1-month plan. This backlog of work provides a bar graph of quantities of work that needs to be done to satisfy the 1-month plan. (The areas will begin using this weekly planning board about August 1.)

8. Comparison of Planned to Accomplished Work

It is anticipated that any superintendent will at first plan more work than will be accomplished, because of overestimates, equipment breakdowns, sick leave, bad weather, unanticipated but urgent maintenance needs, and a host of other unforeseeable events. For this reason he is asked to keep a daily record of his crews and the activities to which they are assigned, and at the end of each month to analyze the relationship of the planned work to that accomplished. By doing this, he will be able to document the discrepancies between the two, and with time be able to improve his estimates of what can be accomplished during a 1-month period.

SUMMARY

As previously stated, the purpose of the project reported here is to reemphasize and strengthen the area superintendent's role and responsibility in assessing needs, planning, and performing the functions necessary for the efficient and economical maintenance of the state's highway system. Involved in the project are the area superintendents in 10 of the Department of Highways & Transportation's 232 area headquarters. These ten have completed the logging of all of their maintainable items on all of their roads, and the results have been found to be helpful to the degree that the state is ready to implement the logging procedure statewide. At present 6 of the 10 superintendent's are identifying their needs for the next 12 months, and each month are preparing monthly work plans by identifying the activities, locations, crew sizes, and equipment needed daily to accomplish the work needed over this period of time. They are keeping daily records so that work accomplished can be compared to work planned and the reasons for differences can be analyzed. On August 1, the superintendents will begin working with specially designed weekly planning boards.

The experimental maintenance program is designed to allow for changes as knowledge is gained. Periodic meetings are held with the area superindendents, maintenance supervisors, resident and assistant resident engineers, a district maintenance engineer, and an assistant state maintenance engineer to evaluate what is being done and to identify desirable modifications. Thus far the superintendents have been receptive to the experimental program and have been quite helpful, not only in looking after the necessary details but also in providing input for modifications.

At present there is high hope of accomplishing an improvement in the state's system for identifying and prioritizing maintenance needs and in planning and accomplishing the work necessary to meet these needs in an economical and efficient manner.

APPENDIX A.
HOW TO CONDUCT THE ROADWAY MAINTENANCE LOG INVENTORY

A roadway maintenance log inventory provides a listing of all roadway features maintained by the Department. The inventory performs several functions necessary for an efficient and effective highway maintenance program. First, it provides all levels of the Department accurate information of the gross quantities of maintainable items with which to plan and budget. Second, it makes the area superintendent aware of the location of all items and their condition by requiring him to inspect, in an orderly manner, all items in his area. Third, it aids the area superintendent in formulating schedules for the performance of day-to-day work.

Logging Procedures

The inventory is taken by 2-man teams. Each team — a driver and a recorder — covers all of the roads in a maintenance area and records all the features maintained by the Department. The driver calls out the odometer reading while the recorder indicates, on an inventory sheet, the location of each feature. The men share the job of locating — or picking out — the features.

The driving speed used will depend on (1) the number of features being recorded, (2) how quickly features can be located and recorded, and (3) traffic conditions. The speed should vary from 5 to 30 mph. Frequently, stops will be required to check or measure certain features. Under normal conditions the inventory process should proceed at a rate of one mile of road each 20 to 30 minutes.

WHAT IS INVENTORIED?

All roadway features maintained by the Department are logged. These include but are not limited to the following:

1. Box Culverts — size and number
2. Bridges — structure number
3. Concrete Median Barriers — length
4. Cross Drains — number
5. Curb and Gutter — length
6. Ditches — miles of ditchable area
7. Drop Inlets — number
8. Entrances — number with and without pipe
9. Flood Gates — number
10. Guardrail — length
11. Lights — number and type
12. Mowable Swaths — length
13. Outfall Ditches — length
14. Paved Ditches — length
15. Picnic Tables — number
16. Pipes — size and direction of flow
17. Rest Rooms — number
18. Retaining Walls — length
19. Right-of-Way Fence — length
20. Shoulder Type — paved, wedge, gravel, or sod
21. Sidewalk — length
22. Signs — number and type on each post
23. Snow Fence — length
24. Surface Type — bituminous, P.C. concrete, surface treatment, stabilized
25. Under Drains — number

UNIT OF MEASUREMENT DESIGNATION FOR MAINTAINABLE ITEMS

Ditches, shoulders, mowable swaths, right-of-way fences, concrete median barriers, and road lengths are measured by estimating the odometer reading to the nearest 0.01 mile. Guardrails, sidewalks, curb and gutters, paved ditches, outfall ditches, snow fences, and retaining walls are measured in feet. Drainage items, signs, entrances, lights, endwalls, flood gates, picnic tables, and rest rooms are totaled as to the number in each category.

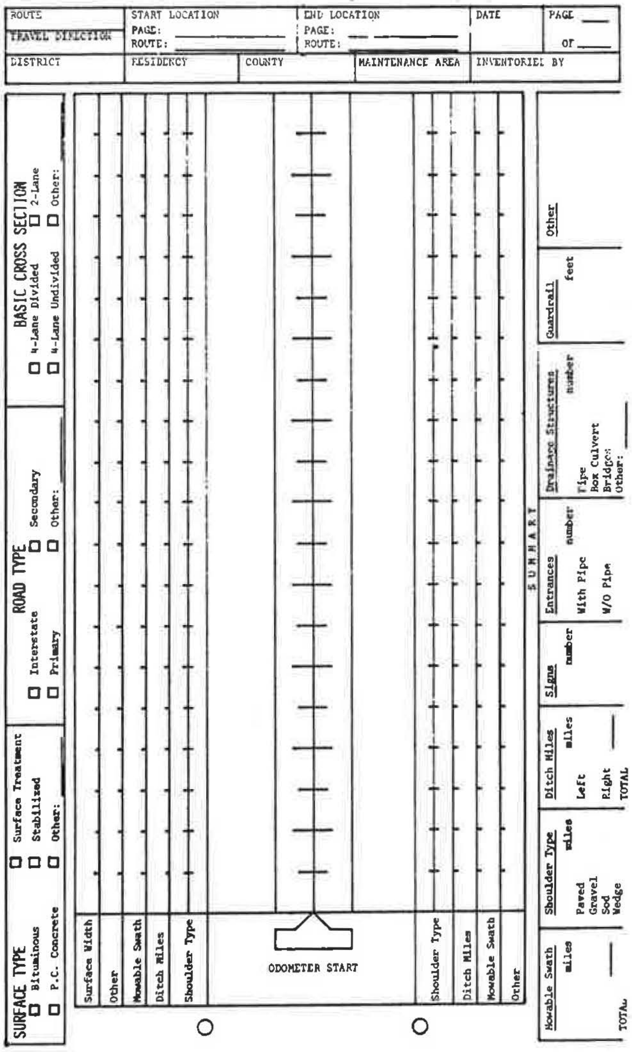
EQUIPMENT REQUIRED FOR LOGGING

1. Vehicle with an odometer that records in tenths of a mile.
2. Clipboard — long enough to hold legal size paper (14").
3. Straightedge — 6" ruler.
4. Carpenter's ruler and tape measure.
5. Road Inventory — T&S-5 (Rev. 2-71) — establishes roadway termini.
6. Sign inventory.
7. Roadway maintenance inventory sheets and pencils.

HOW TO COMPLETE ROADWAY MAINTENANCE INVENTORY SHEETS

All maintainable items are recorded on a Roadway Maintenance Inventory (see Figure 1). The log sheet has three sections: a heading, a roadway section, and a summary. The heading is completed prior to starting the inventory. The roadway section is completed while conducting the inventory and the summary is completed in the office at the end of the day.

Figure 1. Roadway Maintenance Inventory.



ROUTE TRAVEL DIRECTION	START LOCATION PAGE: ______ ROUTE: ______	END LOCATION PAGE: ______ ROUTE: ______	DATE	PAGE ___ OF ___
DISTRICT	RESIDENCY	COUNTY	MAINTENANCE AREA	INVENTORIED BY

BASIC CROSS SECTION
☐ 4-Lane Divided ☐ 2-Lane
☐ 4-Lane Undivided ☐ Other:

ROAD TYPE
☐ Interstate ☐ Secondary
☐ Primary ☐ Other:

SURFACE TYPE
☐ Bituminous ☐ Surface Treatment
☐ P.C. Concrete ☐ Stabilized
☐ Other:

Surface Width
Other
Mowable Swath
Ditch Miles
Shoulder Type
ODOMETER START
Shoulder Type
Ditch Miles
Mowable Swath
Other

SUMMARY
Mowable Swath miles TOTAL
Shoulder Type miles Paved Gravel Sod Wedge
Ditch Miles miles Left Right TOTAL
Signs number
Entrances number With Pipe W/O Pipe
Drainage Structures number Pipe Box Culvert Bridges Other:
Guardrail feet
Other

The Heading

The heading is located on the top and left side of the Roadway Maintenance Inventory shown in Figure 1. The heading identifies general information as to the location and basic characteristics of the roadway section being inventoried. To complete the heading the following procedure is used:

1. Route — the route is State Route number for the roadway being logged.
2. Travel Direction — the travel direction is the general direction in which the route traverses the maintenance area in the direction the logging is performed (North, South, East, or West).
3. Start Location — the start location for the "page" is any local landmark that will help identify the start of the roadway section. The start location for the "route" is determined from the information supplied in the Road Inventory (T&S-5). This identifies the location at which the route enters the maintenance area or terminates at another roadway.
4. End Location — The end location for the "page" is any local landmark that will help to identify the end of the roadway section. The end location for the "route" identifies the place at which the road exits a maintenance area or terminates.

5. Date — the date of the initial inventory is entered. The dates that any revisions are made are also entered.
6. District, Residency, County, Maintenance Area — enter applicable names for these items.
7. Inventoried By — enter names of inventory team members.
8. Surface Type, Road Type, Basic Cross Section — check the characteristic that describes the roadway being logged.

The Roadway

The roadway section of the Roadway Maintenance Inventory is located in the center of the sheet (see Figure 1). The first information to be recorded in the roadway section is the last three digits of the odometer reading in the block labeled "ODOMETER START". It is important that the tenths number be centered on the odometer. Some additional driving may be required to achieve this alignment. Each long mark on the log sheet within the roadway surface represents 0.10 of a mile and should be numbered consecutively from the start reading. (Use 0.05 of a mile in subdivisions and other congested areas.)

With the start location and odometer reading established, the team is ready to begin logging. The roadway surface is represented in the center of the roadway section. Rows are provided to the left and right of the roadway surface to indicate shoulder type, ditches, mowable swaths and other incidental items such as paved ditch, sidewalk, and curb and gutter.

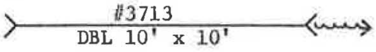
The logging procedure begins by entering maintainable items present at the start location. Shoulder type is entered on the line provided. Space is provided to enter a second shoulder type if present (i.e. wedge and gravel). Ditchable areas are indicated by a solid straight line drawn in the row provided. Mowable swaths, the number of passes necessary to maintain the Department's mowing standards, are also entered on the line provided. The surface width is indicated on the left in the line provided.

Other maintainable items are entered using the following graphic representations:

Pipe —

A pipe is represented by a straight line across roadway surface and an arrowhead indicating the direction of flow. The size of the pipe, and material, are entered on this line. An outfall ditch is shown by indicating its length and the letters "OFD".

Box Culverts —

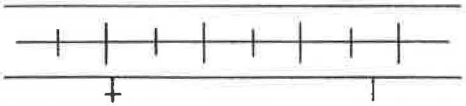


A box culvert is represented by a straight line with wingwalls. The structure number, if present, is noted and the size opening is given. Direction of flow is noted by drawing an arrow on the outlet end.

Bridges —

Bridges are represented by straight lines parallel to the roadway surface with wingwalls and structure number. Stream crossing or open ford should also be noted and described as such. Direction of flow is noted by drawing an arrow on the downstream side.

Entrances —



Entrance with pipe Entrance without pipe

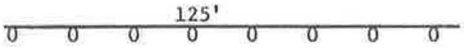
Private driveways, business entrances, etc. are indicated by a short straight line drawn perpendicular to the roadway surface. If a pipe is present, indicate it as shown above. Indication of pipe size is optional.

Signs —

2 - G-32 (Intersection State Route No. Signs)
1 - R-1 (Stop Sign)

Signs are shown as a circle with an X in the middle. The Sign Inventory code designation is also shown. Note that more than one sign can be on a pole.

Guardrail —



Guardrail is shown as a straight line with posts represented by circles and its length. Guardrail length can be figured by counting the number of guardrail sections and multiplying by 12.5'. EXAMPLE: If there are 10 sections of guardrail, the total length of the guardrail would be 10 x 12.5' or 125'.

Paved Ditches — are indicated by a straight line in "other" row and the letters "PD".

Curb & Gutter — are indicated by a straight line in "other" row and the letters "CG".

Sidewalks — are indicated by a straight line in "other" row and the letters "SW".

Drop Inlets — are indicated by a square box in the roadway surface and the letters "DI".

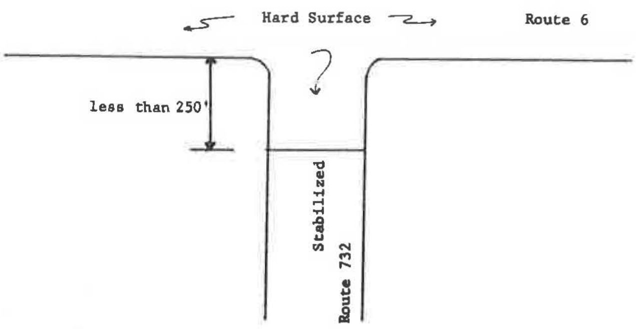
Stop Lights — are indicated by [0] in the center of roadway section and the letters "SPL".

Street Lights — are indicated by  in appropriate location and the letters "STL".

