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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

58

CONSEQUENCES OF DEFERRED MAINTENANCE

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
ADMINISTRATION
MAINTENANCE
(HIGHWAY TRANSPORTATION)
(RAIL TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. MAY 1979

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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

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

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

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation
Research Board

This synthesis will be of special interest and usefulness to maintenance engineers, highway administrators, and others seeking information on the effects of deferring maintenance activities on highway facilities. Information is presented on economic, energy, esthetic, and safety impacts.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Expenditures for maintenance are not keeping pace with the needs of the

nation's highways. Desirable maintenance activity is not being carried out, and the backlog of work needed to restore the facility to good condition is growing. Difficult judgments must be made in deciding to defer maintenance. To effectively manage a maintenance program, levels of service must be able to be defined, measured, and evaluated. This report of the Transportation Research Board reviews concepts for quantifying maintenance needs, setting priorities, and developing strategies. Relevant studies in progress are discussed and additional research needs are outlined.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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Adrian G. Clary, Engineer of Maintenance, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

CONSEQUENCES OF DEFERRED MAINTENANCE

SUMMARY

The magnitude of deferred maintenance and the consequences of these actions are of intense interest to highway administrators, legislators, and highway users. Between 1967 and 1977 there was only a 10 percent real increase in maintenance expenditures while vehicle registrations and vehicle-miles traveled increased by about 50 percent; 160,000 miles (250 000 km) of highway were added to the system; and allowable truck weights were increased.

The consequences of many current decisions to defer maintenance are unknown, but new management concepts are evolving. Because analytical systems are inadequate and data are insufficient, many decisions to defer maintenance are essentially judgmental. Recent studies have attempted to quantify maintenance needs, develop maintenance strategies, and set priorities. The object of these studies is to give management information on the relative merits of various maintenance programs and thus allow the one with the most acceptable costs and impacts to be chosen.

Maintenance service levels must be defined and practical field measurement systems designed to identify and quantify deferred maintenance. There are several reasons why this has not been done effectively in many agencies. First, maintenance levels of service are sometimes difficult to define. Second, these levels are not easy to measure. Third, the levels are difficult to evaluate. Currently a number of agencies are defining and measuring maintenance levels of service.

A distinction can be made between deferring maintenance that is cumulative and ultimately must be done if the facility is to be restored to good condition and deferring, reducing, or eliminating maintenance activities that affect primarily esthetic or functional characteristics of the highway. Because of accelerated deterioration, deferral of certain physical maintenance activities, such as pavement and bridge repairs, may represent added costs rather than a savings.

The absence of data and evaluation procedures for many aspects of maintenance impact provides an open field for research. One research area would be maintenance vs. reconstruction and, specifically, what are the costs and benefits of various levels of maintenance. A practical, consistent, and economical procedure for measurement of maintenance service levels is also needed. Finally, the relationships of all major maintenance activities to maintenance service levels need to be studied.

There is a significant trend toward deferring maintenance on U.S. highways today. The impact of this deferment is not fully understood but is being studied. None of the available management techniques is free of variables that depend on judgment. But the management decision process is being structured through evolution. Out of that structure, managers can achieve a better understanding of the impact that their decisions will have on our highway systems, on the highway users, and on the economy, society, and environment.

CHAPTER ONE

INTRODUCTION

Currently, maintenance is being deferred on a major portion of the highway system in the United States. The magnitude of the uncompleted work and the consequences of this action are topics of intense interest to highway administrators, legislators, and highway users. In response to that interest, information from state and other highway agencies was studied for this synthesis to identify and evaluate current practices, policies, and technology being employed or developed to manage maintenance programs and reach decisions on deferment alternatives.

While nationwide maintenance expenditures rose from $3.8 billion in 1967 to $8.4 billion in 1977, the value of the dollar over that same period of time decreased by 50 percent. In terms of comparative purchasing power, only $4.1 billion 1967 dollars were spent for maintenance activities in 1977, or only about 10 percent more than in 1967. During the same period of time, the number of registered vehicles increased 48 percent, vehicle-miles of travel increased approximately 51 percent, an additional 160,000 miles of highways were added to the system, and federal legislation increased the maximum allowable weight for trucks on Interstate highways.

The statistical evidence of deferred highway maintenance is supported by visual observations readily recognized by highway officials, highway users, and the press. Feature articles have appeared in nationally known publications such as *U.S. News and World Report, Popular Mechanics,* and *The New York Times* on the deterioration of the Interstate System. Federal and state highway administrators also agree that the backlog of needed maintenance work is growing (Figure 1)

The magnitude of the backlog can be quantified to a degree by condition surveys on the highway system. However, an assessment of the consequences of deferred maintenance requires knowledge in several areas including:

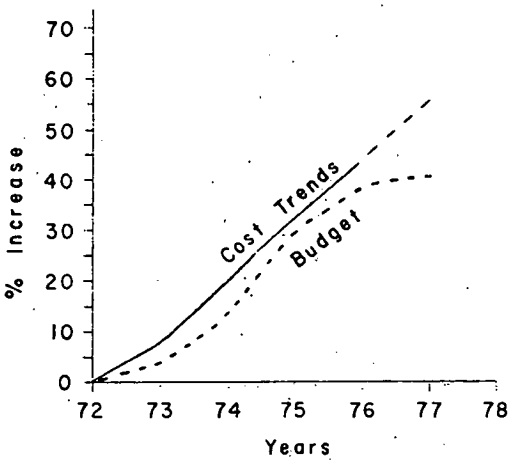


Figure 1. Comparison of cost trends and budget trends for highway maintenance in the Michigan Department of State Highways and Transportation.

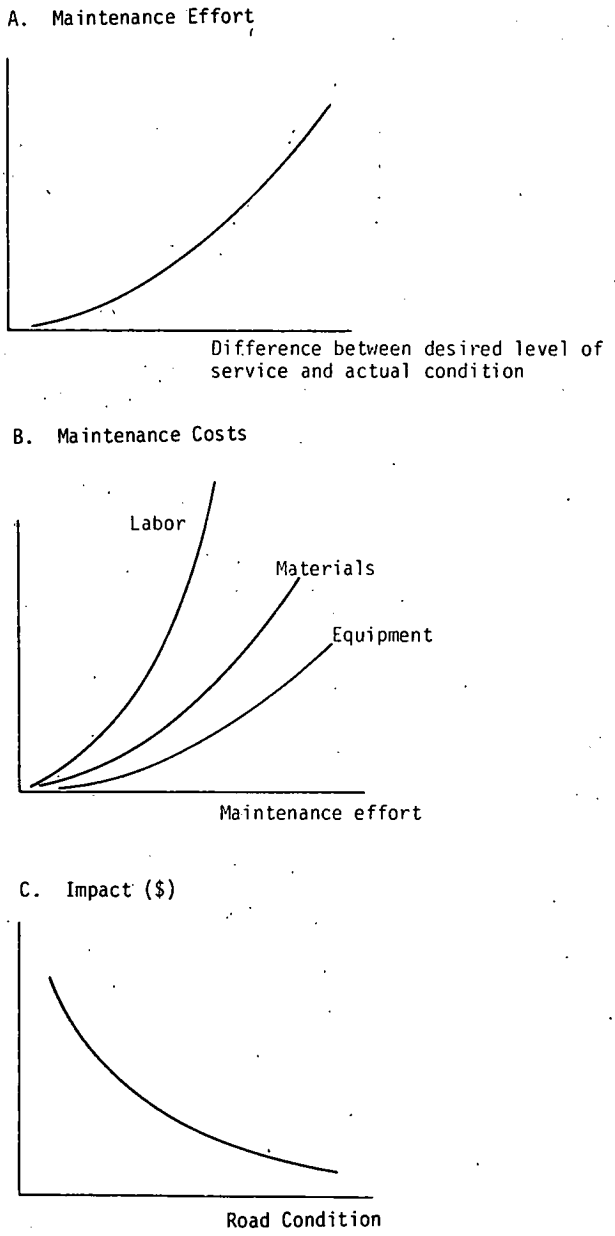


Figure 2. Maintenance relationships.

1. Specific definitions of what constitutes "maintenance."
2. Quantitative measures of changes in the physical condition of the highway system from one time to another.
3. Correlation of maintenance effort (expenditure of resources) with resulting change in physical condition, service life, and function of the highway system (Figure 2).
4. Assignment of common quantitative values ($) to the maintenance effort and the results, so that cost-benefit and other analyses can be made (Figure 2).

Thus, the effort in preparing this synthesis was directed toward these broad areas of knowledge and the management and analytical technology serving or being developed to serve these needs. In the following sections the findings of the study are presented.

CHAPTER TWO

FINDINGS

MANAGEMENT STRATEGIES

The consequences of many current decisions to defer maintenance are unknown, but new management concepts are evolving.

Because analytical systems are inadequate and data insufficient, many decisions being made by highway administrators today to defer maintenance are essentially judgmental. Some decisions to defer are imposed upon highway administrators by short-term economic necessities, some by political or public pressures to assign priorities elsewhere, and a growing number are based upon a reevaluation of the alternatives to historic maintenance policies and procedures (Figure 3).

Factors that are important to highway administrators in formulating maintenance strategies include:

- Public interest and safety.
- Economic effects.
- Energy conservation.
- Social effects.
- Environmental concerns.
- Liability problems.
- Material availability and costs.
- Federal regulations and funding.

There is a growing interest in dealing with the strategy of maintenance management. One of the earliest attempts to quantify the need for maintenance was made in an NCHRP study of Interstate highway maintenance needs (*1*) where models were developed to predict requirements in seven areas of maintenance as they were influenced by such variables as weather, terrain, traffic volumes, and age. A recent national effort was made under an FHWA research contract to model the cost of maintenance throughout the service life of a pavement, as influenced by a set of variables (*2*).