Special Situations —

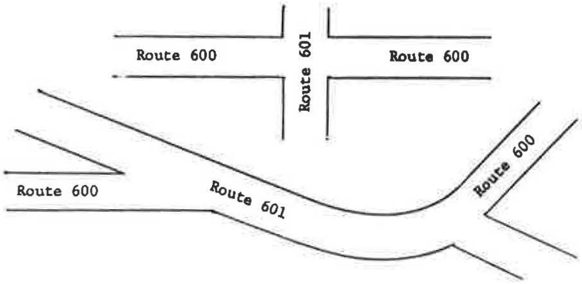
1. If the surface type, road type or basic cross sections change, draw a line across the entire roadway section of the log and terminate all maintainable items at the point corresponding to the odometer reading. Start another inventory sheet at that point.

The only exception to this is when a stabilized (gravel) or unimproved road has less than 250 feet of hard surface at the intersection with a hard surface roadway. In this situation the surface type change is noted on the inventory sheet and the logging is continued without starting a new inventory sheet.



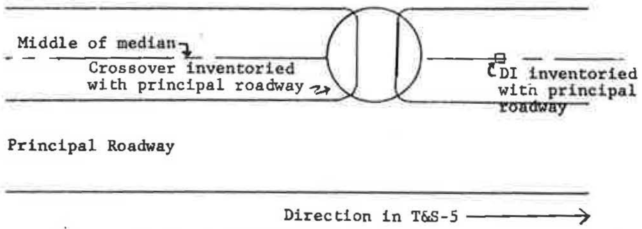
Route 732 is inventoried as a stabilized road with the hard surface portion at the intersection with Route 6 being noted on the inventory sheet as being hard surfaced.

2. When the route intersects another route and continues directly across the intersection, do not begin a new inventory sheet. If the route breaks at an intersection, begin a new sheet with a new odometer reading where it picks up again.



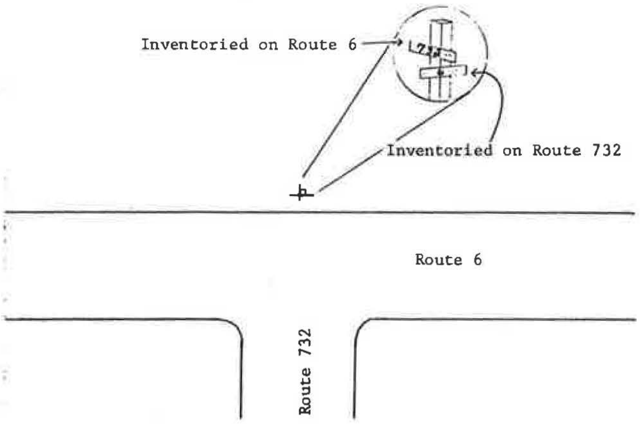
3. In logging a route, the length of road will not always coincide with the end of a log sheet. Therefore, when a route terminates somewhere within the mile section as represented by the inventory sheet, draw a line across the entire roadway section and terminate all maintainable items at the point corresponding to the odometer reading.

4. On 4-lane divided highways each roadway is inventoried separately. The middle of the median is the left boundary for each roadway. The principal roadway is the roadway whose traffic direction corresponds to the direction in the T&S-5. All maintainable items located at the middle of the median and all maintainable items associated with crossovers are inventoried with the principal roadway.



On 4-lane divided highway each roadway is inventoried separately.

5. The determination of which signs at an intersection are inventoried on which roadway is based on the location of the driver for whom the sign information is intended. EXAMPLE: At an intersection of a secondary and primary roadway, the primary route number sign located on the other side of the primary roadway is inventoried with the secondary roadway. The secondary route number sign is inventoried with the primary roadway.



6. The locations of ramps are identified on the mainline inventory sheet. Each ramp is inventoried on a separate sheet and cross-referenced to the mainline inventory sheet.

Example of a Completed Roadway Section —

The maintainable roadway items are as follows with the completed inventory sheet shown in Figure 2.

82.50 — Shoulder — sod left and right
Ditch — left and right
Mowable swaths — (2) left and (1) right
Stop sign — R-1
Surface width - 18'
82.58 — Ditch on right stops
18" c.m. pipe — draining to right — 25'OFD
82.62 — Entrance on left with pipe
82.70 — Ditch on left stops
Mowable swaths on left change from (2) to (1)
82.75 — Box culvert — DBL 4' x 4' - drainage to right
82.84 — Ditch on left and right
(2) Mowable swaths on each side
82.90 — Entrance left with pipe
Entrance right without pipe
83.09 — Sign right — bridge end panel W-54
83.10 — Ditches and mowable swaths stop left and right
Guardrail starts on left and right
83.15 — Bridge #6251 over New River
83.20 — Ditches begin left and right
(2) Mowable swaths left and right
83.21 — Sign left — bridge end panel W-54
83.25 — Connection Route 600
83.30 — Ditches, shoulders, and mowable swaths stop left and right
Sidewalk, and curb and gutter start on left
Curb and gutter start on right
83.40 — Drop inlet on left
83.50 — End of one-mile section

Accuracy in recording information is important. When recording the information be careful to enter the item in the row or surface section in which it is observed. For items requiring estimates, care should be taken to make sure that these estimates are as accurate as possible. To ensure that your estimates are fairly accurate, periodically spot-check them by physically measuring an item. For example, an outfall ditch length should be periodically measured in order to avoid overestimating lengths. Pipes should be measured with a carpenter's rule in order to obtain the proper size.

Section Summary

The maintainable items are totaled for each one-mile section and entered in the summary on the right side of the log sheet shown in Figure 1. A summary is shown below for the one-mile section just completed.

Mowable Swaths —

Total mowable swaths are computed by adding the totals from the left and right sides of the roadway section as either (1), (2), (3) or more mowable swaths. This total will give swath miles or the number of times a tractor mower will be required to pass back and forth over the mile section in order to mow the grass. For example: The total number of miles for the (1) mowable swath is 0.48 whereas the number of miles for the (2) mowable swaths is 0.92. This 0.92 mile must then be multiplied by two to

SUMMARY

Mowable Swath	Shoulder Type	Ditch Miles	Signs	Entrances	Drainage Structures	Guardrail	Other
miles	miles	miles	number	number	number	feet	OFD - 25'
1@.48 0.48	Paved	Left 0.56		With Pipe 2	Pipe 1		SW - 1056'
2@.92 1.84	Gravel		3		Box Culvert 1	500'	CFG - 2112'
	Sod 1.6	Right 0.44		W/O Pipe 1	Bridges 1		DI - 1
TOTAL 2.32	Wedge	TOTAL 1.00			Other: ______		

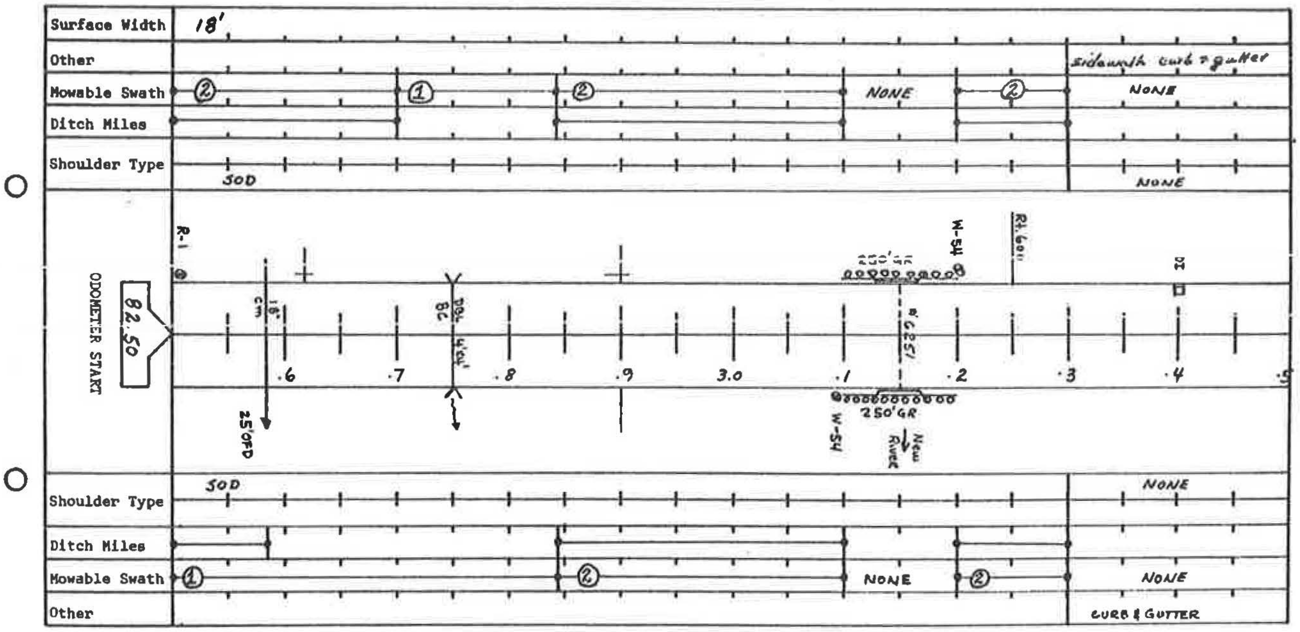


Figure 2. Example of completed roadway section.

obtain the total mileage because this section requires two passes of the tractor mower.

Shoulder Type —

The length of shoulder by type is taken directly from the roadway section for the left and right sides. Shoulder type as well as mowable swaths may change several times within the one-mile section. It is possible to have two or more shoulder types entered into the summary. However, the example section remained sod for 0.8 mile on both sides and thus gave a total of 1.6 miles of sod shoulder.

Ditch Miles —

Ditch miles are totaled directly from the roadway section for the left and right sides. In the example above there were 0.56 mile of ditch on the left side and 0.44 mile on the right. Total ditch miles for the one-mile section was 1.00.

Signs —

The sign summary is the total number of the various types of signs. Note that one sign post may contain one or more signs.

Entrances —

Entrances are totaled directly from the roadway section. Note that the entrances with pipe are summarized separately from those without pipe.

Drainage Structures —

Drainage structures include such items as pipe, box culverts, and bridges. They are totaled for each one-mile section and are listed in the appropriate space.

Guardrail —

The lengths of guardrail are obtained directly from the roadway section for the left and right sides. In this example there was a total of 500 feet of guardrail.

"Other" —

The "other" column is a "catch all" for listing such items as outfall ditch, sidewalk, curb and gutter, drop inlets, paved ditch, railroad crossings, and stream crossings.

The outfall ditch, sidewalk, curb and gutter, and paved ditch are entered in the summary in feet for the one-mile section. These summaries are completed for each mile section contained in the route.

ROADWAY MAINTENANCE INVENTORY SUMMARY

After summarizing the roadway inventory information for each mile of roadway, summarize all of the information for each route within the maintenance area. This is accomplished through the use of the Roadway Maintenance Inventory Summary (Table 1). Basically, the summary consists of a heading and a body. The heading serves to locate the route within the District, Residency, and County as well as in the maintenance area. Applicable names are entered in these blocks.

The body of the Roadway Maintenance Inventory Summary is an expansion of the section summary of the Roadway Maintenance Inventory. The information in the section summary of the Roadway Maintenance Inventory sheets for each roadway is summarized as to gross quantities of maintainable items and entered into the Roadway Maintenance Inventory Summary sheet. After the Roadway Maintenance Inventory Summary is completed, then a grand total can be made for the entire maintenance area as well as the entire Residency, District, and State.

Table 1. Roadway Maintenance Inventory Summary — (Sheet A)

DISTRICT	RESIDENCY	COUNTY	MAINTENANCE AREA	ROAD TYPE	DATE	Page ____ of ____

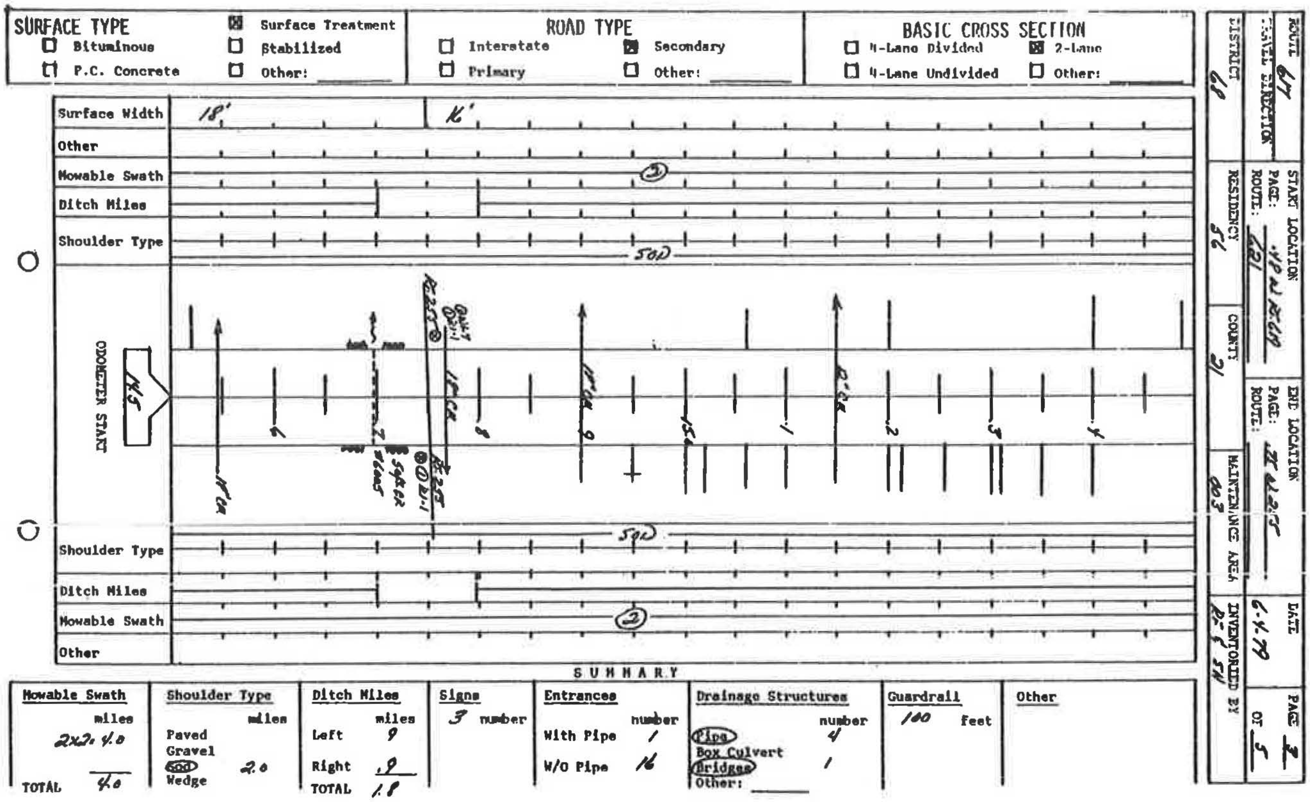
					SHOULDER TYPE						ENTRANCES		DRAINAGE STRUCTURES						OTHER		
Route Number	Surface Type	Basic Cross Section	Length	Mowable Swath	Paved	Gravel	Sod	Wedge	Ditch Miles	Signs	With Pipe	Without Pipe	Pipe	Box Culvert	Bridges	Other ____	Guardrail	Sidewalk	Curb & Gutter	Paved Ditch	Outfall Ditch
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
UNITS			← MILES						→	← NUMBER						→	← FEET				→

Table 2. Roadway Maintenance Inventory Summary — (Sheet B)

DISTRICT	RESIDENCY	COUNTY	MAINTENANCE AREA	ROAD TYPE	DATE	Page ____ of ____

Route Number																					
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Units																					

APPENDIX B. COMPLETED ROADWAY SECTION



SURFACE TYPE
☐ Bituminous ☐ P.C. Concrete ☒ Surface Treatment ☐ Stabilized ☐ Other: ______

ROAD TYPE
☐ Interstate ☐ Primary ☒ Secondary ☐ Other: ______

BASIC CROSS SECTION
☐ 4-Lane Divided ☐ 4-Lane Undivided ☒ 2-Lane ☐ Other: ______

ROUTE 617
TRAVEL DIRECTION
START LOCATION PAGE: .4 P of Rt 619 ROUTE: 621
END LOCATION PAGE: Int of Rt 2.75 ROUTE:
DATE 6-4-79
PAGE 2 OF 5
DISTRICT 68
RESIDENCY 56
COUNTY 21
MAINTENANCE AREA 003
INVENTORIED BY RF & SH

SUMMARY

Mowable Swath: miles 2x2: 4.0; TOTAL 4.0
Shoulder Type (miles): Paved; Gravel; [✓ Sod] 2.0; Wedge
Ditch Miles (miles): Left .9; Right .9; TOTAL 1.8
Signs: 3 number
Entrances (number): With Pipe 1; W/O Pipe 16
Drainage Structures (number): [✓ Pipe] 4; Box Culvert; [✓ Bridges] 1; Other: ______
Guardrail: 100 feet
Other

APPENDIX C. ROADWAY MAINTENANCE INVENTORY GRAND SUMMARY — INTERSTATE SYSTEM

DISTRICT	RESIDENCY	COUNTY	MAINTENANCE AREA	DATE COMPLETED
Staunton 68	Edinburg 55	Shenandoah 85	Mt. Jackson 001	October 1979

ROADWAY TYPE: ☐ ALL ☒ INTERSTATE ☐ PRIMARY ☐ SECONDARY

	SURFACE TYPE	Bituminous			P. C. Concrete			Surface Treatment		Stabilized		TOTAL			TOTAL
	CROSS-SECTION	4-Lane	2-Lane	Other	4-Lane	2-Lane	Other	2-Lane	Other	2-Lane	Other	4-Lane	2-Lane	Other	ALL
MILES	LENGTH	22.40		3.95								22.40		3.95	26.35
	MOWABLE SWATH	174.40		10.45								174.40		10.45	184.85
	SHOULDER TYPE														
	Paved	43.80		5.70								43.80		5.70	49.50
	Gravel	----		----								----		----	----
	Sod	----		----								----		----	----
	Wedge	----		----								----		----	----
	DITCH MILES	19.45		1.10								19.45		1.10	20.55
NUMBER	SIGNS	123		90								123		90	213
	ENTRANCES														
	With Pipe	----		----								----		----	----
	Without Pipe	----		----								----		----	----
	DRAINAGE STRS.														
	Pipe	60		7								60		7	67
	Box Culvert	27		5								27		5	32
	Bridges	8		----								8		----	8
	Overflow	----		----								----		----	----
	Drop Inlet	5		2								5		2	7
FEET	GUARDRAIL	58983.0		10470.0								58983.0		10470.0	69453.0
	SIDEWALK	----		----								----		----	----
	CURB & GUTTER	300.0		1371								300.0		1371	1671.0
	PAVED DITCH	15166.0		2376								15166		2376	17542
	OUTFALL DITCH	----		----								----		----	----
	SNOW FENCE	----		----								----		----	----

APPENDIX C. ROADWAY MAINTENANCE INVENTORY GRAND SUMMARY — PRIMARY SYSTEM

DISTRICT Staunton 68	**RESIDENCY** Edinburg 55	**COUNTY** Shenandoah 85	**MAINTENANCE AREA** Mt. Jackson 001	**DATE COMPLETED** October 1979

ROADWAY TYPE: ☐ ALL ☐ INTERSTATE ☒ PRIMARY ☐ SECONDARY

	SURFACE TYPE	Bituminous			P. C. Concrete			Surface Treatment		Stabilized		TOTAL			TOTAL
	CROSS-SECTION	4-Lane	2-Lane	Other	4-Lane	2-Lane	Other	2-Lane	Other	2-Lane	Other	4-Lane	2-Lane	Other	ALL
MILES	LENGTH	3.35	32.92	10.70				1.5				3.35	34.42	10.70	48.47
	MOWABLE SWATH	18.55	137.60	59.31				6.0				18.55	143.60	59.31	221.46
	SHOULDER TYPE														
	Paved	----	----	----				----				----	----	----	----
	Gravel	----	----	----				----				----	----	----	----
	Sod	5.30	63.00	21.10				3.0				5.30	66.00	21.10	92.40
	Wedge	----	----	----				----				----	----	----	----
	DITCH MILES	4.85	71.27	5.50				0.75				4.85	72.02	5.50	82.37
NUMBER	SIGNS	113	757	241				7				113	764	241	1,118
	ENTRANCES														
	With Pipe	19	152	46				5				19	157	46	222
	Without Pipe	42	418	212				0				42	418	212	672
	DRAINAGE STRS.														
	Pipe	14	184	60				3				14	187	60	261
	Box Culvert	2	11	3				1				2	12	3	17
	Bridges	2	7	1				----				2	7	1	10
	Overflow	----	----	----				----				----	----	----	----
	Drop Inlet	6	----	----				----				6	----	----	6
FEET	GUARDRAIL	11.87	9,885.5	5,091.0				325.0				11.87	10,210.5	5,091.0	15,313.37
	SIDEWALK	----	----	----				----				----	----	----	----
	CURB & GUTTER	7,392.00	26,616.0	4,224.0				----				7,392.00	26,616.0	4,224.0	38,232.0
	PAVED DITCH	5,280.00	7,392.0	----				1,320.0				5,280.00	8,712.0	----	13,992.0
	OUTFALL DITCH	----	500	150				----				----	500	150	650
	SNOW FENCE														

APPENDIX C. ROADWAY MAINTENANCE INVENTORY GRAND SUMMARY — SECONDARY SYSTEM

DISTRICT Staunton 68	**RESIDENCY** Edinburg 55	**COUNTY** Shenandoah 85	**MAINTENANCE AREA** Mt. Jackson 001	**DATE COMPLETED** August 1979

ROADWAY TYPE: ☐ ALL ☐ INTERSTATE ☐ PRIMARY ☒ SECONDARY

	SURFACE TYPE	BITUMINOUS / SLURRY SEAL			P. C. Concrete			Surface Treatment		Stabilized		TOTAL			TOTAL
	CROSS-SECTION	4-Lane	2-Lane	Other	4-Lane	2-Lane	Other	2-Lane	Other	2-Lane	Other	4-Lane	2-Lane	Other	ALL
MILES	LENGTH		10.95 / 6.17					94.40		99.68			211.20		211.20
	MOWABLE SWATH		43.60 / 17.70					373.20		364.22			798.72		798.72
	SHOULDER TYPE														
	Paved		--- / ---					----		----			----		----
	Gravel		--- / ---					----		----			----		----
	Sod		21.80 / 11.64					186.64		----			220.08		220.08
	Wedge		--- / ---					----		----			----		----
	DITCH MILES		21.00 / 11.26					173.28		192.11			397.55		397.65
NUMBER	SIGNS		60 / 175					839		291			1,365		1,365
	ENTRANCES														
	With Pipe		32 / 69					371		86			558		558
	Without Pipe		111 / 148					1,000		729			1,988		1,988
	DRAINAGE STRS.														
	Pipe		59 / 19					483		526			1,087		1,087
	Box Culvert		--- / ---					16		3			19		19
	Bridges		1 / ---					27		20			48		48
	Overflow		1 / 1					2		9			13		13
	Drop Inlet		--- / ---					----		----			----		----
FEET	GUARDRAIL		300.00 / 288.00					16,847		2,676			20,111		20,111
	SIDEWALK		--- / ---					0.26		----			0.26		0.26
	CURB & GUTTER		--- / ---					----		----			----		----
	PAVED DITCH		--- / 264.00					2,984		----			3,248		3,248
	OUTFALL DITCH		--- / ---					500		220			720		720
	SNOW FENCE		--- / ---					----		----			----		----

VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
MAINTENANCE DIVISION
STANDARD

ACTIVITY 111 Sheet 1 of 1	DATE February 15, 1980	WORK UNIT Tons

DESCRIPTION — SPOT SEALING OR SKIN PATCHING OF THE ROAD SURFACE

Putting light application of an emulsified asphalt on the bituminous surface and covering with sharp, clean, uniformly graded stone.

PURPOSE

The primary purpose of skin patching is to maintain pavement strength by sealing cracks in the surface layer and thus preventing moisture from weakening the base materials. To prevent serious pavement failure, small cracking should be monitored and should be skin patched when the opening exceeds 1/8".

The common types of surface cracking and their causes are as follows:

1. Alligator Cracking — Poor drainage or small cracks allowing water to saturate and weaken base materials.
2. Edge Cracking — Poor drainage, inadequate base or insufficient lateral support.
3. Ravelling — Dusty stone or too little asphalt binder.
4. Longitudinal Cracking — Unstable base; first stage of alligator cracking.

SCHEDULING FREQUENCY

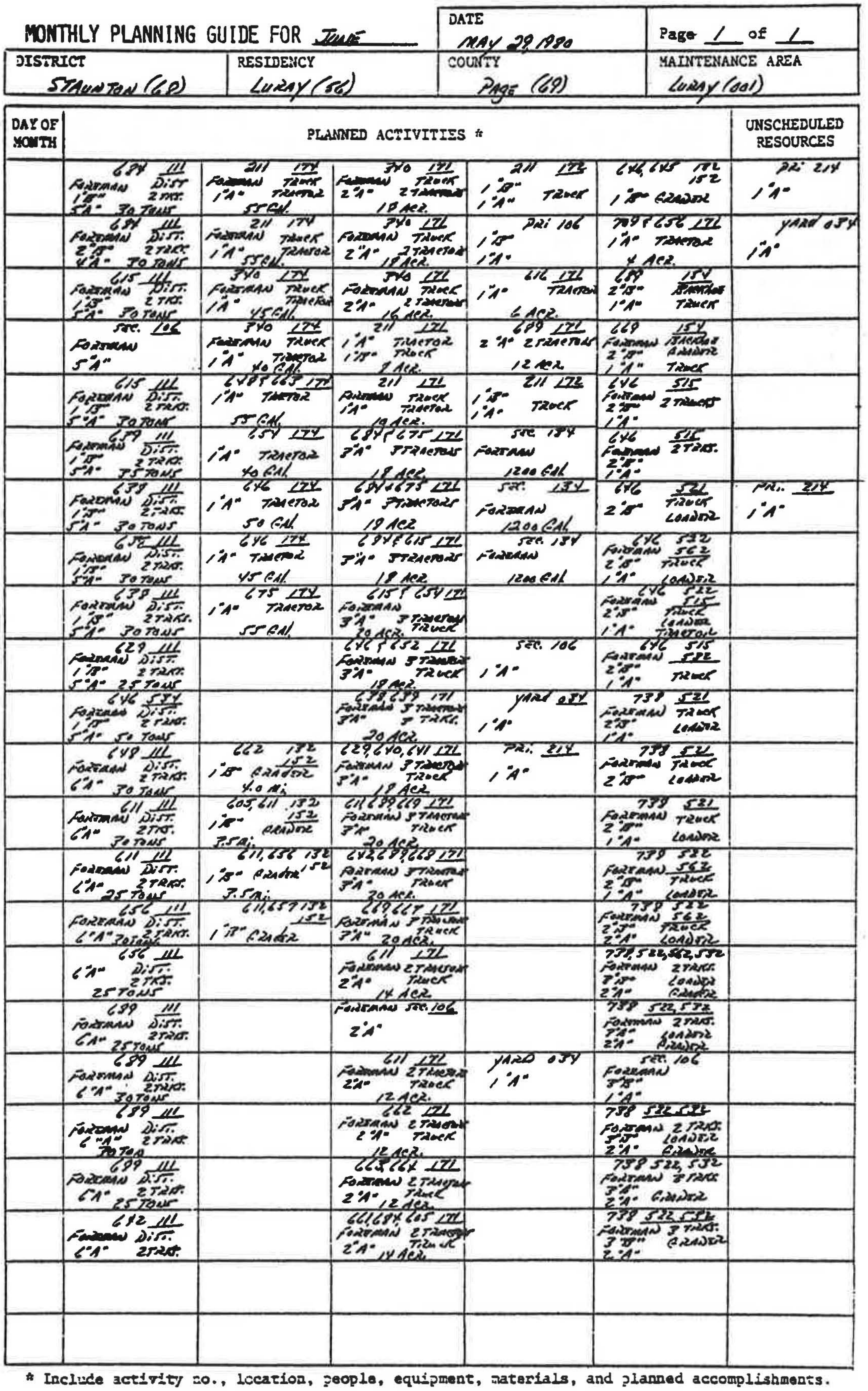
MONTH	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
MAJOR EMPHASIS			▤	▤					▤	▤	▤	▤
MINOR EMPHASIS					▤							
AS REQUIRED	▤	▤				▤	▤	▤				

PROCEDURE

1. Place traffic control devices in accordance with current Department guidelines, "Typical Traffic Control For Work Area Protection". See Section 14 of the Maintenance Division Policy Manual.
2. When necessary clean and dry the area to be patched. Broom area if necessary.
3. Spray a light application of asphalt over the deteriorated area and extend spray one foot beyond on each side. Provide a square patch for a neat appearance and minimal annoyance to the travelling public. Application will vary due to the type asphalt, size, and absorption of underlying pavement. As a guide, the proper application will not flow and the texture of the existing pavement will be visible.
4. Apply cover stone. The stone should be applied within one minute of spraying the asphalt. The cover stone should be applied in the direction of traffic, one stone thick and touching on all sides.
5. Begin rolling immediately after the stone is spread and continue until the stone is properly seated or the asphalt shows signs of hardening. On large patches roll from the outside toward the center of the pavement. Care should be taken not to over roll. Stop rolling if crushing of the stone occurs.
6. Recover traffic control devices.