In California, a new maintenance strategy was developed when it appeared that revenue from gasoline taxes would be insufficient to meet "needed" expenditures. The strategy was the product of several specific analytical steps:

1. The magnitude of the resource problem was determined.

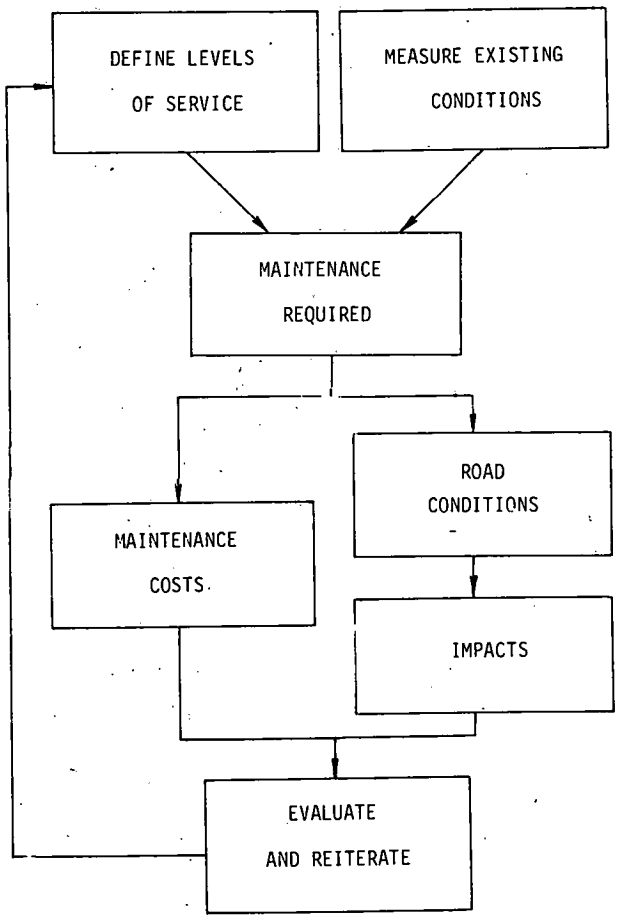


Figure 3. Maintenance levels, evaluation process.

2. Maintenance work by program, subprogram, and activity was identified.
3. Activities were classified as to importance or priority in terms of safety, investment, user service, and esthetics.
4. A review was made by district and headquarters maintenance managers to determine where program reductions could be made to fit revised resource levels.
5. Within the program, activities were reviewed in terms of priority and reductions assigned.
6. The dollar, man-year, and production unit impact of each reduction were determined.
7. Annual work plans, by program and activity at the field unit level, were revised to fit the new resource levels.

A Pennsylvania maintenance strategy was based upon the definition of five alternate maintenance levels that ranged from full system maintenance at high standards down to a minimal program designed to perform only essential structural repairs required to keep roads open (Figure 4). The Pennsylvania task force recommended that future priorities in highway funding be pointed toward: (a) preservation of existing highway plant, and (b) a capital program to enhance the maintenance function.

In Kansas, a strategy was developed in which maintenance is done in "reverse order": the highways in the best condition and with the highest traffic volumes receive first priority, the second-best roads receive the next priority, and the assignments are continued until the poorest roads are repaired. The Kansas operation has been in effect for 10 years. After the first four years, quantities of aggregate and asphalt used for both surface repairs and resurfacing were reported to be progressively lower each year.

The Massachusetts Department of Public Works has developed a tableau that displays, for purposes of management decisions, the impact of alternative levels of maintenance funding on service levels of maintenance.

Obviously, impacts must be related to safety and serviceability of the highway system and service life of the facilities being maintained as well as to maintenance budgets.

The Michigan Department of State Highways and Transportation studied two alternative strategies for its highway system:

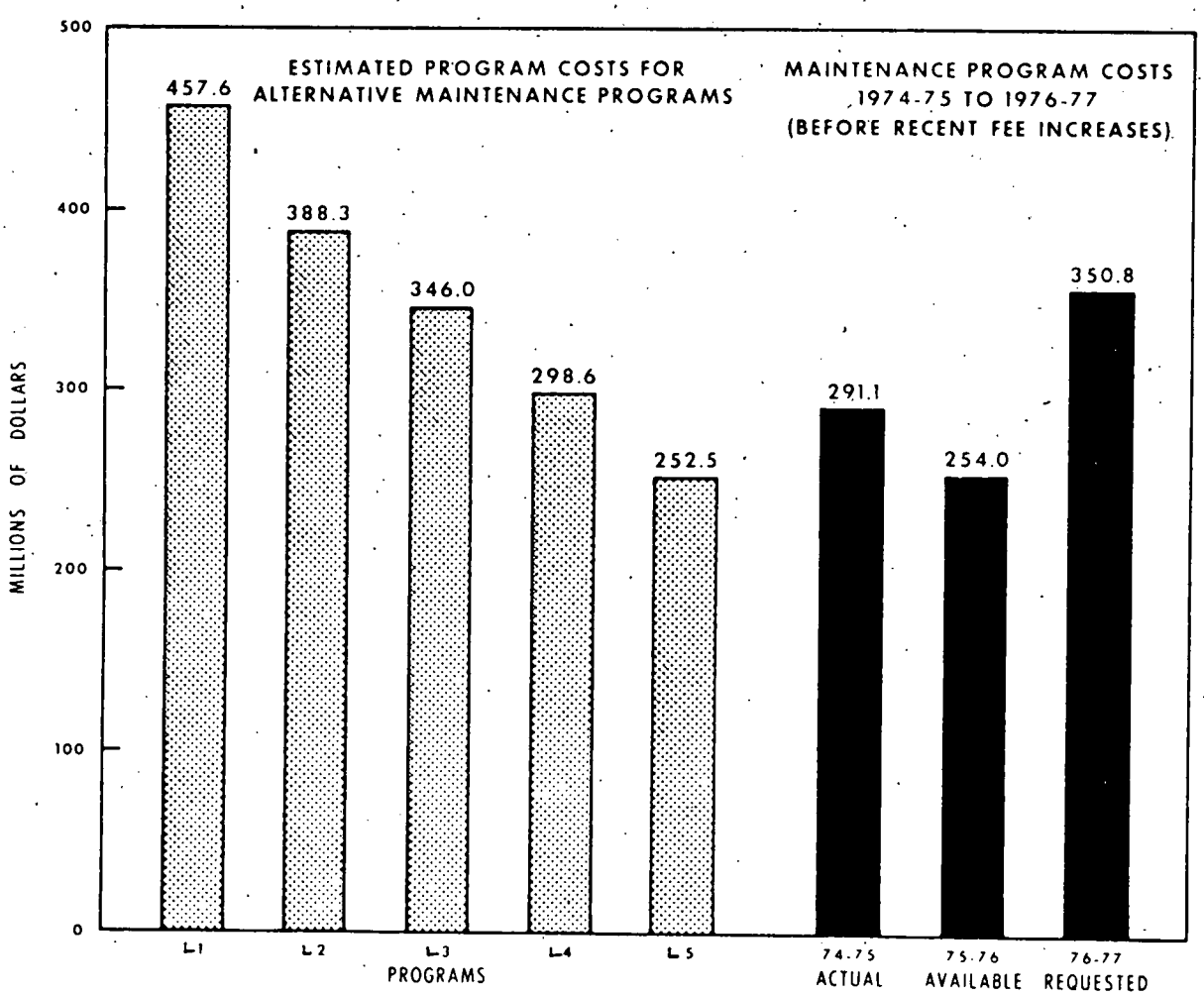


Figure 4. PennDOT estimated program costs for alternative maintenance programs (1976).

1. Construct and maintain.
   - Maintain to high standards.
   - Extend service life of facility.
2. Construct and reconstruct.
   - Perform essential maintenance only.
   - Reconstruct earlier.

Using an assumed 30-year service life under the first alternative and 20 years for the second, Michigan estimated that the cost per year per mile for maintenance and construction over the service life of the pavement would be $5,667 ($3,521/km) for alternative 1 and $6,000 ($3,728/km) for alternative 2.

Thus, the high maintenance standards represented a 5 percent savings. If user benefits had been added to the analysis, the differential may have been even greater in favor of alternative 1.

The Research and Development Unit of the Utah DOT developed a table assigning ratings for the effect of deferring 27 different maintenance activities (Table 1). Effects were subdivided into six areas and individual ratings assigned for each.

Models for the economic evaluation of road maintenance were developed by a United Nations team for the Jamaican government (*3*). The evaluation procedure for maintenance strategies used in the Jamaican models is shown in Figure 5.

In a report on maintenance of low-volume, low-cost roads by the World Bank (*4*), a tabulation (Table 2) was

TABLE 1

EFFECTS OF DEFERRING MAINTENANCE ACTIVITIES, UTAH DOT

DEFERRED ACTIVITY	EFFECT ON: Safety	Condition of Facility	Liability	Level of Service	Energy	Society-Environment
•Flexible Pavements						
Overlay	M	H	L	H	H	M
Planing (Hot & Cold)	M	H	L	H	H	M
Surface Seal (Flush Coat)	L	M	L	M	L	L
Friction Course	H	M	H	M	L	L
Stress-relieving Membranes	L	H	L	H	M	L
Rejuvenator	L	M	L	M	M	L
Crack Sealing or Repair						
Longitudinal	L	M	L	L	L	L
Transverse	L	M	L	L	L	L
Block	L	M	L	M	L	L
Alligator	M	H	M	H	M	L
Pot Hole Repair	H	H	H	H	H	M
Shoulder Maint.	M	H	M	H	M	M
Drainage	M	H	M	H	L	M
•Rigid Pavement						
Overlay	M	H	L	H	H	L
Joint Reseal	L	M	L	M	L	L
Faulting Repair	M	H	M	H	M	L
Blowup Repair	H	H	H	H	H	M
Random Crack Sealing	L	M	L	L	L	L
Spalling Repair	M	H	M	M	M	L
Shoulder Repair	H	H	H	H	L	M
•Structures						
Joint Sealing	L	M	M	L	L	L
Painting	L	H	L	L	L	L
Surface Sealing	L	H	L	M	L	L
Spalling Repair	M	H	M	H	M	L
•Other						
Erosion Repair	L	H	M	L	L	H
Guard Rail	H	L	H	L	L	L
Signs	H	L	H	M	M	L
Roadway Delineation	H	L	H	M	L	L
Lighting	M	L	M	M	L	M
Clean Up	L	L	L	L	L	H

Note: H = High, M = Moderate, L = Low

prepared in which the impacts of 11 different maintenance activities were described in terms of physical condition of the roadway and vehicle operating characteristics.