PERSONNEL	EQUIPMENT	MATERIALS
1 operator 1 asphalt spray operator 1 person	1 truck w/ asphalt kettle & cover stone 1 front end loader (at stockpile)	**Asphalt** CMS-2 90°-110° CRS-2 130°-160°
3 operators 1 asphalt spray operator 2 persons	1 truck w/ asphalt kettle or tow distributor 1 truck w/ cover stone & roller 1 front end loader (at stockpile)	**Cover Stone** #8 stone - 3/8" max. size #78 stone - 1/2" max. size
		SMALL TOOLS
1 Foreman 7 operators 1 spray bar operator 3 persons on tailgate spreaders	1 distributor 3 trucks (vary to suit haul) w/ tailgate spreaders 1 roller 1 front end loader (at stockpile) 1 tractor broom (if needed)	shovels brooms

APPENDIX E. MONTHLY PLANNING GUIDE



MONTHLY PLANNING GUIDE FOR JUNE

DATE MAY 29 1980

Page 1 of 1

DISTRICT STAUNTON (68)

RESIDENCY LURAY (56)

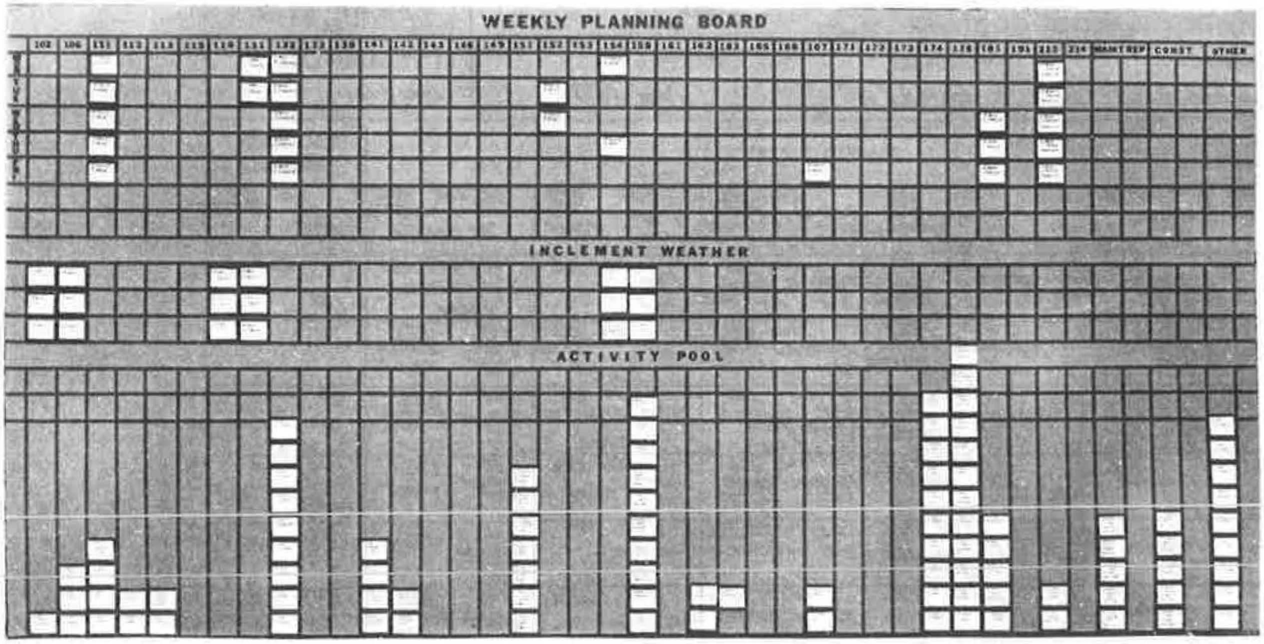
COUNTY PAGE (69)

MAINTENANCE AREA LURAY (001)

DAY OF MONTH	PLANNED ACTIVITIES *					UNSCHEDULED RESOURCES
	684 111 FOREMAN DIST 1"B" 2 TRKS. 5"A" 30 TONS	211 174 FOREMAN TRUCK 1"A" TRACTOR 55 GAL.	340 171 FOREMAN TRUCK 2"A" 2 TRACTORS 18 ACR.	211 173 1"B" 1"A" TRUCK	646, 645 132 152 1"B" GRADER	PRI 214 1"A"
	684 111 FOREMAN DIST. 2"B" 2 TRKS. 4"A" 30 TONS	211 174 FOREMAN TRUCK 1"A" TRACTOR 55 GAL.	340 171 FOREMAN TRUCK 2"A" 2 TRACTORS 18 ACR.	PRI 106 1"B" 1"A"	709 & 656 171 1"A" TRACTOR 4 ACR.	YARD 034 1"A"
	615 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 30 TONS	340 174 FOREMAN TRUCK 1"A" TRACTOR 45 GAL.	340 171 FOREMAN TRUCK 2"A" 2 TRACTORS 16 ACR.	616 171 1"A" TRACTOR 6 ACR.	689 154 2"B" BACKHOE 1"A" TRUCK	
	SEC. 106 FOREMAN 5"A"	340 174 FOREMAN TRUCK 1"A" TRACTOR 40 GAL.	211 171 1"A" TRACTOR 1"B" TRUCK 8 ACR.	689 171 2"A" 2 TRACTORS 12 ACR.	669 154 FOREMAN BACKHOE 2"B" GRADER 1"A" TRUCK	
	615 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 30 TONS	648 & 663 174 1"A" TRACTOR 55 GAL.	211 171 FOREMAN TRUCK 1"A" TRACTOR 10 ACR.	211 173 1"B" 1"A" TRUCK	646 515 FOREMAN 2 TRUCKS 2"B" 1"A"	
	639 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 35 TONS	654 174 1"A" TRACTOR 40 GAL.	684 & 675 171 3"A" 3 TRACTORS 18 ACR.	SEC. 134 FOREMAN 1200 GAL.	646 515 FOREMAN 2 TRKS. 2"B" 1"A"	
	639 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 30 TONS	646 174 1"A" TRACTOR 50 GAL.	684 & 675 171 3"A" 3 TRACTORS 19 ACR.	SEC. 134 FOREMAN 1200 GAL.	646 521 2"B" TRUCK LOADER	PRI. 214 1"A"
	658 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 30 TONS	646 174 1"A" TRACTOR 45 GAL.	694 & 615 171 3"A" 3 TRACTORS 18 ACR.	SEC. 134 FOREMAN 1200 GAL.	646 532 FOREMAN 562 2"B" TRUCK 1"A" LOADER	
	638 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 30 TONS	675 174 1"A" TRACTOR 55 GAL.	615 & 654 171 FOREMAN 3"A" 3 TRACTORS TRUCK 20 ACR.		646 522 FOREMAN 515 2"B" TRUCK LOADER 1"A" TRACTOR	
	629 111 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 25 TONS		646 & 652 171 FOREMAN 3 TRACTORS 3"A" TRUCK 18 ACR.	SEC. 106 1"A"	646 515 FOREMAN 522 2"B" 1"A" TRUCK	
	646 534 FOREMAN DIST. 1"B" 2 TRKS. 5"A" 50 TONS		638 639 171 FOREMAN 3 TRACTORS 3"A" 3 TRKS. 20 ACR.	YARD 034 1"A"	738 521 FOREMAN TRUCK 2"B" LOADER 1"A"	
	648 111 FOREMAN DIST. 2 TRKS. 6"A" 30 TONS	662 132 152 1"B" GRADER 4.0 Mi.	629, 640, 641 171 FOREMAN 3 TRACTORS 3"A" TRUCK 18 ACR.	PRI. 214 1"A"	738 521 FOREMAN TRUCK 2"B" LOADER	
	611 111 FOREMAN DIST. 6"A" 2 TKS. 30 TONS	605, 611 132 152 1"B" GRADER 7.5 Mi.	611 638 669 171 FOREMAN 3 TRACTORS 3"A" TRUCK 20 ACR.		739 521 FOREMAN TRUCK 2"B" 1"A" LOADER	
	611 111 FOREMAN DIST. 6"A" 2 TRKS. 25 TONS	611, 656 132 152 1"B" GRADER 7.5 Mi.	642, 684, 668 171 FOREMAN 3 TRACTORS 3"A" TRUCK 20 ACR.		739 522 FOREMAN 562 2"B" TRUCK 1"A" LOADER	
	656 111 FOREMAN DIST. 6"A" 2 TRKS. 30 TONS	611, 657 132 152 1"B" GRADER	669, 667 171 FOREMAN 3 TRACTORS TRUCK 3"A" 20 ACR.		738 522 FOREMAN 562 2"B" TRUCK 2"A" LOADER	
	656 111 6"A" DIST. 2 TKS. 25 TONS		611 171 FOREMAN 2 TRACTORS 2"A" TRUCK 14 ACR.		738, 522, 562, 532 FOREMAN 2 TRKS. 3"B" LOADER 2"A" GRADER	
	699 111 FOREMAN DIST. 2 TRKS. 6"A" 25 TONS		FOREMAN SEC. 106 2"A"		738 522, 532 FOREMAN 2 TRKS. 3"A" LOADER 2"A" GRADER	
	689 111 FOREMAN DIST. 6"A" 2 TRKS. 30 TONS		611 171 FOREMAN 2 TRACTORS 2"A" TRUCK 12 ACR.	YARD 034 1"A"	SEC. 106 FOREMAN 3"B" 1"A"	
	689 111 FOREMAN DIST. 6"A" 2 TRKS. 30 TONS		662 171 FOREMAN 2 TRACTORS 2"A" TRUCK 12 ACR.		738 522, 532 FOREMAN 2 TRKS. 3"B" LOADER 2"A" GRADER	
	699 111 FOREMAN DIST. 2 TRKS. 6"A" 25 TONS		663, 664 171 FOREMAN 2 TRACTORS TRUCK 2"A" 12 ACR.		738 522, 532 FOREMAN 3 TRKS. 3"A" 2"A" GRADER	
	682 111 FOREMAN DIST. 6"A" 25 TRKS.		661, 684, 665 171 FOREMAN 2 TRACTORS TRUCK 2"A" 14 ACR.		738 522, 532 FOREMAN 3 TRKS. 3"B" GRADER 2"A"	

* Include activity no., location, people, equipment, materials, and planned accomplishments.

APPENDIX F. PLANNING BOARD



RISK MANAGEMENT

Charles T. Edson
Assistant Chief Engineer
Construction & Maintenance
New Jersey Department of Transportation

Risk Management means different things to different people and industries. In the insurance industry it means that if a client pays a certain fee, the company assumes the risk for his errors. The insurance management concept applies to the determination of the amount of the fee required to offset the probabilities that a claim will be filed in the first instance, and for specific incremental dollar amounts of a possible claim in the second instance.

Risk is something we quickly analyze in our human computer each time we make a decision. Many times we even compute the dollar value of decisions. Imagine it has been snowing hard all night, and when your radio alarm awakens you with, "This station suggests you stay home unless you absolutely have to travel today, the highways and streets are hazardous", immediately you become concerned and the computer in your head starts to analyze the situation. What are the chances that I can get to work at a reasonable time, if at all? If the roads are really icy, what is the risk I could be involved in an accident? Could I get stranded somewhere and freeze! If I get to work, will anyone else be there, or will my boss say it is so bad that I should go on home? Is it worth a day's pay to avoid these risks and stay home? If I get hurt, I could miss a lot of work, or if my car is out of action for repairs, how will I get to work? Maybe I can take the bus or train! If I get to the bus stop, will it come? If it does, will I get home? If I get to the train station, will the train be there in time to get me to work? Can I get home later on in the day? Do I have the money for the train? After all consideration, the decision is derived by, "What will it cost me if I stay home? What will it cost me if I go to work? As a maintenance manager, you make many decisions which affect a diverse group of people. Each time a decision is reached a different combination of facts are used for analytical purposes which impact people in different ways. You affect the motorist, the resident adjacent to the highway, community groups, manufacturers, contractors, vendors, employees, and work groups.