A strategy for deferred maintenance program development outlined (Figure 6) in a recent Federal Highway Administration research report (*5*) called for:

1. Identifying maintenance objectives.
2. Establishing priorities for maintenance activities.
3. Selecting activities to defer.
4. Assigning deferment periods.
5. Evaluating the consequences of deferment.
6. Adjusting and reevaluating.

The FHWA report also suggested a process for evaluating the consequences of alternative deferment strategies (Figure 7).

AASHTO's Operating Subcommittee on Maintenance suggested that priorities be adopted to direct maintenance activities toward more effective and efficient use of energy

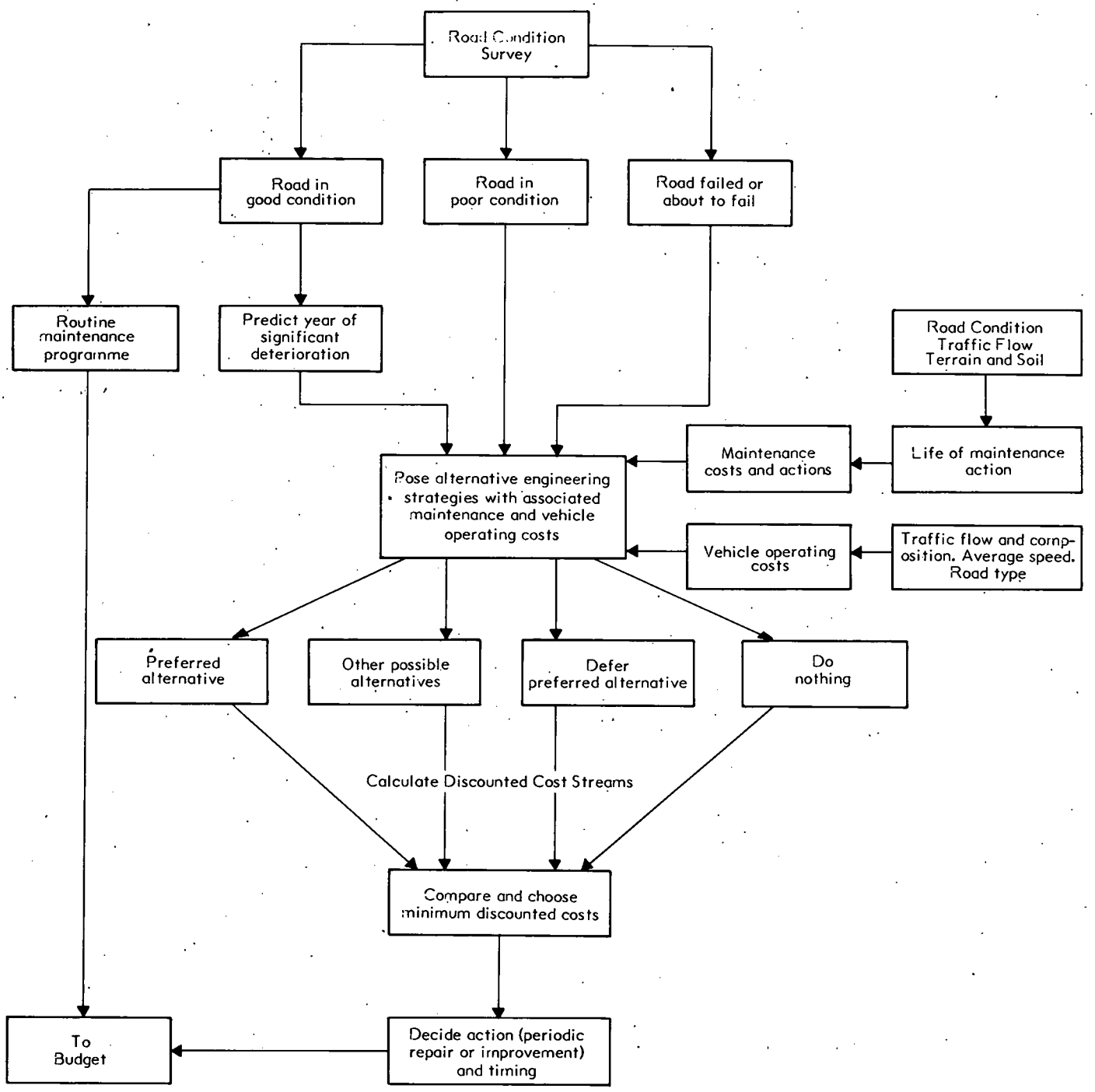


Figure 5. Procedure for evaluating road maintenance strategies.

resources, materials, manpower, and available funds and to continue to provide consistently high levels of service as demanded by the traveling public. The AASHTO priorities were based on highway safety, preservation of the capital investment in the highway system, operational characteristics of the highway, and esthetic qualities of the facility.

The AASHTO committee listed 19 specific maintenance activities in order of decreasing priority:

1. Elimination of hazards or other conditions leading to road closure (avalanche danger, mud slides, washouts, heavy snowfall, severe icing conditions, severe bridge damage, pavement blowups, and so on).
2. Removal of hazardous objects in roadway.
3. Repair of damaged or structurally inadequate structures.
4. Repair of hazardous pavement conditions such as bumps, holes, slippery areas, minor heaves and blowups, or snow and ice.
5. Replacement or repair of damaged, obscured, or missing signs, signals, pavement markings, and lighting.
6. Correction of pavement drop-off at shoulders.
7. Repair of damaged guardrail, guiderail, barricades, traffic barriers, impact attenuators, and other off-roadway safety features.
8. Repair of nonhazardous pavement deficiencies including overlays to preserve capital investment.
9. Maintenance of drainage features.
10. Minimal landscape maintenance to keep plants alive.
11. Maintenance and minor repair of signing and signals.
12. Routine maintenance and minor repair of structures.
13. Safety rest area maintenance.
14. Mowing to maintain adequate sight distance, prevent erosion, and maintain drainage.
15. Routine maintenance of roadside features (including guardrail, fences, and so on).
16. Provision of motorist aid patrols.
17. Roadside cleanup.
18. Mowing and other work for esthetic purposes.
19. Work for other agencies.

Zero-based budgeting concepts have also been used for a fresh evaluation of traditional maintenance needs and procedures. This process of evaluating each budget item on the basis of current and documented needs rather than historic trends has challenged maintenance managers to assess the value of traditional maintenance activities before budgets are proposed.

Another approach to the maintenance planning process has been through performance budgeting concepts. Performance budgets are derived by determining a program of work to be performed and then the resources (labor, equipment, and materials) required to do it. This is an important break from earlier line-item budgets in which dollars first were allocated for labor, equipment, and materials and then work programs grew out of available resources.

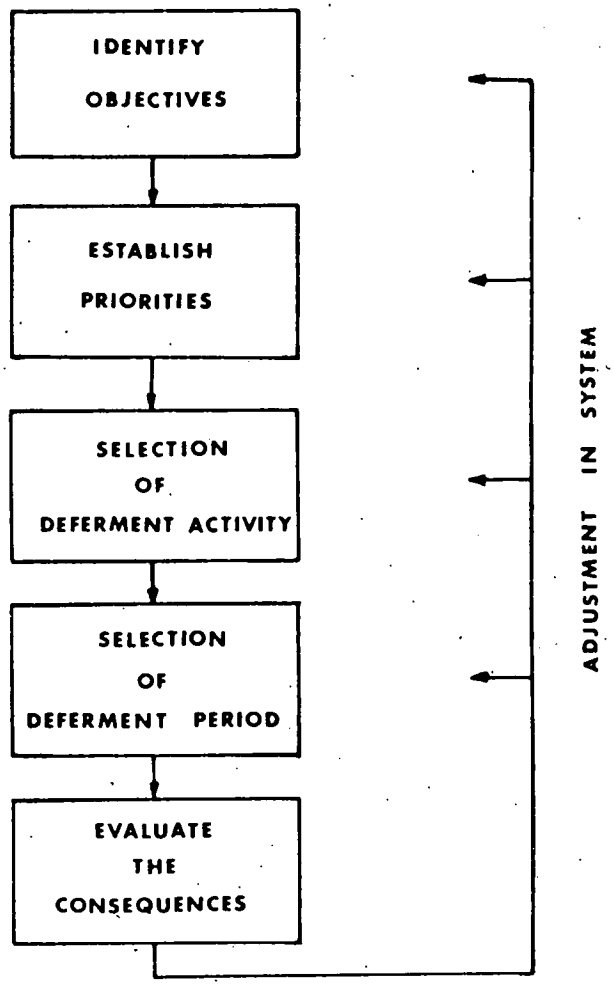


Figure 6. Logic in planning a deferred maintenance activity (5).

The impact data for all maintenance activities, together with the costs of maintenance performance, can be organized in tables or impact tableaus. The impact tableau, usually in graphic format, provides a convenient way of summarizing the comparative costs and impacts of different maintenance policies, where each policy is defined by a particular set of quality standards. Managers may then judge the relative merits of several proposed maintenance programs to adopt that one whose costs and impacts are the most acceptable.

SERVICE LEVELS

Maintenance service levels must be defined and practical field measurement systems designed in order to identify and quantify deferred maintenance.

Part of the difficulty faced by highway administrators in maintenance planning has been the lack of a clear base line against which to measure changes in the maintenance service levels. Unless a maintenance program can be defined with specificity, it is difficult to determine what and how much change represents a deferment of maintenance. Some activities, performed on an established frequency

TABLE 2

ECONOMIC BENEFITS OF HIGHWAY MAINTENANCE—CONCEPTUAL FRAMEWORK *(4)*

Maintenance Activity	Surface Type	Impact: Idealized	Impact: Current Model
Routine Maintenance			
Drainage Clearance	Paved, Unpaved	Reduces water penetration of road structure, decreasing deterioration of structural strength and surface condition.	None: assumes "normal" maintenance.
Shoulder Maintenance	Paved, Unpaved	Reduces shoulder erosion and roughness, decreasing pavement raveling, vehicle operating costs (VOC) and accidents.	None: assumes "normal" maintenance.
Vegetation Control	Paved, Unpaved	Improves lateral vision and increases vehicle speeds.	None: assumes "normal" maintenance.
Dragging	Lateritic Gravels	Reduces roughness, increases vehicle speeds, reduces vehicle operating costs.	None, but could be arbitrarily specified as some fraction of the effect of grading operation.
Normal Grading (no wetting or compaction)	Gravels, Earth	Improves surface condition (roughness, rut depth), increases vehicle speeds, reduces vehicle operating costs.	Fully incorporated as measured by Kenya study.
Patching of Cracks and Potholes	Paved	Reduces water penetration of road structure thereby decreasing deterioration of structural strength, rate of growth of road roughness and hence vehicle operating costs.	Fully incorporated as measured by Kenya study and extrapolated for extreme conditions.
		Patching increases immediate surface roughness for small cracks, but decreases immediate roughness for severe cracking and potholes.	No effect on immediate level of roughness.
Periodic Maintenance and Rehabilitation			
Heavy Grading and Reshaping (wetting and compacting)	Gravel, Earth	Restores shape, improves drainage, reducing rate of deterioration, increases vehicle speeds, reduces vehicle operating costs.	No additional benefit compared to normal grading.
Graveling	Gravel, Earth	Creates higher strength, reducing rate of surface deterioration, increasing vehicle speeds and reducing vehicle operating costs.	Fully incorporated as measured by the Kenya study for gravel roads; earth roads arbitrarily assumed to have rate of deterioration (roughness) 15X faster than gravel roads in the absence of any evidence.
		May increase or decrease immediate roughness depending on pre-existing condition and quality of gravel.	Assumes same immediate roughness after grading for both earth and gravel roads (=3250 mm/km).
		Preserves all-weather characteristics.	Does not calculate estimate of economic loss due to road closures but exogenous estimate may be specified.
Resealing (single or double bitum. surface dressing)	Paved	Reduces water penetration, etc. (See Patching)	Fully incorporated.
		May decrease slightly immediate roughness of badly patched surface, but may increase slightly roughness of smoothly polished surfaces.	No effect; thought to be negligible in effect on vehicle speeds and operating costs.

Maintenance Activity	Surface Type	Impact: Idealized	Impact: Current Model
Asphalt Overlays	Paved	Reduces water penetration, etc. (See Patching)	Fully incorporated.
		Restores/increases structural strength, reducing rate of deterioration to new condition.	Fully incorporated from AASHO Illinois Test results and Asphalt Institute.
Reconstruction	Paved	Similar effects to overlay except reconstruction with light bituminous surface likely to have different deterioration including greater susceptibility to cracking and water penetration than heavy asphalt concrete overlay.	Assumes same behavior as asphalt concrete overlay with equal structural number.

basis, clearly can be deferred by reducing the frequency of performance. Activities that are performed on a demand or as-needed basis, however, require specific definitions of the need (sometimes referred to as the threshold level) and the response (in terms of promptness, quantity and quality). Even with need and response definitions in hand, it is difficult for highway agencies to quantify the results of changes (deferment) in maintenance activities in terms of costs and facility service levels because of the many variables that influence highway conditions.

Despite their recognized importance, however, levels of service have to date not been incorporated practically and objectively within most maintenance management systems. More often, one finds that levels of service are established as judgmental decisions by the field level managers in the maintenance organization, often based on personal preferences or assumed values for various elements of the maintenance program.

There are several reasons why the level of service component of maintenance management control systems has not been used effectively in many organizations. First, maintenance levels of service are sometimes difficult to define. The levels of service provided through the maintenance of highway elements such as pavement surfaces, shoulders, turfed areas, drainage, and structures do not always lend themselves to simple physical descriptions.

Second, maintenance levels of service are not easy to measure. If the levels are reduced to quantifiable physical conditions, measurements may be taken for some of them. Others will require special instrumentation. Also, the practicality of applying measuring procedures on a typical state highway system that may represent tens of thousands of centerline miles must be considered.

Third, maintenance levels of service are difficult to evaluate. Even if managers were able to define them in a clear manner and measurements could be taken, the establishment of optimum levels of service still represents an undeveloped technology. A complex matrix of tradeoffs must be assessed before the optimum use of the limited dollar resources available for highway programs is assured.

A current NCHRP research project (*6*) is seeking to develop new techniques for measuring and evaluating maintenance quality levels. The ability to measure maintenance service levels on a highway system is a key to the evaluation of the consequences of deferred maintenance. The measurement of roughness and computation of a serviceability index have been effective, practical tools for pavement maintenance program planning. However, a myriad of other maintenance activities from mowing to culvert cleaning to litter collection do not lend themselves to instrumented, quantitative measurements of resulting conditions.

A number of organizations are attempting to measure maintenance levels of service through the use of index systems. The Army's Construction Engineering Research Laboratory in Champaign, Illinois has developed a pavement management and repair system designed to help maintenance personnel in military installations (*7*). The procedures involve dividing pavement networks into sections, inspecting and recording pavement conditions, determining the needs and priorities, and developing work plans.

An Ohio study (*8*) defined quality of maintenance as a measure of the accomplishment of AASHTO's maintenance objective of keeping the highway in its as-built condition. Thus, measurements of the quality level of maintenance were measurements of the condition of the various physical elements of the highway system (Table 3).

The Ohio system recognized the impracticality of measuring the entire 18,000-mile highway network in that state. As an alternative, a random sampling procedure was established whereby a statistically acceptable sample of measurements could be taken for each classification of highway in each county within the state. Through sampling techniques, levels of service were determined by highway classification for each field level maintenance jurisdiction. The first complete survey in Ohio was conducted in 1971. Since that time surveys have been completed each year on a semi-annual basis. The results are presented in computer-generated plots that show the recordable conditions per mile on a bar chart. The chart is overprinted in a different color with a bar chart showing the cost-per-lane-mile for the maintenance activities related to that highway element.

Many states have developed measuring systems for pavement conditions on the highway systems. In 1976, New York published the first annual network summary of the condition of its pavements. Pavements were evaluated in terms of their "functionality"—how well they functioned

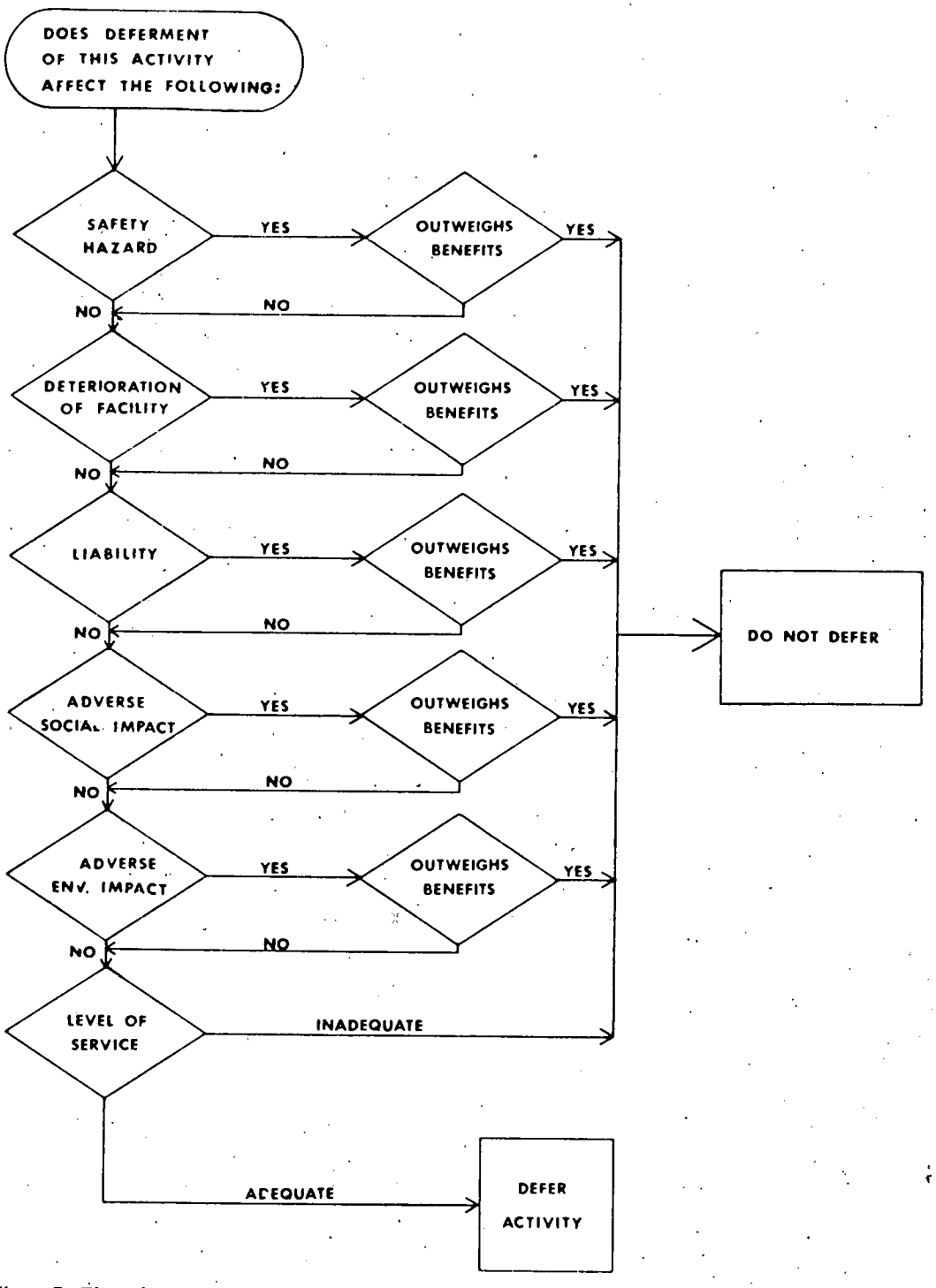


Figure 7. Flow chart for evaluating the consequences of deferred maintenance (5).