As a highway maintenance manager, you make many decisions each day, and unless you evaluate the risk of the decision you may produce an unforgiving situation because of the impact of your decision. This paper will discuss RISK MANAGEMENT as it applies to a maintenance manager.

Whenever a decision is made about any maintenance work item, it impacts either the public or your agency. If you receive a complaint about mowing a section of roadside, you will either mow it or tell the complaintant that there is a reason why you cannot perform this service. In the first instance, the impact to your agency is money spent on a project, and if it was not already on your schedule, it will cause some other project to be deferred. A no answer to the complaintant may cause a problem in the form of a habitat for undesirable animals or pollen irritants to property owners, in addition to an irritated complaintants' ego with further public relations problems.

Decisions are made at many different levels in an organization which may impact a very small segment of the population, or millions of motorists. Who decides which pothole to patch, the maintenance worker? Who decides which section of roadway is to be patched? Who decides on how patching material and equipment will be distributed? Who decides the quantity of patching material to be purchased for a year? Who decides how much funding will be given for maintenance activities?

A pothole could cause problems to several thousand motorists in a day such as, misaligned front end alignment in the car, a tire blowout or other failure, a swerving accident, a general slowdown in speed causing lost time, excess fuel consumption and noise transmitted from the bump to adjacent houses. If there is a series of potholes, the accident potential increases as does the potential for vehicle damage, slow speeds and noise transmission. In addition, the vehicles may be using significantly more fuel causing a local pollution problem. What is the environmental harm to humans, wildlife, and vegetation? If groups of potholes are not patched promptly, the deferred maintenance can cause considerable future rehabilitation costs. In the event potholes become rampant throughout the jurisdiction of a public agency, what can the total cost of rehabilitation be, due to accelerated decay?

Other examples of decision impacts are:

1. Mowing sight areas - cost vs. potential accidents.
2. Signs that are missing or illegible - shall they be replaced in 24 hours, 1 week, 1 month, as they relate to the type of sign and the cost to the agency or potential accidents.
3. A fence is cut and it is possible that entrance could be gained to the highway. What is the cost of repair, potential for accident or withdrawal of federal funds?
4. Snow removal and ice control is an operation that is required over a large geographic area at the same time. If one area is left unattended while crews are working in another, what is the potential for accidents, extra fuel consumed, additional pollution, extra travel time, expense of lost available work hours, potential for a closed road for a period of time, additional cost for removal or added expense of winter materials? On a wider basis, is the equipment and materials stored at the most economical or most responsive location, and what is that effect on response time, which directly impacts all of the above? Do you have a residence requirement to have a determined response time which will cause an impact on the agency and the public?

A manager of maintenance activities always has to deal with budgetary allotments that affect manpower equipment and materials. The management of these resources can be handled in many different ways. In general, most maintenance organizations have a defined schedule of certain work activities. Some of these activities are resurfacing, guide rail replacement, surface seal coating, crack sealing, mowing and line striping. While certain areas of maintenance work can be effectively scheduled far in advance, other activities cannot be scheduled in that manner and the work program therefore must be flexible to accept certain work activities that can only be scheduled on a short-term basis. Examples of some of these short-term activities are: snow removal, pothole patching, sign replacement due to knockdown, repair pavement blowups, and relief of flooding.

A budget is provided that allows for a mix of the three basic resources and a manager has to decide what type of mix he will utilize. When the manager makes this decision, he is setting priorities on the work that will be accomplished on the highway system. In addition to setting priorities through the budgetary allocation process, there are other ways that priorities are set for the maintenance activities, particularly through many of the outside restraints such as legislative activities, political pressures, complaints, court settlements and the supervisor's directive. A manager may also have his personal preference on what type of work is most important to his agency. My personal preference is to patch main pavement and maintain the drainage, while someone else's personal preference may be to maintain the safety of the motorist through striping, sign replacement, sight distance clearing, and warning devices.

Another way work is planned that reflects in the total program is related to the availability of a particular resource. If patching materials are not available, you cannot patch potholes. If manpower is not available, you cannot patch potholes. If equipment is not available, you cannot patch potholes. A combination of resources must be available to perform pothole patching, while another activity may only use either one or two of the available resources. When one of the required resources (manpower, materials or equipment) for any assigned work activity is not available, alternate solutions must be implemented through schedule changes. This rescheduling is a quick reactionary planning technique that changes the work program.

It is important that the impact of all our decisions are married with the management of resources and work programs. A total program would include the evaluation of the assignment of the resources and the impact of decisions that are made. Many of the decisions that are made, either in resource assignment or in the establishment of a work activity, will have a great impact on someone. This impact may turn around to be a tort liability suit against the manager and his agency, which can either be based on the fact that the agency knew about a dangerous condition and did not correct it, or that the condition lasted sufficiently long that they should have known about it and therefore performed corrective work activities. When the program is established, it is very important that the manager weigh the impact of his decision to see what the total affect will be.

Risk Management in the maintenance area could be defined as "the management of a work program that is implemented after all possible impacts are analyzed in an effort to minimize the aggregate expenditure of funds." This expenditure should be all impacts reduced to their dollar value as they affect the agency, a citizen or a motorist. Many definitions of Risk Management include the fatality of the motorist, but eventually that works out to a dollar value which can be incorporated into a Risk Management Program. In developing a Risk Management Program, it is very important to determine the objectives, identify the risks that you are willing to accept, and evaluate the alternatives to accepting the risk, either through the elimination or transfer of the risk to another source.

An example of this risk transfer was recently the object of a court decision where a large amount of money was awarded to an accident victim in Newtown, Pennsylvania. The scene appeared to be a typical winter maintenance operation, with slippery pavements. The town was notified that there were icing conditions and accidents were occurring. The road in question was under the jurisdiction of the state, not the municipality, but the court ruled that the municipality should have reacted since they were notified and they were immediately available as it was within the limits of the municipality's borders. This oversimplifies the situation, but apparently the state effectively transferred the risk to the town. There may be other ways of transferring risk back to the motorist, such as in New York State were certain roads are reported closed on designated radio stations during periods of heavy snowfall, even though they could be passable.

An example of Risk Management Program is one that occurred in New Jersey, relating to service to the public during the winter maintenance season. A thorough analysis was made of the need for winter material storage facilities. This analysis included the use of several year's data relating to the amount of snowfall, the usage of chemicals on each section of roadway by a given foreman, and the amount of storage facilities available at a specific geographic location. Each storage facility was analyzed to see what its capacity was, as related to the expected need for that assigned area. Knowing the limits of the assigned foreman's section, it was then determined how effectively materials could be stored for use within that section. After analyzing each location, a map was drawn, similar to a contour map, for the whole state. Utilizing this information, the high areas of need and the areas already adequately supplied were identified. The map was then colored in three colors, one indicated all of those facilities and geographic areas that could be covered with an adequate supply of materials. Another represented those considered to be marginally acceptable since they would meet the minimum requirement for less than the average winter. The third area was considered completely inadequate for storage facilities. It was quickly determined that there were several geographic areas that needed immediate attention. One area was in the most densely traveled section of the state, known as Philadelphia-New York Corridor. The area was roughly 55 miles long and 20 miles wide. In the center of this geographic area, there was an intersection of three major state highways and one interstate highway. Calculations indicated that if one large storage facility were built at this intersection, it would provide the necessary materials to change the character of this entire geographical area from inadequate to adequate. Several sites were considered and were ruled out because of their location. Property not owned by the state was not considered as a possible site due to insufficiency of funds and to the time requirements involved. An abandoned maintenance facility, about one mile from the intersection of these major routes, was identified as the best location, and since it had been a maintenance site for more than 20 years, it was selected as the best site from management perspective. Past history had indicated that residents in the area were not favorable to having a maintenance facility at that location; however, it was indicated that the increase in transportation time and response time from any other location would be an unacceptable risk to the motorist and the incurred expense to the Department for transportation of materials would be too great. Although numbers could be applied, they will not be included in this presentation. After the risks to the motorist and the Department were evaluated and considered, it was then reviewed from the perspective of the land owners in the township where the building was to be constructed. Major public opinion would be against the Department in this venture and it was decided to assume the risk of any opposition from either the local citizens or the municipality itself. In reality, the municipality went to court and obtained an injunction against the construction of the facility. Court action occurred and an eventual decision was rendered that the state had wisely proceeded and protected the general public to the best of its ability. Although the court costs and the legal fees were high, the risk involved was the minimum condition. If the court had ruled against the specific location, it would have cost more to purchase land and build at a nearby site. That was the risk that was assumed in making this Risk Management decision.

The maintenance manager should be aware of the Risk Management technique, and review each decision in light of the various tradeoffs, at either a very local level in activities such as expensive traffic control through work zones vs. a decrease in productivity, or tort liability suits, the scheduling system of maintenance work by managers or through the allotment of resources by upper echelon management. The impacts of all affected groups and the environment should be considered. The ultimate decision should be that one with the lowest risk of money and lives, through the use of a management system, that utilizes all available information that would stand up against any hostile adversay.

ACHIEVING INTERGOVERNMENTAL COOPERATION

John M. Kirtland, Chief, Maintenance Division, Hennepin County, Minnesota, Department of Transportation

Today's growing demands and diminishing revenues make sharing our resources (equipment, manpower, special services) more desirable than ever before. Sharing resources with others is certainly not new or unique, but often it is used only in the simplest forms. In some cases this may result from a reluctance to change the status quo. However, more likely it is a concern for the legal and administrative entanglements involved. Perhaps the biggest deterrent to achieving intergovernmental cooperation in resource sharing is the legal aspect. Is it permissible under present laws, ordinances, etc.? In some instances state laws have to be revised or new ones drafted to provide for such sharing. For protection, most any sharing policy will require an official written agreement. We, at Hennepin County, are fortunate in having developed a variety of resource sharing programs encompassing a diverse field of services. Hennepin County has been very receptive to cooperative agreements and the rewards have been more than worthwhile. The following are descriptions of a few such areas of sharing, and comments regarding the results.

Hennepin County loaned its staff of labor negotiators to assist Scott, Wright, and Anoka Counties in their first formal negotiations. These services were provided under formal agreement, and continued until Hennepin County's own needs became too great. With demands growing throughout the state, the Association of Minnesota Counties then hired professional help to serve all Minnesota counties upon request. Hennepin County presently handles labor negotiations for the Hennepin County Park Reserve District and the Metropolitan Mosquito Control Commission, both independent agencies. Besides the obvious advantages of uniformity in the bargaining field, the added work allowed Hennepin County to enlarge and develop its resource staff to better respond to its own future needs. The other agencies gained through the use of trained, knowledgeable and interested negotiators at a cost far less than they could have provided individually.

Through a formal cooperative agreement the county maintains a portion of state highway that runs common with a county freeway. It also, by formal agreement, maintains three river bridges joining Scott and Wright Counties with Hennepin County. In the same manner, the City of Minneapolis provides routine maintenance on the county system within the city limits. By informal agreements, many trade-offs are made between the Minnesota and Hennepin County Transportation Departments, such as splitting the winter maintenance of an intersection (ramps and clover leafs) to eliminate deadheading, or in other ways improving service or efficiency. Through informal agreements, the county, with assistance from the cities, loads and hauls snow from the heavily traveled, multilane county highways within their borders. By this cooperative effort, the county and the cities provide snow-free traffic lanes, gutters and sidewalk areas for the convenience of the motorist and pedestrian. All of these measures tend to reduce equipment and manpower needs through better utilization of present facilities and help maintain a level of service not always possible by one agency alone.

Hennepin County, by formal agreement, maintains traffic control signals for some of the cities. This is beneficial to both parties, because through this arrangement the county can better afford to maintain a first rate signal repair shop with highly trained technicians, test equipment, and parts supply, plus adequate field equipment and personnel. Independently, the cities could not justify the necessary expenditures for this activity and therefore, the level of service provided would generally fall below desirable or acceptable, and could result in accident claim losses.

Today the county's computer systems are receiving great attention and demand for participation sharing. The engineering functions for highway design have been shared, and in some cases jointly developed, through formal agreements with the City of Minneapolis. The engineering graphics system promises many exciting possibilities. Demands for program and time sharing are already challenging. As software is developed for property descriptions and roadway and utility information is incorporated, it adds to the one call utility program prospect. Sharing of this information is eagerly awaited by both governmental agencies and utility companies. Further programs will make possible accurate data by location for such things as crimes, accidents, fires, etc. Computerized traffic accident reports are now being furnished to the county by the Minnesota Department of

Transportation. To upgrade the present system, through a federal grant, the county is purchasing a microfilm reader/printer. This traffic information will, upon request, be made available to cities for use in their accident prevention and safety improvement programs.

There are many more examples of intergovernmental cooperation I would like to review, but I want to cover two programs that have a long proven track record. First is the Hennepin County Cooperative Purchasing Program. In 1967, seven Hennepin County suburbs, ranging in population from 23,000 to 77,500, joined with the county to form the Cooperative Purchasing Group. All municipalities in Hennepin County were invited to join in mid-1968. The next year the invitation was extended to school districts and other governmental units, such as the Metropolitan Sewer Board and Metropolitan Sports Commission. In 1970, communities from adjoining counties joined the program. In four years, the number had grown to forty-nine agencies. As stated earlier, a legal basis is needed to permit the existence of a cooperative purchasing membership agreement, as well as to commit members to the terms of the agreement. In Minnesota this is possible under a state law permitting a 'joint exercise of powers agreement'. This statute allows two or more governmental units to cooperatively exercise any power common to all and allows one governmental unit to act in behalf of the other participating members. The county was selected to act as the lead agency, taking advantage of their existing purchasing department and greater experience. The first major purchase for the group was automobiles. Gaining concensus for standardization of equipment specification is perhaps one of the toughest of all items. The group, working together, had to compromise to arrive at eight standards for vehicle and engine size, styles, etc. Upon completion, the request for bids was advertized. Nine dealers submitted quotes and orders were made for a hundred and twelve automobiles. Estimates indicate the participating agencies saved from one hundred to seven hundred dollars per unit. Much the same procedure is being used today, except that now the group holds a public auction to dispose of a variety of mobile equipment rather than accept a generally lower trade-in credit. Some of the other major commodities jointly purchased are rock salt, diesel and heating oil, gasoline, signs, grass seed, fertilizer, chemicals, traffic paint, batteries, office furniture and supplies. The cooperative purchasing membership now numbers over seventy. Of this number approximatedly 50% are very active. Insurance of several types is also purchased through the cooperative group. However, this is handled as a totally separate program. Except for the auction of the vehicles, which costs each participant approximately twenty dollars per unit, the county absorbs the full cost of all administration. The added expense above purchasing solely for the county has been vastly offset by lower prices through combined volume purchases. An article describing this multi-agency purchasing procedure, written by Richard Ryberg, Executive Director of the Hennepin County Cooperative Program, appeared in the April, 1980 issue of American City and County.

The second and most far reaching of the intergovernmental cooperation projects is the Minnesota Local Roads Research Program. The legislative frame work was established in the Minnesota rules and regulations for state aid operations under Chapter 500, laws of 1959. Perhaps it is stretching a point to call this a truly intergovernmental cooperative project. However, it was brought about through the democratic process and operates on cooperative efforts and principals. Briefly stated, the Commissioner of Highways (now Commissioner or Transportation) is responsible for the program's administration. The State Aid Screening Committee annually determines and recommends the amount of money the commissioner shall set aside from the state aid funds to be used solely for conducting research in methods of, and materials for, the construction and maintenance of county and municipal state aid streets and highways. The regulation further provides that the commissioner shall appoint a local roads research board consisting of the following: four county engineers, two city engineers, two department of transportation staff engineers, one University of Minnesota staff engineer, and one ex-officio secretary, who shall be the department's research and development engineer. Many needed research projects have been, or are being carried out through this intergovernmental cooperative plan. Suggested research projects are submitted by the county and city engineers. From this list the board makes its selection of research projects and submits its recommendation to the commissioner. The commissioner makes the final determination. I would like to point out two research projects that I feel indicate the "home town" value of the program. Project 618, "REVIEWING AND ABSTRACTING TECHNICAL REPORTS": Technical reports and magazine articles thought to be of interest to state and local transportation engineers are abstracted. About twelve reports are published yearly. Project 645, "IMPLEMENTATION OF RESEARCH FINDINGS": Selected research reports by various agencies are digested and assistance given to county and municipal engineering personnel in implementing appropriate findings. Methods include slide presentation,summary reports, and field demonstrations.

This brief presentation gives an indication of the wide variety of intergovernmental cooperative sharing programs we enjoy. They range from the very complex, as just described, to the very simple. The results have more than justified the effort through convenience, higher levels of service, and dollar savings.

COMMENTS ON INTERGOVERNMENTAL COOPERATION

Samuel F. Lanford, Arizona Department of Transportation

Each year, case histories of various types of inter-governmental cooperation are presented at various conferences or meetings; yet, the practical occurrence of such arrangements are not as wide spread as might be advantageous to our society. Governmental entitles or agencies may often be overwhelmed by the constraints which make cooperative efforts difficult to achieve. Some of the hazards encountered are: ego or authority domination, political antagonisms, legal or statutory, inadequate budgeting, and poor planning or management. When constraints to desirable cooperative programs are property identified, successful solutions can be devised.

Most of the TRB, AASHTO and WASHTO Conferences and Maintenance Committee Meetings that I have attended during the past twelve years have contained papers or discussions presenting ideas on how to perform some maintenance function or activity by some alternate means or procedure to the normally accepted practice. In some cases, these discussions or papers offered case histories of unique multiple jurisdictional utilization of resources in a cooperative venture to achieve common objectives. Frequently I, along with many of you, have attempted to apply some of these presented ideas to our own work problem areas. All too often we have not been as successful as we would have liked to have been. We have discovered constraints in our own environment either not encountered or not recognized in the originator's presentation.

You have heard John Kirtland present some very excellent cases on accomplishing goals through cooperation of various levels of government and through participation of people who have different employers and different objectives. As we say and hear these comments on how people achieve and make their efforts spread over a large base, we wonder why it is not more universal. If it is as simple as has been described by the various papers and previous comments, why do we not all do it? What does it take to get such movements off dead center and going? I think we are often overwhelmed by the many constraints which govern each of us in our own particular political areas.

Some constraints we can overcome by our own efforts, others will take legislative action. One of the major constraints we encounter is ego, pride of authorship or individual authority. Whose's the boss? Who is going to run the show? Many progressive programs have been killed or extremely maimed at birth due to these ego situations. We have all known those individuals who, if they didn't think of it, it wasn't worth a damn. How many times in reviewing a proposal by someone else, we finally conclude, "the guy had a good idea for a start, but I am going to revise his whole program to make it work for me". I can recall the extreme efforts we made to inaugurate a highway maintenance management system in Arizona. Half of the district engineers immediately wanted to revise the entire system to fit their individual ideas for their districts. This, of course, would lose all uniformity in a state program. I also recall some experiences in the early committee planning work for transportation systems in the Salt River Valley of Arizona, when I, as a county engineer, participated with the various cities and towns in the valley along with the state and federal people. There was a dominant feeling by the staff from one of the participating agencies who felt if they weren't running the show as the most important entity involved, the show would not go on. Eventually these problems were surmounted by great effort of various individuals and of good thinking people until objectives were reached.

Frequently, we run into political constraints where either political sympathies or political antagonisms prevent full cooperation or participation in desirable programs. Sometimes these kinds of constraints clear themselves up at the next election. Frequently we live with them and must endeavor to make our progress in spite of these kinds of burdens.

Perhaps the greatest constraints are the legal constraints that are imposed on each of us who work in government. I once had a lawyer explain to me exactly the definition of legal constraint. I wanted to accomplish some useful purpose and he advised me that this could not happen under the existing legal constraint. I responded something about being prevented from running this particular operation like a business and solving my problems efficiently and economically. The lawyer replied, "Lanford, you do not run government like a private business. In business or in your private life, you may do anything, you may do what you please without external controls, unless our legislative bodies have enacted a law making it illegal. However, when you work for government, it is the reciprocal of such a situation. In government you are not authorized to do anything unless it is specifically enabled or required by the statutes. In order for you to proceed as a government employee with any endeavor, it must be directed or enabled by the State Legislature, the Congress, the Courts or other lawful government. Thus, you can see there are many areas in which we might easily achieve the goals desired except that no law has been passed which allows us to do so.

Endeavors of multi-jurisdicational cooperation must also be adequately planned in order to circumvent all possible constraints. The programs must be well thought out and organized in advance as to exactly what is to be achieved, who is to manage or direct, who is to participate, and how it is going to be paid for, and when it is going to be accomplished. Back in my county engineering days, I could always count on receiving a phone call about the middle of August from a school superintendent saying to me, "Lanford, we are going to open a new school on September 1st. It is out in the middle of the section, and there aren't any roads leading into it. How are we going to get our school buses to the school. We are opening in two weeks". This event seemed to occur every year at mid August regardless of the notice I gave to the various educational institutions and offices that any road planning had to be done at least one year in advance. As you can well appreciate, these crises situations are solved by stopping ongoing work, by rushing in and losing all of the efficiencies gained by organization and planning. We always managed to get the school buses to the schools; but, frequently over very primitive facilities. Then there was always the hassle of getting the proper access designed and constructed simply because someone forgot to coordinate planning.

During the last decade or perhaps longer, most states, many counties and cities, have adopted maintenance management techniques and systems. I have found since we implemented and perfected our state highway maintenance management system in Arizona, the areas of cooperation and participation with other agencies or political subdivisions has been much enhanced. We are now more capable of predicting and performing our share in an intelligent manner. A few years ago, the State Park Department came to the Department (ADOT) and said they had many roads, parking lots, and driveways extending from a few hundred feet to eight or nine miles in length that are part of the state parks system. However, their organization being park oriented, did not have road equipment, maintenance equipment or the knowledge and skill to perform the work activities necessary to maintain and preserve their street and road system. They were proposing that the Department of Transportation take these facilities over. This is where we bumped into our first legal constraint. Maintenance funds for the Department of Transportation are generated out of the fuel revenues and other such related taxes and are specified to use only on the state highway system. The requested service could not be considered by law, unless the State Board of Transportation would declare these park systems into the state highway system. This would reduce authority of the park services on those facilities. The parks people didn't want to have their authority within the state parks watered down by that sort of arrangement. A study of the state parks proposal was made. Using maintenance management techniques, the total resource needed and a schedule to accomplish the needed activities was defined. This was presented to the Legislature who made a budgetary agreement. They budgeted funds for the State Parks Department to be transferred to the Department of Transportation under an inter-governmental agreement which was initiated and executed for the Department of Transportation Maintenance Froces to maintain these parks facilities within the various districts. This has worked very well. Our recording system has a suffix to designate the parks identified work activities. It is all computerized. It comes out in a report and monies are transferred from the State Parks Department to the Department of Transportation Maintenance Fund for accomplishing these activities. In this matter, we are also able to provide the appropriate amount of manpower and equipment resources without robbing the highway of their activity needs.

Inter-agency or inter-governmental cooperation can frequently be the answer to the most efficient and economical use of available resources to achieve desired objectives. However, there is more to it than just agreeing to do so. We must consider all of the constraints that are involved. Planning cooperative programs must be thorough. All financial agreements should be budgeted and programed in advance. The advantages of the proposed activities should be well defined so that political oppositions can be minimized. Managerial authorities must be established, but most important of all, the legal authority to do what is intended needs to be thoroughly ascertained in advance; and, if necessary, legislative action should be recommended to make the proposed activities legally responsible.

We must always keep in mind, the citizens we serve frequently are the same people regardless of which institution or political subdivision we may be representing. The motorist as he drives down the highway does not readily identify or react to a political boundary or a change in jurisdication. The average citizen normally does not care from whence the money is derived or who provides a service as long as the benefits are there. With the high inflation rate we all have been suffering these past few years and with the continued deflating of our ability to achieve normal results; it behooves each and everyone of us to make every effort to make our community's meager resources extend further to accomplish necessary services. The very idea of joint community use of resources available may extend each of our goals to areas of fuller service with more economical advantages than we can by each going their separate way.

MAINTENANCE DATA

John S. Jorgensen

The questions of what type, how much, how accurate, at what cost, and for what purpose--related to maintenance data--are timely. Maintenance management has evolved in the last 30 years from a 1951 federally financed work methods research study in the Connecticut Highway Department through the development and implementation of sophisticated maintenance management systems in most of the states in the United States. Since the first comprehensive system was designed and implemented almost 15 years ago, much has been learned about making systems more effective. Many modifications have been incorporated. Many additional opportunities for improvement still exist.

Recent discussions have centered around the types and amounts of data necessary for the effective management of the maintenance function. These discussions have been motivated by the following realizations:

1. Reporting requirements have become so detailed that field input data are often invalid and therefore raise serious doubts about report credibility;
2. Existing systems generate reports too numerous and voluminous to provide practical assistance in managing maintenance operations;
3. Expectations regarding data accuracy exceed the practical abilities and/or capacities of the field recording personnel;
4. The full costs of maintenance data collection have become excessive when the very real costs of frustration and the resulting loss of interest by the field personnel are included; and
5. Emphasis has been on computerized reports for upper- and middle-management whereas management system effectiveness depends on lower-level managerial control.

Some proposed solutions to these developments include simplifying data input processes by using hand-held portable recording devices. It has also been suggested that solutions lie in the development of improved management report formats. These certainly represent opportunities that warrant pursuit. However, there is a more basic need to step back and reassess the types, amounts, and accuracy of that maintenance data necessary to effectively manage operations.

Satisfying that need for reassessment involves a look back at the results of the maintenance management research conducted some 15 years ago. The purpose of this is to once again identify those factors most influential in determining maintenance effectiveness. It is the collection of data related to those factors with which maintenance management reporting systems need to be primarily concerned.

The intent of this paper is to stimulate thought about and suggest an approach to reevaluating maintenance management reporting systems through

1. A review of the key management factors;
2. Consideration of how much reporting detail is enough;
3. A review of the full costs of reporting systems; and
4. A review of their use to field management.

KEY FACTORS

What, then, are the data needs that are practical and key to effective operation?

Early maintenance management research findings identified the influence of management decisions on the costs of maintenance. Managers' decisions regarding work methods, crew sizes, and service levels were defined as major determinants of cost effectiveness.

Figure 1 illustrates the point well. Two management units, "A" and "B", in one agency were selected as being comparable in terms of work load, traffic volume, traffic type, age of pavement, weather, and terrain. The managers of both units reported to the same supervisor. The supervisor, upon questioning, felt both managers were performing satisfactorily and results were equal. The supervisor's conviction as to comparability was further demonstrated by his allocation of essentially equal financial resources to both units "A" and "B" ($879.58 and $894.09 per mile, respectively). Yet from an evaluation of the ways in which each unit manager expended his resources, it is apparent they made different "management decisions" affecting costs.

Given the comparability of all other factors, each supervisor's decisions regarding crew size, work method, and/or service level had significant economic impact. A combination of those decisions resulted in unit "A" expending (a) 50 percent less on surface work; (b) 50 percent less on shoulders;

Figure 1. Comparison of per-mile maintenance costs for units A and B.