TABLE 3

SUMMARY OF RECORDABLE CONDITIONS (OHIO)

Condition	Procedure	Description	One Unit Count for Each	Observation Scope	Test
Pavement					
Surface					
Deterioration	40 MPH	Depth 2" & Area 20 sq. in.	2 sq. yd.	Pavement	Safety &
Obstructions	40 MPH	Depth 2"	Location	Pavement	Integrity
Flushing	40 MPH	Area > 1 sq. yd.	100 lin. ft.	Pavement	
Striping					
Deterioration	40 MPH	Stripe > 6 lin. ft.	.10 Mi.	Pavement	Safety
Auxiliary Marking					
Deterioration	STOP	Any Marking	Location	Pavement	Safety
Shoulders					
Surface					
Drop Off	20 MPH	Depth 2" by 6 lin. ft.	100 lin. ft.	One Shoulder	Safety
Obstructions	20 MPH	Depth 2"	Location	One Shoulder	Safety
Appurtenances					
Guardrail					
Appearance	40 MPH	Rust	100 lin. ft.	All Guardrail	Appearance
Deterioration	STOP	6 Runs	100 lin. ft.	6 Runs	Function
Signing					
Deterioration	STOP	All Signs	Sign	All Signs	Function
Roadway					
Vegetation					
Appearance	40 MPH	Policy Deviation	1/5 Mile	Roadsides & Medians	Appearance
Litter					
Appearance	40 MPH	Count > 10 Spots	1/10 Mile	Roadsides & Medians	Appearance
Drainage					
Ditches					
Obstruction	40 MPH	50% Obstruction	100 lin. ft.	All Ditches	Function
Structures					
Deterioration	STOP	Repair Required	2 sq. yd.	6 Structures	Integrity
Obstruction	STOP	50% Obstruction	Structure	6 Structures	Function

in providing an adequate traveling surface for the highway user. The degree of functionality provided to the highway user by a pavement was expressed by means of the Present Rideability Index or PRI. Figure 8 shows the relationship of PRI to user attitude when riding on a particular pavement and also what the implications are for restoration or correction of that pavement (*9*).

IMPACT ASSESSMENT

A distinction can be made between (a) deferring physical maintenance that is cumulative and ultimately must be done if the facility is to be restored to good condition; and (b) deferring, reducing, or eliminating maintenance activities that affect primarily esthetic or functional characteristics of the highway.

Although many maintenance programs require that certain physical maintenance activities—such as pavement and bridge repairs—be deferred, the economic consequences of such action often are undesirable. Pavement and bridge structures may undergo accelerating rates of deterioration as defects go uncorrected, with the accumulated cost of repair increasing geometrically over time. Where such conditions exist, the deferment decision represents an added cost rather than a savings to the highway agency. This impact is compounded by the added user costs and inflationary effects of delay on repair costs.

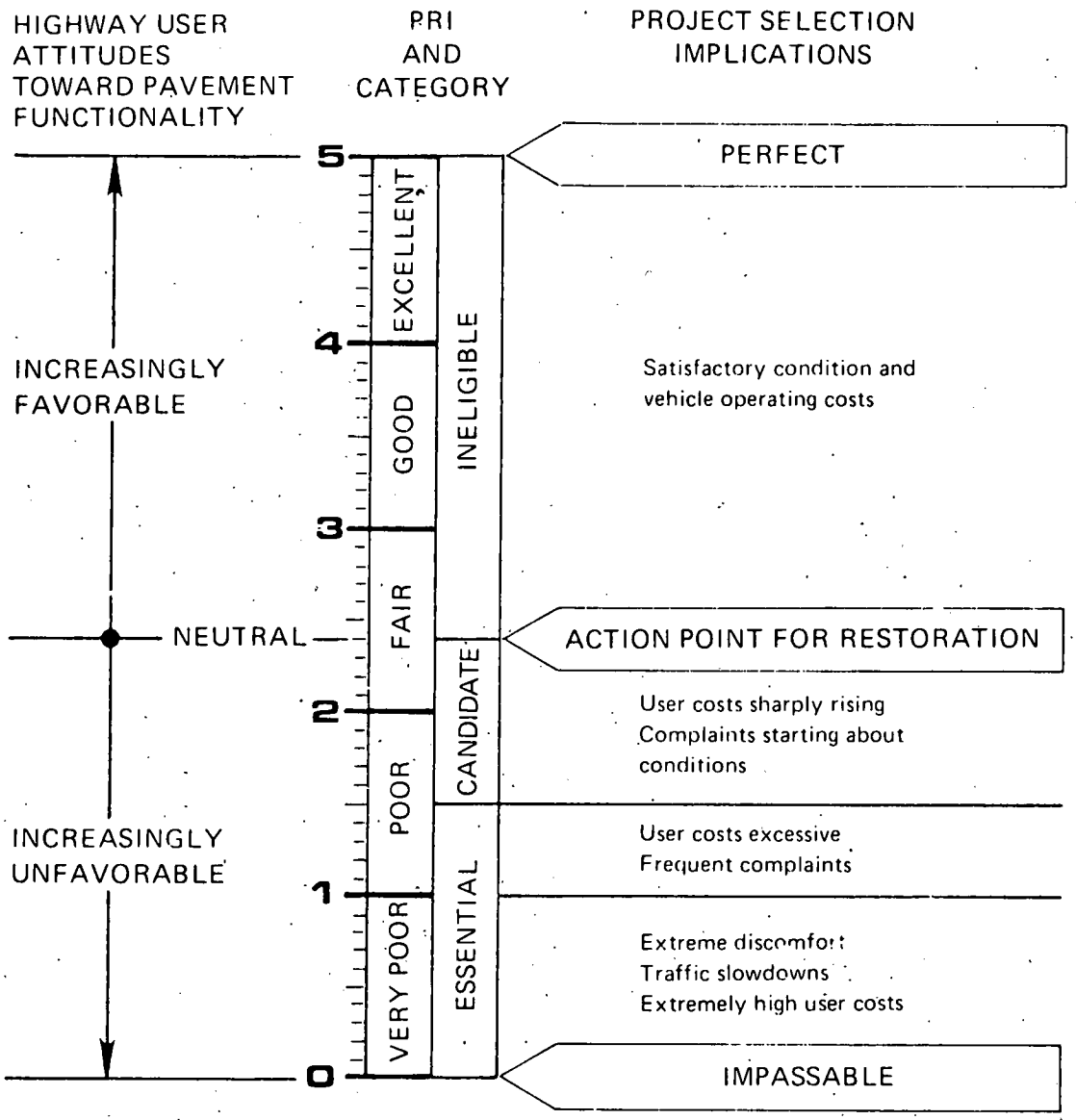
Pavements

Utah studied four different rehabilitation strategies for pavement evaluation. The difference between these strategies was the choice of the value for the lowest acceptable Present Serviceability Index (PSI) level, which controlled the number of years between overlays. Each strategy was based on the use of normal maintenance and the placement of a chip seal coat (cover aggregate) every seven years (*10*).

Strategy A requires that each pavement be rehabilitated when its PSI drops to 3.0. This requires that each pavement be overlaid every 17 years (Figure 9).

Strategy B requires that each pavement be rehabilitated when its PSI decreases to 2.5, which would require an overlay every 20 years (Figure 9). This is the present design level for high volume roads.

Strategy C requires that each pavement be rehabilitated at a PSI level of 2.0, which means it would be overlaid approximately once every 23 years (Figure 9).



NOTE All PRI values are dependent on travel speed which is taken to be the posted speed; both PRI and User Attitudes vary with travel speeds.

Figure 8. Significance of the Present Rideability Index (PRI) for effective pavement management.

The Utah DOT's level of funding and overlay program in 1977 was such that each pavement could be overlaid on average once every 27 years. As pavements deteriorate to a poor level of performance, additional effort is required to maintain their integrity. Strategy D, as shown in Figure 9, represents the typical 1977 Utah pavement performance curve, with increased maintenance effort required to hold pavement at the PSI 1.9 level until rehabilitated.

The four rehabilitation strategies were evaluated by the Utah DOT based on the anticipated pavement conditions and associated costs. Table 4 summarizes the annual surfacing and maintenance costs for the different highway systems for each strategy. Costs for both surfacing and maintenance increase as the strategy level decreases for each system. Strategy A has the lowest annual cost of any strategy. Benefit values were computed using Strategy D as the benchmark. The annual benefit summary, shown in Table 5, includes surfacing, maintenance, and savings in motor fuel costs.

A series of curves was developed by the Utah DOT comparing costs to rehabilitate pavements at different condition levels for different highway systems. These are illustrated in Figure 10. The estimated cost to upgrade a pavement is determined by entering the graph at the present serviceability index value for that pavement, moving horizontally to the intersection with the proper system curve and then down to the cost per mile of pavement.

As the pavement condition becomes poorer, additional effort is required to prepare the old surface for a new over-

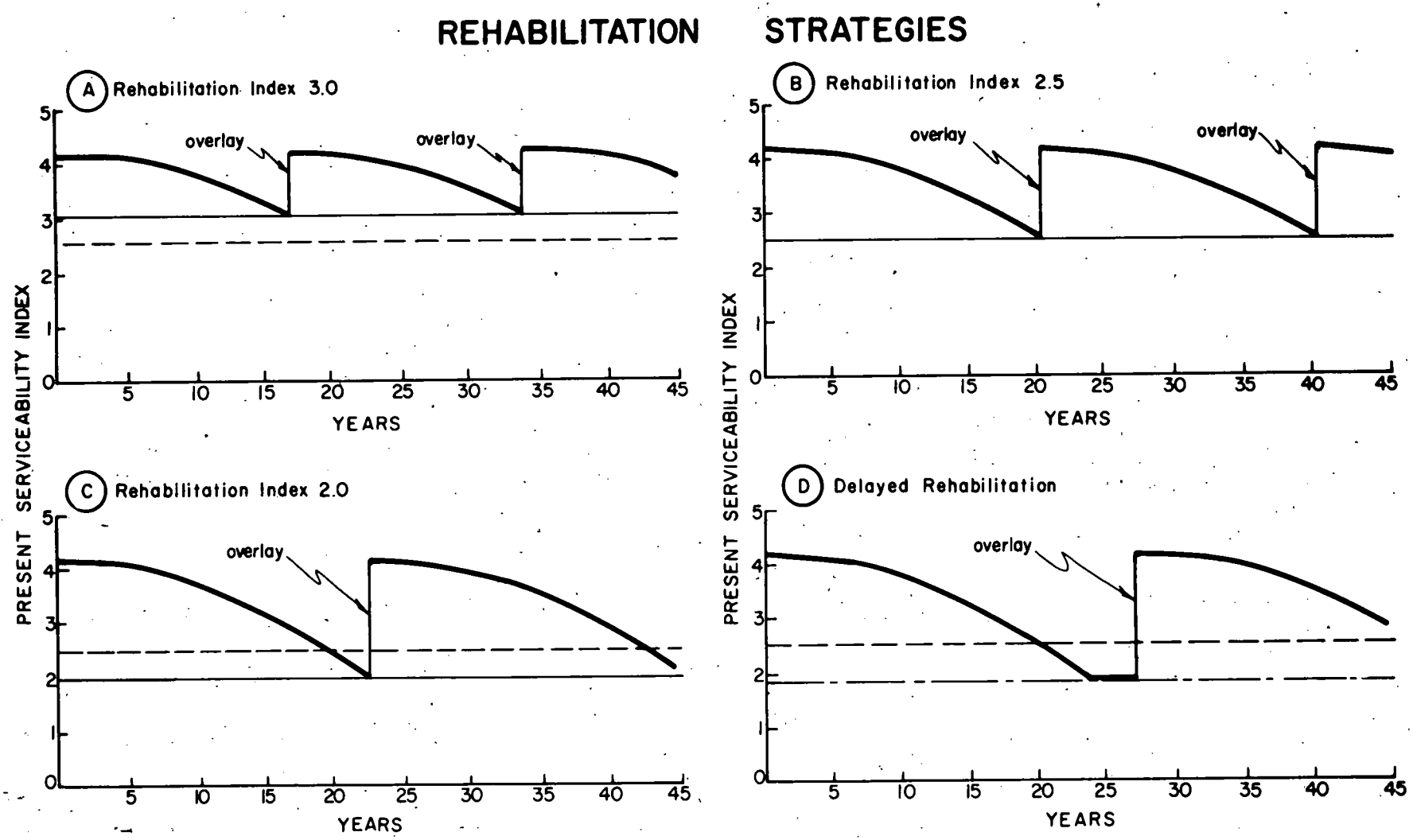


Figure 9. Rehabilitation strategies (10).

lay. This is reflected in the costs indicated on the curves in Figure 10.

The increased cost of deferring maintenance past a certain point is illustrated in Figure 11 with an 8-in. (200-mm) thick pavement designed to carry 1,500,000 load applications. As loads are applied to the pavement surface, there is a loss in structural value, with a more rapid loss in the later phases of the pavement design life. For example, after 1,200,000 load applications, the 8-in. bituminous surface would have an equivalent thickness value of only 6 inches (150 mm) of new pavement.

As a pavement deteriorates under loads, it requires a greater overlay thickness to restore it and extend the service life. This is illustrated in Figures 12 and 13 where the lower left curve represents the decrease in equivalent thickness for the existing surface with increased numbers of loads. The upper right curve represents the projected life of the surface after an overlay. Figure 12 shows that an overlay thickness of two inches (50 mm) would be required if the pavement were overlaid at about 1,200,000 loads. Figure 13 shows that an overlay thickness of 5¾ inches (145 mm) would be required if the existing pavement were allowed to fail before overlaying. A comparison between the relative thickness and cost for the two strategies is shown in Figure 14. The Utah study indicates that considerable savings can be realized by properly timing the rehabilitation of pavement surfaces.

TABLE 4

ANNUAL COST SUMMARY, UTAH DOT (1977)

SYSTEM	STRATEGY	ANNUAL COSTS IN MILLIONS DOLLARS		
		SURFACING	MAINTENANCE	TOTAL
PRIMARY	A	4.94	1.35	6.29
	B	6.44	1.59	8.03
	C	7.92	1.67	9.59
	D	8.85	1.76	10.61
SECONDARY	A	5.23	2.71	7.94
	B	7.78	3.17	10.95
	C	9.81	3.34	13.15
	D	10.37	3.50	13.87
URBAN	A	2.53	0.82	3.35
	B	3.24	0.96	4.20
	C	3.97	1.01	4.98
	D	4.33	1.06	5.39
TOTAL	A	12.70	4.88	17.58
	B	17.46	5.72	23.18
	C	21.70	6.02	27.72
	D	23.55	6.32	29.87
	COMBINATION A-PRIMARY B-SECONDARY B-URBAN	15.96	5.48	21.44

Structures

An example of a maintenance impact assessment procedure applied to structures was provided by a Minnesota study (*11*). A task force was formed to develop a feasible and realistic policy for protecting and rehabilitating bridge decks in Minnesota. The task force studied the levels of deterioration at which bridges should have routine maintenance performed and the levels at which routine maintenance should be deferred until the deck is rehabilitated or

TABLE 5

ANNUAL BENEFIT SUMMARY (1977)

System	Strategy Comparison	Annual Benefits in Millions Dollars			
		Surfacing	Maintenance	Motor Fuel	Total
Primary	D-A	3.91	0.41	2.44	6.76
	D-B	2.41	0.17	1.90	4.48
	D-C	0.93	0.09	1.10	2.12
Secondary	D-A	5.14	0.79	1.78	7.71
	D-B	2.59	0.33	1.42	4.34
	D-C	0.56	0.16	1.06	1.78
Urban	D-A	1.80	0.24	3.90	5.94
	D-B	1.09	0.10	2.88	4.07
	D-C	0.36	0.05	1.57	1.98
TOTAL	D-A	10.85	1.44	8.12	20.41
	D-B	6.09	0.60	6.20	12.89
	D-C	1.85	0.30	3.73	5.88
	Combination D-A Primary D-B Secondary D-B Urban	7.59	0.84	6.74	15.17

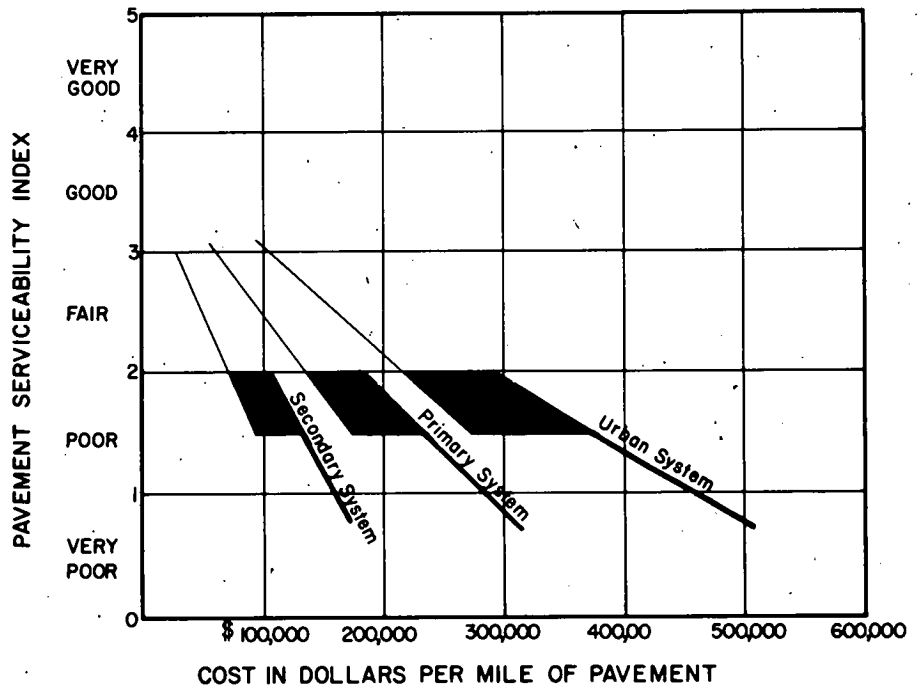


Figure 10. Pavement overlay cost vs. pavement conditions—20-year life (flexible pavements).