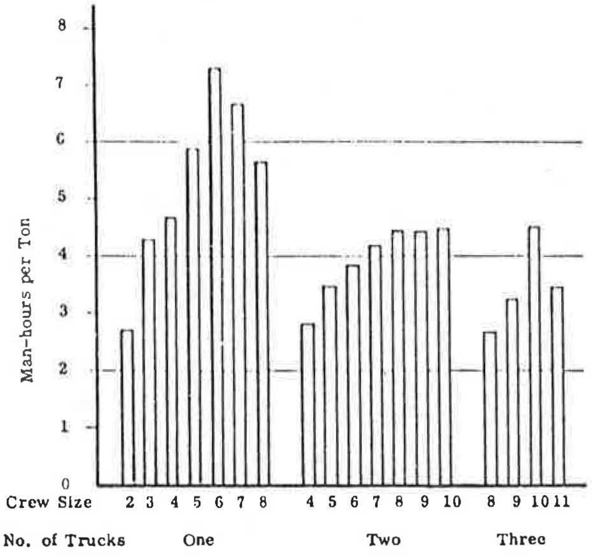
Maintenance Activity	Total $/Mile Unit A	Total $/Mile Unit B
Surface	$ 85.20	$166.10
Shoulders	94.92	176.33
Mowing	102.82	83.41
Forestry	39.03	83.80
Clean R.O.W.	43.52	57.61
Parks and Picnic Sites	30.70	.63
Drainage and Structures	251.39	138.40
Bridges	44.83	4.54
Signs	115.01	98.66
Other Miscellaneous	72.16	84.61
TOTAL	$879.58	$894.09

These are three-year average annual costs.
Units A and B are adjacent with comparable roads and terrain.

Figure 2. Productivity related to staffing (man-hours per ton of premix patching).

Organization Unit	One Truck Number of Men in Crew 2	3	4	5	6
1	7.27	10.57	12.38		
2		7.48	10.23		13.18
3		11.06	13.82		15.39
4	5.05	5.73	10.40		
5	2.95	3.05	3.85	4.20	5.86
6	6.57		11.23	11.40	15.69
Average All	3.34	4.12	6.17	8.82	11.60

Figure 3. Productivity related to staffing (man-hours per ton of skin patching).



(c) 25 percent more on mowing; and (d) 50 percent less on forestry--to point out just some of the differences. The significant point is that the results--as far as their supervisor was concerned--were both satisfactory and essentially comparable, yet the differences from a cost-effective standpoint were striking. This example from early research in Ontario, and duplicated in numerous agencies since then, represents convincing evidence that management decisions regarding what is to be done (service level) and how it is to be done (work method and crew size) are key controllable determinants to effective highway maintenance management.

Work method decisions affect the crew size, equipment types and numbers, and the material types and quantities that are required to perform a maintenance activity. By ensuring the consistent selection of the most appropriate method, major cost and effectiveness factors are predefined.

Figure 2 illustrates the clear impact of various crew sizes on the productivity in one agency for one activity--premix patching. The average productivity--as measured by man-hours per ton of materials placed--ranges from a low of 3.34 for a crew size of two, up to a high of 11.60 for a crew size of six. Crew size, a controllable variable, obviously has a direct impact on productivity and therefore is a key factor in effectiveness.

Figure 3 illustrates the effect on productivity by varying both crew size and truck complement for one agency's skin-patching activity. As seen in Figure 3, a direct and significant relation exists between the crew size, equipment complement, and resulting productivity effectiveness.

The results of differing service level decisions being made by individual supervisors--in the absence of guidance--is illustrated by the data in Figure 4. Work quantities are used as a measure of service level. Mowing quantities on high-type, two-lane roadways are shown for each of nine management areas. A low of two mowings, a high of seven, and an average of three and one-half point out significant service level variations. Accepting some influence by variations in rainfall, the remaining variations in service levels and resulting cost effectiveness identify work quantities (service

Figure 4. Typical mowing quantities on high-type two-lane roadways.

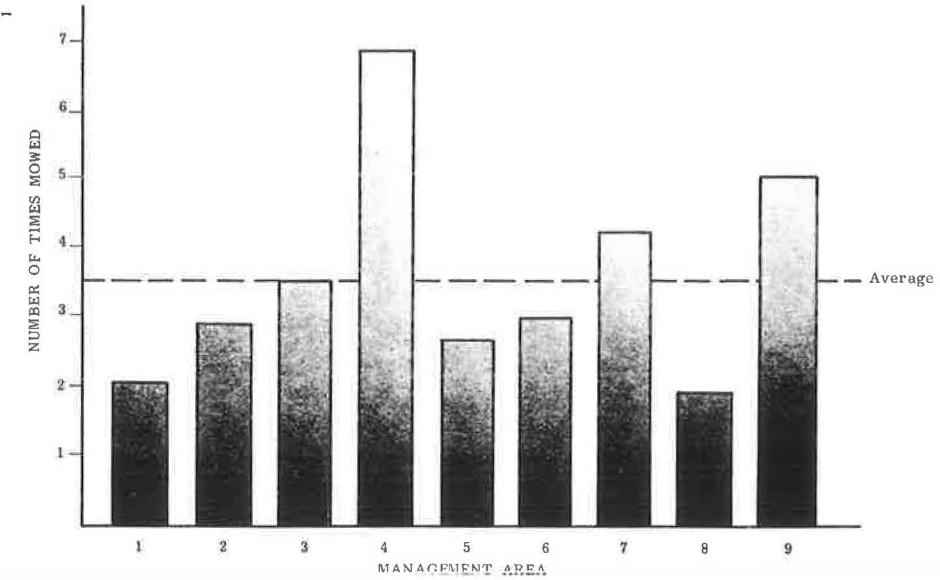


Figure 5. Example of the vital few maintenance activities.

Activities	% of Total Dollar Expenditures	Cumulative % of Total Expenditures
1. Snow & Ice Control	39.2	39.2
2. Asphalt Patching--Manual	9.7	48.9
3. Asphalt Patching--Mechanized	6.1	55.0
4. Base Repair	5.5	60.5
5. Surface Treatment--Mixer Paver	4.3	64.8
6. Surface Treatment--Liquid Bitumen	3.5	68.3
7. Unpaved Shoulder Patching	2.5	70.8
8. Ditching	2.4	73.2
9. Sign Installation and Repair	2.0	75.2
10. Stabilize Unpaved Shoulders	1.9	77.1
11. Brush Cutting	1.5	78.6
12. Pipe Placement	1.4	80.0
13. Shoulder Grading	1.3	81.3
14 through 140 Activities	18.7	100.0%
	100.0%	

Figure 6. Maintenance man-hour distribution for organization units, fiscal year 1979.

Reporting Category	UNIT "X" % Man-hrs.	UNIT "X" Est. Labor Cost	UNIT "Y" % Man-hrs.	UNIT "Y" Est. Labor Cost
PRODUCTION	64.2%	$2,118,356	59.3%	$1,181,089
SUPPORT:				
Travel	0.9	29,676	1.8	35,850
Other Types	34.9	1,151,566	38.9	775,137
GRAND TOTAL	100.0%	$3,299,598	100.0%	$1,992,076

levels) also as key controllable factors.

In summary, it is apparent from research findings that the key controllable variables in highway maintenance management are service levels, work method, and crew size. Therefore, maintenance management systems must focus on data about these key factors.

HOW MUCH DETAIL?

Several considerations limit the amount of data detail that should be routinely collected for purposes of managing maintenance. The first is the limit all managers have on the time that can be devoted to data review and evaluation. A manager properly using his time cannot routinely get involved in the small details of operations. His attention must be directed toward those operations of greatest importance from the standpoint of resource expenditures. By so doing, he limits his focus of attention and maximizes his impact and effectiveness.

Figure 5 illustrates this point by ranking the activities of a maintenance organization by the percentage of total dollar expenditures in descending order. It is apparent that of the more than 140 maintenance activities identified and programmed by that agency's maintenance management system, 13 account for 81.3 percent of the effort. By directing primary attention toward the effective performance of those 13 activities, the manager will maximize his limited time and attention. Data-collection requirements, procedures, and report formats should be designed to assist the manager in maximizing his energies and effectiveness.

A manager's time to evaluate data is not limitless. A field recorder's ability to record field operations in detail is also not limitless. Experience has shown that the greater the detail requested, the lesser the validity. This occurs because typically the recorders are working members of the crew or supervisors who already have other pressing demands on their time. The recorders likely see no practical value in highly detailed data requests and, therefore, are not inclined to conscientiously record the detail. Assuming an enlightened supervisor, he may judge his time identifying maintenance needs, ensuring consistent use of best work methods, and scheduling work as taking priority over detail recording.

Figure 6 seems to illustrate the results of unrealistic expectations for two organizations, units "X" and "Y" in one agency. In addition to recording the maintenance activity worked on, the field recorder in that agency also is required to record production time separately from support time. Further detail is required regarding whether the support work is hauling, safety, travel, or other. The data in Figure 6, taken from the agency's records, show, over the one-year period covered, an average of 0.9 percent of the man-hours was expended on travel in unit "X". Unit "Y" expended 1.8 percent on travel. Expressing this in other terms means that on the average, each crew

Figure 7. Sample of one agency's snow and ice control activities.

Activity	Unit of Measure
1. Plow with a truck	Miles
2. Plow with a grader	Miles
3. Plow with a loader	Miles
4. Apply abrasives	Miles
5. Apply salt	Miles
6. Plow and spread simultaneously	Miles
7. Wing back	Man-hours
8. Patrol	Miles

NOTE: Excludes material mixing activities, and snow fence erection and removal.

member in unit "X" spent only four minutes in a travel status each day and eight minutes per day by unit "Y" personnel.

When expressed in minutes per day, the time reported for travel to and from work sites is of questionable validity. Obviously, the expectations exceed the recorder's ability or willingness. Perhaps the recorder fails to appreciate the value in such detail or feels that such data might be better obtained by sampling techniques.

The value of the data in planning and controlling work should also limit the amount of detail that ought to be routinely collected by a reporting system. In Figure 5, the snow and ice control activity represented almost 40 percent of total expenditures for maintenance activities for one agency. In that instance, how much detailed data should be routinely reported for that activity? Such major importance suggests justification for reporting considerable detailed data.

Figure 7 shows the detail required by that agency--eight separate activities. This detail implies that the snow and ice control activities can be planned and controlled in great detail. Unfortunately, that is not the case. Because of the great unpredictability of snowfall occurrence and intensity, development of a maintenance work program and controlling against that plan is at best an interesting academic exercise. Collection of detail data for those purposes must be recognized as contributing to that sort of exercise--not as bases for meaningful evaluations of performance. In addition to the questionable value of the data for planning and control purposes, it must also be recognized that information recorded under storm conditions must be of questionable accuracy.

It is generally recognized that effectively managing snow and ice control activities lies in developing good routing plans, appropriate treatment strategies, and providing field supervision during storm conditions to ensure the plans and strategies are properly implemented. After-the-fact data are of little value for evaluating performance.

When considering the amount of detail that is appropriate for routine recording, it is necessary to realistically consider the limitations of the recorder and the practical value of the data for planning and controlling the specific highway maintenance activity.

AT WHAT COST?

To a large extent, the cost of data collection is a function of the detail required. Historically, the costs recognized as significant include the time of the recorder, the time of his supervisor in reviewing the data, clerical review time for completeness, cost for manual and/or machine processing, and time for review of prepared reports. With the improved efficiency of computers, the direct unit costs for data processing have encouraged further application. Computer capabilities have also increased tremendously in recent years. The combination of reduced unit costs and increased capabilities contributed to sophisticated system designs that require detail data. As a result, indirect costs have begun to play significant roles.

One of those indirect costs relates to the indirect--but very real--cost of reduced field staff motivation. As data-collection requirements imposed on field personnel become excessively detailed or unrealistic, the desire to do a conscientious job is affected. Often the loss of that desire extends beyond the area of reporting. It can be reflected in a loss of interest in such vital areas as the use of standard crew sizes and work methods.

Similarly significant indirect costs occur when the middle managers frequently question the credibility of highly detailed and presumably accurate reports they receive. Once this happens, the intended purposes of the reports are likely no longer served. Managers are then forced to short-circuit the system and generate their own bootleg reports to satisfy the key management requirements.

When either of the above indirect costs are observed, it is past time to reevaluate the maintenance management reporting system.

In summary, it is the indirect costs of reporting systems that have become significant and in the process strongly suggest the need for reassessment.

FOR WHAT PURPOSE?

To this point, the focus has been on identifying the data crucial to effective field management. Of equal importance is the need to recognize the proper role of that data in guiding the management decisions of the first-line supervisors.

Effective management of field maintenance operations is achieved when the first-line supervisor knows what service levels to provide (as defined in his work program), and what crew sizes and work methods to use (as defined in standards). In addition, he must be constantly aware of how his actual performance compares with the work program and standards. That kind of feedback is vital if the first-line supervisor is expected to manage to those objectives. To be useful, these data must be timely and serve as the bases for the short-term (weekly or biweekly) scheduling processes.

Timeliness of the data is most important. Monthly or quarterly summary reports are not satisfactory. Weekly computer or manually prepared data reports are a must if the scheduling process is to be meaningful and continually directed toward the objectives.

In addition to the need for short turnaround times, it is necessary that the short-term scheduling processes themselves are designed to direct first-line supervisor attention toward work program and standard compliance.

It is necessary in the reevaluation process to both identify the key management data and also to provide for and ensure its proper use. Unless both functions are performed by maintenance management staff and operating personnel, systems will continue to operate at less-than-full effectiveness.

OTHER DATA REQUIREMENTS

It is recognized that maintenance management systems in some cases are expected to provide data for other purposes. Two of the more frequent sorts of data requests relate to fiscal data and research data.

The process of incorporating those needs with maintenance reporting systems must be done with great deliberation and recognition that the end result should serve all functions in the most cost-effective way--including consideration of all indirect costs.

For example, the nature of research data is such that they are unique and highly detailed, require absolute degrees of accuracy, usually involve specific locations or operations, and are of a specific time duration. Because of their nature, research data needs can frequently be satisfied without imposing additional reporting requirements on existing maintenance reporting systems. Sometimes the solution is a specially designed data-collection system and special recorders or the development of a sampling plan. Whatever the solution, it must avoid jeopardizing the integrity of the basic agencywide maintenance reporting system.

Close scrutiny of data requests tends to eliminate "nice-to-know" information and the associated direct and indirect costs.

SUMMARY

Maintenance management systems developed over the past 15 years deserve continual review. They are crucial to the management of millions of dollars of maintenance expenditures annually. Improved design features--developed in recent years--must be incorporated to ensure continued effectiveness.

One of the basic system elements currently in need of reevaluation is the reporting system element. The basic maintenance management research of 30 years ago provides direction for that reevaluation by identifying the management data related to service level, work method, and crew size as the keys to effective management. More recent experience with the consequences of excessive reporting detail suggests the need to carefully re-define data needs. Recognition of the relative significance and controllability of specific maintenance activities is important. Important also is consideration for the practical limitations on the time and capacities of the field managers and field recorders.

The significant costs of data collection must now be recognized to include the indirect costs resulting from ineffective systems. Those indirect costs include reduced field staff motivation and lost management report credibility.

To date, considerable emphasis has been placed on computerized reports for upper and middle management. However, management system effectiveness depends on lower-level management control. It is toward improvement of the first-line supervisor's managerial control that reporting system reevaluations must direct attention. In addition to identifying the data crucial to the management decision-making process, that attention must also ensure that the scheduling processes and procedures are in place and functioning.

ROAD NEEDS STUDIED IN ONTARIO

E. R. Simonen

Funds are provided to municipalities by the Province of Ontario to subsidize road maintenance and construction of roads under the municipality's jurisdiction. The province also is responsible for the maintenance and construction of its own highway system. This is funded separately.

For most of the larger municipalities, the funds are allocated on the basis of (a) the condition of the roads as measured by the "needs study" and (b) the capability of the municipality to provide funding through its local taxing capability, as measured by its total assessment. The level of subsidy varies between 50 and 80 percent of the expenditures for maintenance and construction. A maximum subsidy is established from the needs study and "fixed costs" based on historic maintenance expenditures.

The needs study is updated annually. It involves breaking the road system into sections of similar characteristics. Each section is evaluated and any deficiencies are identified, costed (according to bench mark costs) and the timing of the needed improvement estimated. The timing is broken into three time categories: now, 1-5 years, and 6-10 years.

The province's stated policy is to maintain the road system at its current level of adequacy (or lack of deficiency). The total amount of needs in the now time period for all municipalities indicates the level of adequacy of all municipal roads. The amount of subsidy in relation to the needs can be established as a percentage of needs. Funding is based on the now, plus 1-5 year deficiencies, with a five-year objective established. For example, recently the province's objective was to provide funds to eliminate 45 percent of the now plus 1-5 year needs over a five-year period as the construction portion of its allocation. This percentage has now been reduced to 30 as a result of the most recent information updating.

Maintenance funding is based on historic spending and a determination by the province of the estimated fixed cost is adequate.

Once the total spending objective has been established, the province and the municipality contribute equally up to 1.25 mills based on total assessment. The unmet needs are funded by the province at 90.9090 percent. The amount of subsidy can vary between 50 and 80 percent. An example calculation follows. A municipality received subsidy based on the following: (a) needs--6 percent of now and 1-5 year needs (e.g., $30 million = 1.8 million; and (b) fixed cost--based on historic maintenance spending = $1.7 million. The total spending objective then is $3.5 million.

Next, the municipality's ability to provide matching funds is evaluated. If its total assessment is $200 million and a standard mill rate of 1.25 mills is applied, the local effort at 50 percent subsidy would be $2.5 million. A matching contribution from the province would result in a total effort of $5 million. Because this is greater than the total spending objective, its subsidy rate would be 50 percent. However, if it were a poorer municipality with similar needs, the following might occur. Suppose its assessment was $100 million, then its local effort would be $1.25 million. The province's matching contribution results in a total effort of $2.5 million with a spending objective of $3.5 million; this results in $1 million of unmet needs that are funded at 90.90909 percent. The total subsidy would therefore be $1.25 million plus $909 090 or $2 159 090, resulting in an optimum subsidy rate of 61.7 percent. There is a restriction that the optimum subsidy rate (total subsidy divided by total spending objective) cannot exceed 80 percent.

The municipality is not obligated to spend the construction portion of its subsidy on construction nor the maintenance portion on maintenance; however, it cannot be spent on non-road items.

For more information, contact John Moffat, Manager, Municipal Roads Office, Ministry of Transportation and Communications, 1201 Wilson Avenue, Downsview, Ontario, Canada. A manual explaining the process in detail is available.

General Comments

SESSION A--STANDARDS
(Raymond A. Zink, moderator)

When we use the term level of service, it is necessary to define that term because level of service and quality standards are sometimes used interchangeably when, in fact, they may not be synonymous. For example, a level-of-service standard may indicate that "a shoulder drop-off shall be repaired when a differential of 4 in exists." The quality standard for that situation may be "Shoulder drop-offs shall be repaired using Class IV mix except in those cases where the shoulder subbase is saturated. In those situations, Class III aggregate shall be used to level the shoulder until such time as the subbase regains strength. When the subbase regains strength, then Class IV mix will be used to effect a final repair."

Ronald Kulkarni indicated that various items, such as safety and aesthetics, could be weighted to aid in a decision process relative to a standard. In fact, such factors as a change in administration or a shift in public attitude may influence the setting of standards as much as any single internal item. Funding restraints and other legislative restraints, such as reduction in manpower, will also weigh heavily in establishing standards.

Concerns about possible tort action are increasing the importance of when standards are established. It appears that the courts are interested in whether or not standards are reasonable, and not what the budget could afford. Also, the courts want to know how well established standards are adhered to.

Several states have applied the principle of industrial engineering in analyzing their maintenance crews. Some states have used video tape rather than movies as used by Florida. Video tape was effective when it was used as a training tool as well.

Some states have used time-lapse photography. It greatly reduced the time required to review films. In many instances time-lapse photography spotlights the idle worker and makes him more noticeable when analyzing work procedures.

Crews seem to react better to being photographed rather than being checked by the clipboard-and-stopwatch method. Even though movies produced some actors, this method still provides a valid basis for analysis and the films are also available in the training process.

In assessing the impact on the highway systems and the users of that system, we need to know the results of the use of standards. There appears to be a lack of data relative to the impact of various standards. Even though some data are available in other states or other countries, the mathematical analysis may be rather intricate for the everyday standards engineer.

SESSION B--MEASURING PERFORMANCE
(George M. Briggs, moderator)

One of the final steps in the management process is to assess your accomplishments. We need to know if we are doing the work that needed doing, if the projects we set out to do are accomplished, to what degree our factors of production are being utilized and if the management system is managing the organization, or if the organization is managing the system.

Four different methods of performance measurement were presented by five panelists during this workshop session.

Charles Barbee of the New Mexico Highway Department presented that department's method of rating the effectiveness of their system of managing resources. Each management unit was judged on its effectiveness in two important areas--One for its adherence to its annual work plan by quarters and the other for that management unit's adherence to standard crew size for important operations. This evaluation technique was misnamed "Foreman Score Card"--a fact that Barbee cautioned caused many problems in acceptance of the concept. Although a foreman's ability to schedule and supervise is measured by this system, other very important attributes of a foreman are not rated, such as consistency in meeting quality standards and his ability in personnel and public relations. On the other hand, the system was influenced greatly by things beyond the foreman's control such as budget reductions, inadequate training, lack of resources, incorrect standards, and lack of equipment. Many attendees are under pressure to develop a method to rate foremen for "bonus" purposes and they were cautioned by Barbee that an incorrect application of this system could result in loss of morale and "penciled" accomplishments. The evaluation system is computerized and comes off as a product of the Highway Maintenance Information System so it is not costing a great deal of effort. Its benefit is that it causes supervisors to perform in-depth analyses in order to find out why a foreman has a low rating. This discovery often leads to correction.

Mohammed Shahin has developed a pavement rating system for the U.S. Air Force and the U.S. Army pavement management systems. The system first identifies the network and divides it into segments of uniform structural composition and condition. The number of sampling units required for each segment is determined. The location of the site to be inspected on each sampling unit is determined by using either the "stratified-random" or the "systematic-random" technique. A very complete examination is then made of each site of the distress of the pavement. This includes the type of distress, the severity of the distress, and the density of the distress. The index used is called the Pavement Conditions Index (PCI). Weighted values are assigned to the elements of distress and used as a deduction from the maximum possible PCI. Each sample unit then has a PCI value recorded. By the use of frequent sampling, the deterioration of a given section is available. The effect of various maintenance and rehabilitation techniques on PCI is determined. The objectives of the system then are that the current condition of the pavement system is known, maintenance and rehabilitation needs can be determined, and priorities established. The system also enables them to determine consequences of various actions and non-actions so that long-range plans and budgets can be established.

Charles Dougan of the Connecticut Department of Transportation discussed photologging as a maintenance management tool. Their basic system is composed of 35-mm color frame slides taken each 0.01 mile with a camera mounted in a van. The route, direction, and cumulative mile point are indicated on the film. One-third of the system is updated each year. Film libraries are available at various offices of the Connecticut Department of Transportation and are widely used by people in traffic and design, as well as maintenance. Specific maintenance uses are in investigation of high-accident area locations, geometrics, signing, dangerous fixed objects, and adequacy of pavement markings. The system is expanded to railroads through the use of a similar system mounted in a high-rail vehicle.

Attendees were concerned that such a record could lead to its use by lawyers in claims against the state. New Jersey indicated that it can be used as a defense against a claim as often as it is a weapon for the claimant.

A citizens' survey in Pennsylvania found that the condition of the highways was one of the major concerns. The administration desired that a survey be made of the condition of the highway system and also to provide a mechanism to measure performance on a continuing basis.

Personnel from Pennsylvania's Department of Transportation Operations Review Group and Pennsylvania's State Transportation Institute set about developing the system as a joint endeavor. They developed the "Trained Observer" approach. That used laid-off construction inspectors to physically inspect, in detail, a number of conditions on a sample of highway sections in each of the state's 67 counties on a periodic basis. This approach was chosen since it offered the advantage of low initial investment, quick results, ability to survey many highway elements, and the ability to define limits of deficiency and both the kind and degree of stress.

A team set a 3 percent sample of the system twice a year for a total sample of 6 percent for an initial goal. Certain patterns are already emerging--for example, substandard conditions may be more influenced by geographic locations than they are by abstract boundary.

Attendees were concerned with the use of outsiders to evaluate maintenance instead of maintenance personnel. The Pennsylvania Department of Transportation indicates that it wants to avoid burdening maintenance with more work and to ensure neutrality. The random selection of sampling sites will continue with each survey so that there can be no "manipulation of conditions" such as could occur if the same site was used for each inspection.

Ultimately, the system could be used to better allocate maintenance and repair funds. It was noted that the system could be used to defend itself against a charge that one area was overstaffed versus another. Attendees were apprehensive that such a system penalizes the good manager and rewards the poor one by giving him a larger share of the budget. Substantial interest was also shown in the possibility of using this system as a means of predicting the costs of not performing various maintenance operations. There is need to be able to determine the consequences of various actions or lack of same. The conclusion was that this system might be a first step toward that goal.

The general consensus of participants seemed to be that there is a definite need for more timely and accurate performance-measuring systems and that the systems and techniques described at this session represent a substantial contribution to that end.

SESSION C--ELECTRONIC DATA PROCESSING
(Louis G. O'Brien, moderator)

Maintenance management systems are dynamic. Essential data identification, collection, processing, analyzing, and adjusting are changing as the use of these systems rapidly changes. The explosion in microprocessing equipment, remote terminals, and main frames has reduced the time and cost of data processing. The fear is that we may be drowned in data.

Modeling a highway maintenance organization represents a leading edge of technology that simulates the allocation of resources. This systems approach to changing the resource mix enables an organization to conduct what-if analysis at low cost and without any impact on operating organizations. The model development includes a front-end software package that will permit non-electronic data-processing (non-EDP)-oriented managers to perform planning and programming analysis. This EDP tool will undoubtedly have applications in budget development, routine work planning, and resource planning and allocation.

Concerns were expressed about the practicality of this technique. Can the manager in a staff or a line position use this to help him do a better job quicker? The answer appears to be maybe with a properly conceived data base and information flow, an easy-to-understand input program, and proper training and motivation.

Maintenance data collection, processing, and use represent a large investment in time and money. What type? How much? How accurate? At what cost? These are questions whose answers are not easy and are not the same for each highway maintenance organization. Accounting information, executive need-to-know, and line-manager control dictate different data requirements. Maintenance managers must periodically review data requirements and uses. It is important to have first-line supervisors' needs and concerns included in the data-collection and reporting systems.

Transportation agencies are being pulled in opposite directions by fiscal constraints. The need to work "smarter and harder" creates a need for information on what, where, and how work is performed. Analysis of this data may lead to ways of improving productivity. The need to cut costs calls into question the need for data analysis, and systems development pulls us in the other direction.

SESSION D--GENERAL TOPICS
(Charles O. Leigh, moderator)

Session D examined five topics of general interest. All topics evoked questions and discussion. These are briefly summarized here.

Identifying maintenance needs was concerned primarily with planning at the level of first-line supervisors. The general consensus of the participants was that effective planning at this level was a problem common to many highway and transportation departments. Several state representatives discussed their planning procedures, and it appeared that many states are still looking for improved planning procedures.

Alternate equipment designs prompted discussion of the methods used to purchase equipment. The participants indicated that the low-bid process that most states use does not always provide the type of equipment needed. Factors that should also be considered are cost per unit of work that the equipment can perform, quality of work, quantity of work, and fuel efficiency.

Purchasing procedures do not usually take these factors into consideration, and a research project may be applicable in the development of improved purchasing procedures.

Risk management provides an approach that may have many applications in transportation operations. It could prove a useful tool in formulating standards, establishing priorities, and preparing work plans. From the discussion, however, it appears that this concept as applied to highway maintenance is in its infancy. Research is needed to provide basic data for the system.

Achieving intergovernmental cooperation and intergovernmental relations were discussed jointly because they are closely related.

Discussion revealed that most departments, to some degree, have cooperative projects with other government agencies. There was also a consensus that departments need to explore additional avenues of intergovernmental cooperation in order that we may make the most efficient use of all resources.