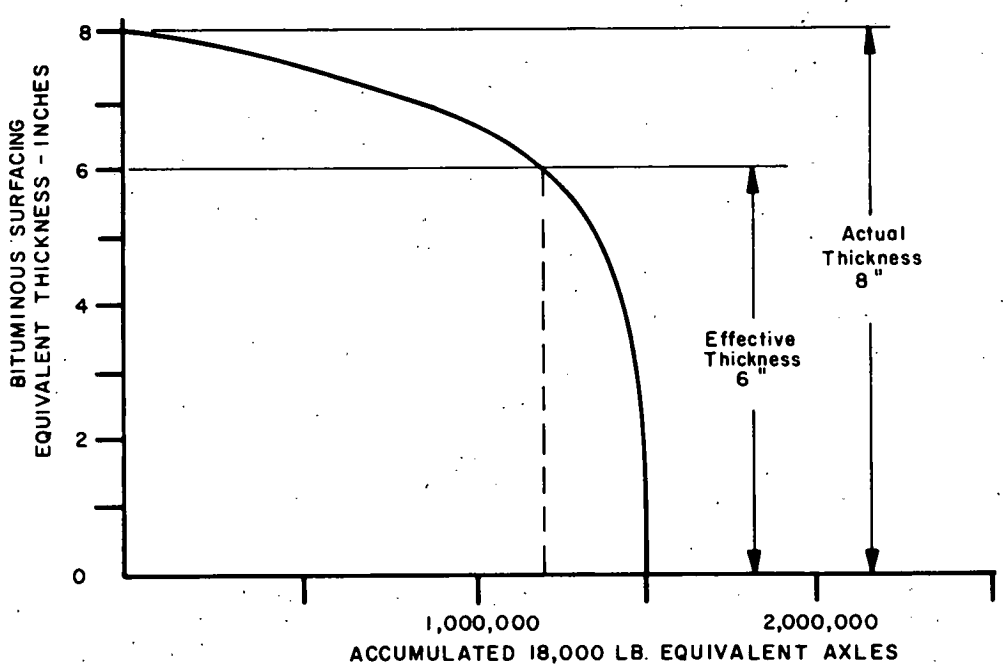


Figure 11. Relationship of pavement equivalent thickness to axle loads from Utah DOT study (1 in. = 25.4 mm, 1 lb = 0.4536 kg).

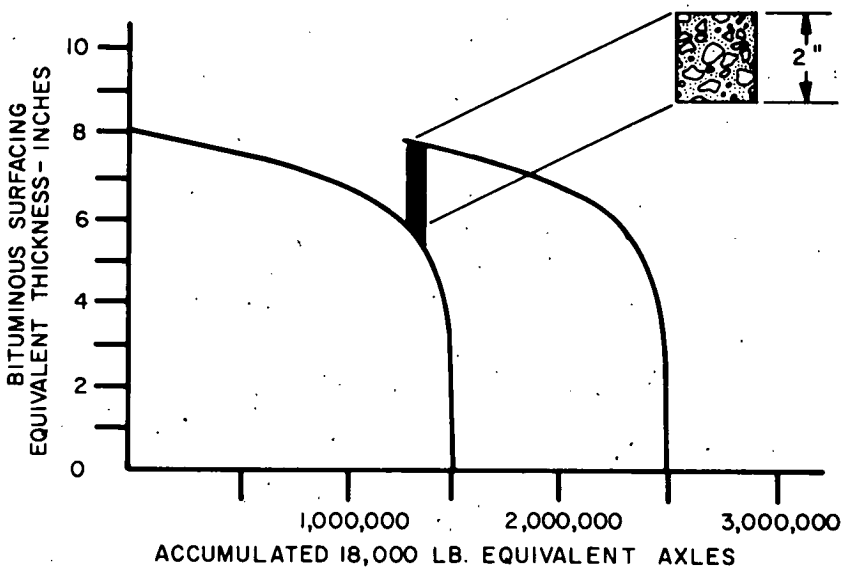


Figure 12. Additional surfacing required before failure.

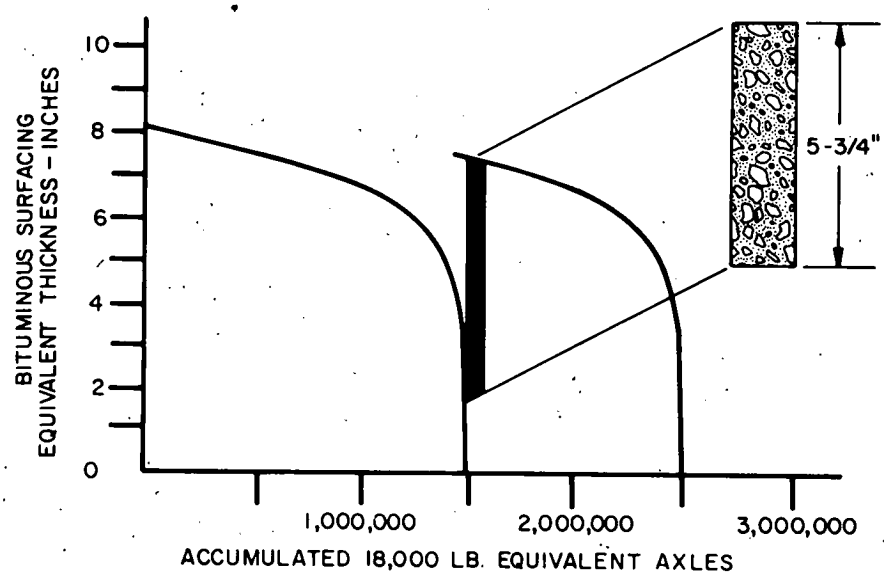


Figure 13. Additional surfacing required after failure.

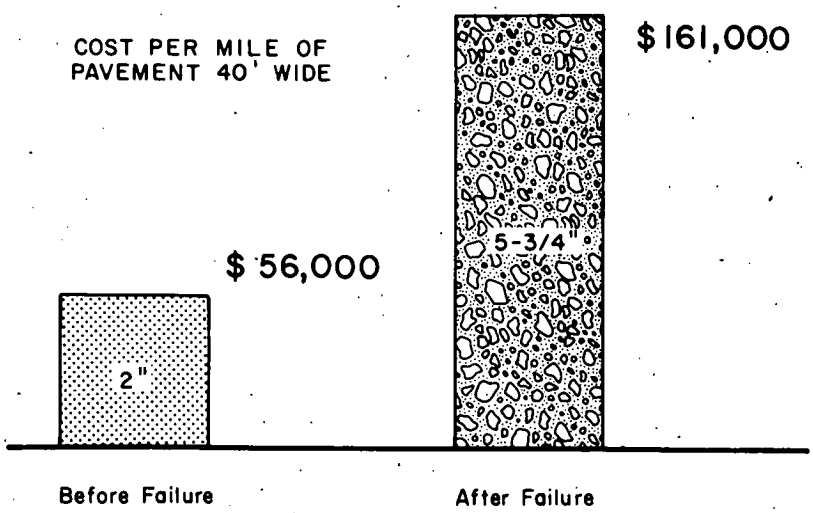


Figure 14. Comparison strategies.

replaced. The group determined by a benefit-cost analysis that it would be most cost effective to give first priority maintenance to bridges with little or no deterioration, based upon several considerations.

Positive Impacts

- Structures can be *protected* with today's dollars at much lower costs than it will take to *repair* them after deterioration starts.
- Lane closures can be minimized due to limited concrete removal prior to protection. Normal closures take half of the time it would take to repair and overlay.
- Effectiveness of protection is superior to the effectiveness of any repair or rehabilitation short of replacing the entire deck.

Negative Impacts

- The public may complain when motorists see crews working on apparently "new" decks.
- The current funding of bridge repairs may be inadequate to permit repair of critically deficient bridges and to protect the new ones.
- A program of testing and evaluating bridges that should be protected is a prerequisite to initiating the policy.

Drainage

The cleaning and repair of drainage facilities are performed on an as-needed basis and are not scheduled as routine maintenance in other than emergency situations in many states. No data on rate of deterioration versus increase in costs for rehabilitation were found for drainage. Drainage affects a large number of highway items. Many shoulder and pavement problems stem from poor or inadequate drainage. Because drainage is subtle and slow-moving water is very quiet unless a failure or catastrophe occurs, drainage is often deferred.

Services

The elimination or reduction of some "traditional" maintenance activities in a program can save money and may not cause a reduction in levels of service. Maintenance programs sometimes evolve from personal preferences, special concerns and emphasis areas, anticipated changes in traffic characteristics, availability or shortages of materials, then-current technology, and varied other sources of input and influence. Regardless of how they originated, however, in time the resulting maintenance practices tend to become fixed and to continue unchanged even when technology and needs change.

For example, the cutting of vegetation on highway rights-of-way began as a means of maintaining a clear travelway and necessary sight distances. Over time, mowing of side slopes and median areas gradually increased in area and frequency and was often complicated by landscape plantings added to the right-of-way. The resulting "fairway" quality on highways was approved and eventually expected by highway users.

However, reduction or elimination of mowing programs in some states has achieved positive results in addition to cost savings. Natural vegetation has returned to cover slopes with native plants and flowers. Wildlife cover has been provided. Runoff has been reduced and roadway drainage systems have been protected from overloading.

The Queensland, Australia, Main Roads Department undertook a study of the impact of painting (or deferring painting) edge lines on 17-ft (5.5-m) wide pavements. The study revealed that the marking of edge lines on these pavements resulted in savings in shoulder maintenance that outweighed the painting costs. Thus, deferring edge lining in this instance would represent a net cost rather than a savings to the road department, without consideration of safety and other road user benefits that must be added to the equation.

Economic incentives led Virginia, California, and several other states to study the effects of alternative dimensions for the paint line and gap (or skip) on highway centerlines. As a result of its study, Virginia has increased the gap dimension and reduced the paint line length in its centerline striping program. California found that 16 percent of the pavement delineation budget could be saved through reduction and control of paint thickness, glass bead application, and revised paint and marker patterns. The reduced use of paints on highways has represented a significant savings in material costs without loss of safety or service to motorists (Table 6).

Other examples can be cited in reduced roadway lighting, elimination of painted guardrail, and similar activities where reductions in traditional maintenance programs have had no adverse impact on highway serviceability or safety.

The impact of snow and ice control levels of service was reported by FHWA in 1977 (*12*). The areas covered in the study were maintenance, traffic and safety (Figure 15), environment, structure damage, and vehicle corrosion. User costs in terms of accident rates, delay, traffic volumes and speeds during storms (Figure 16), and business losses were evaluated. An economic model, developed for use by maintenance program managers, computes costs and benefits for alternative levels of service. Levels of service (Table 7) were defined as:

Level of Service 1—The roadway is plowed; sanded; cleared of frost, snow, and ice pack; and widened as quickly as possible even though this may involve working extra hours at night, Sundays, or legal holidays. The work is carried out continuously during the storm to keep all lanes open for traffic. Exceptions are when blizzard conditions, poor visibility, avalanche danger, or other hazards require alternate action be taken.

Level of Service 2—Snow will be removed continuously during the storm to keep roads open for traffic. After plowing is started, the major effort is keeping the road open with less emphasis on keeping it bare (not to preclude removing loose snow before becoming snow or ice pack). Also, it provides a reasonable bare portion of sufficient width near the centerline to give traction for traffic in both directions. Completely bare pavement should, however, be provided on hills, curves, and at intersections as soon as possible. On highways with

four or more lanes, two lanes in each direction should be kept open during the storm. When this condition is reached and is likely to sustain itself, overtime work will cease.

Level of Service 3—Snow should be removed during the storm to keep the travel way (one lane each direction) open for traffic. (On divided highways, left lanes should be half bare with sanded curves and hills before termination of snow removal efforts.)

Level of Service 4—Snow should be removed only during regular working hours as required to obtain passable conditions—snow pack is acceptable. When necessary, road can be closed for intermittent periods of time.

Level of Service 5—Routes are allowed to be closed during the winter by snow and remain closed (except under unusual conditions). Routes are reopened in the spring when it is reasonable to assume the storm possibilities are over.

Energy

An aspect of deferred maintenance that is growing in economic and social significance today is the impact of energy use or energy conservation. In the fuel shortage crisis period of 1973-74, a flurry of activity was generated by state transportation agencies to explore energy conservation measures. Considered at that time for maintenance operations were:

- Program reductions.
- Equipment downsizing.
- Alternative fuel use (diesel, LPG, electricity).

Only limited quantitative data on program impacts and benefits from energy conservation were developed, however, and like the highway user, many transportation departments have not emphasized the potential problem as fuel supplies returned to normal.

The Washington State DOT has maintained a continuing energy conservation program that includes four general

TABLE 6

CALIFORNIA PAVEMENT MARKING PROGRAM ANALYSIS (ANNUAL SAVINGS ESTIMATE BY PROGRAM MODIFICATION)

Reduce Paint Thickness (by 1/3)

		ANNUAL USAGE Existing		Revised		Reduction
Stripe	Miles	Rate	Gal	Rate	Gal	Gal
Dash	12,420	6.5	80,730	4.5	55,890	24,840
Double Yellow	1,875	36	67,500	24	45,000	22,500
Solid 4"	9,910	18	178,380	12	118,920	59,460
Solid 8"	560	36	20,160	24	13,440	6,720
						113,520

Annual Savings: 113,520 x 3.00 = $340,000

Reduction in Glass Beads (from 6 lbs. to 4 lbs. per gal. of paint)

Paint Usage -- 240,000 gal.
Estimated Reduction -- 1 lb. per gal.
Bead Cost -- $0.135

Annual Savings: 240,000 x 1 x .135 = $32,000

Reduction due to reduced paint application:

Paint Reduction -- 113,520 gal.
Bead Rate -- 6 lbs. per gal
113,520 x 6 x .135 = $92,000

Annual Savings = 125,000

Revised Stripe Pattern

- Pattern 1: Freeways & Rural Conventionals w/Design Speed 45
- Pattern 2: Conventional Urban & Rural w/Design Speed 45

Reduction:
- Pattern 1 - 33%
- Pattern 2 - 22%

Avg. 60% - 1,40% -2, 28.5%

Annual Dash Stripe Paint Usage (reduced thickness) 55,890 gal.

Reductions:
Paint - 55,890 x 28.5% = 15,925
Beads - 15,925 x 4 = 63,700

Annual Savings: Paint - 15,925 x 3.00 = 47,780
Beads - 63,700 x .135 = 8,600 — 55,000

Revised Marker Pattern 245,000

Reduced Red Backs 35,000

Total Annual Savings $800,000

(Equals 15.7% of total pavement delineation budget)

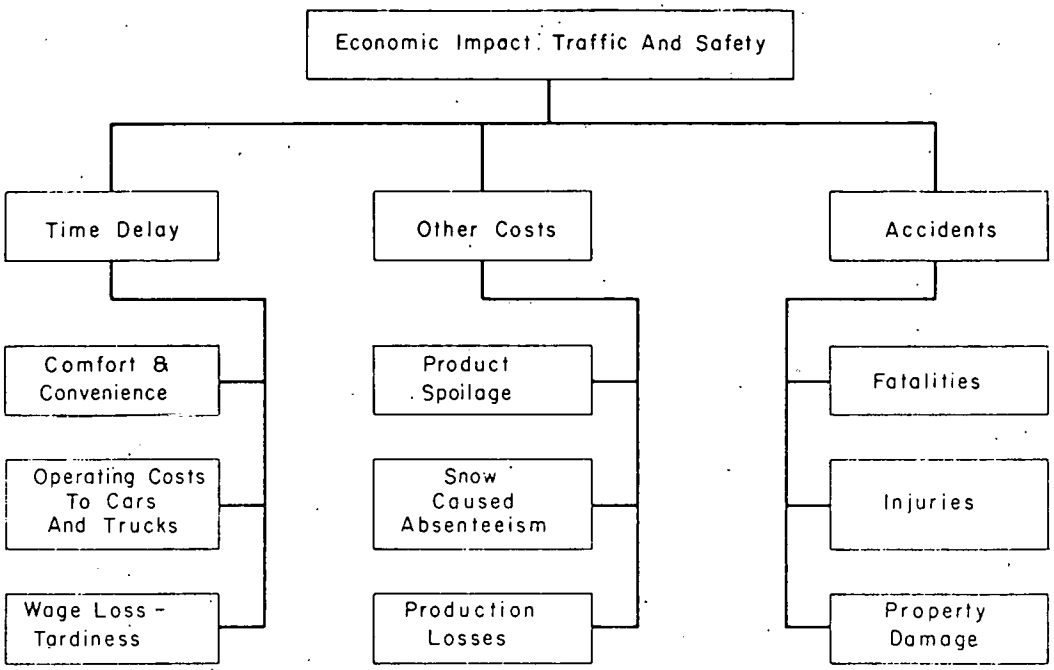


Figure 15. Economic loss caused by roadway snow and ice (12).

categories of maintenance activity where savings can be realized through reduced service levels.

Routine maintenance—Reduction in roadway lighting, litter pickup, patrolling, guardrail and sign cleaning, and mowing have been implemented and evaluated.
Snow and ice control—This program has been modified by reducing patrols, eliminating some night shifts, using smaller vehicles where possible, and changing plowing procedures.
Equipment use—Fuel economies were realized through use of smaller vehicles for personnel movements and better vehicle maintenance and operating procedures.
Miscellaneous—Other energy savings were achieved by application of 4-day (10-hour) work weeks, use of emulsions, and better management of parts and materials movements.

Although Washington State indicates that public information programs and carefully administered conservation measures have not caused observable impacts in highway appearance or public criticism, no quantifiable measures of impacts on the highways or users were reported to have been taken.

Design

Deferred maintenance decisions may include consideration of the optimum timing for maintenance decisions—at the time the facility is being designed. Many design decisions have had an important effect in reducing or deferring maintenance without loss of service life or reductions in maintenance quality.

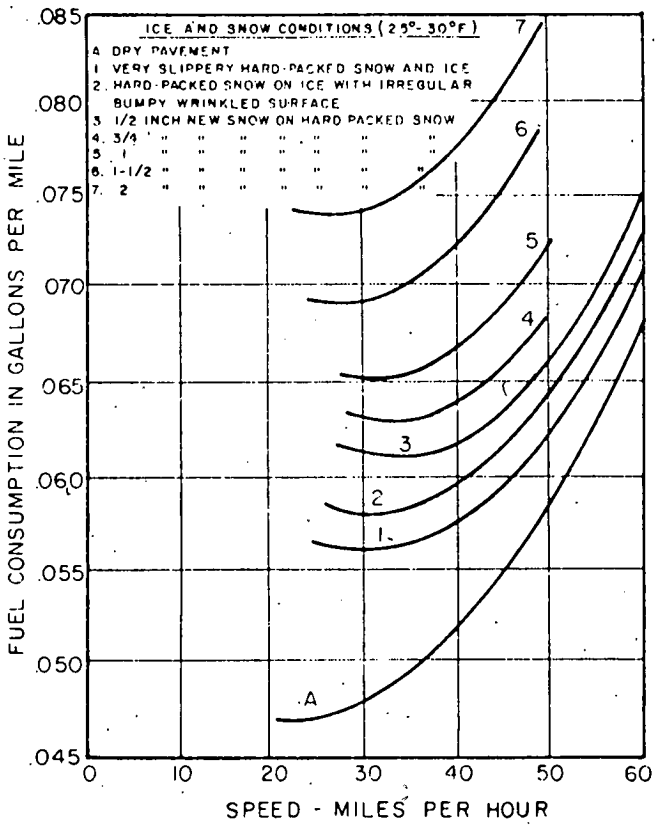
Design alternatives can be evaluated when considering ways to defer maintenance programs. The opportunity exists for significant additional improvements in the maintainability of highway systems. The FHWA published a report in 1978 on the "Integration of Maintenance Needs into Preconstruction Procedures," which provides details and recommendations for accommodating or reducing maintenance in planning and design of roadways and structures (Figures 17-19).

Location and design studies need to include such maintenance considerations as:

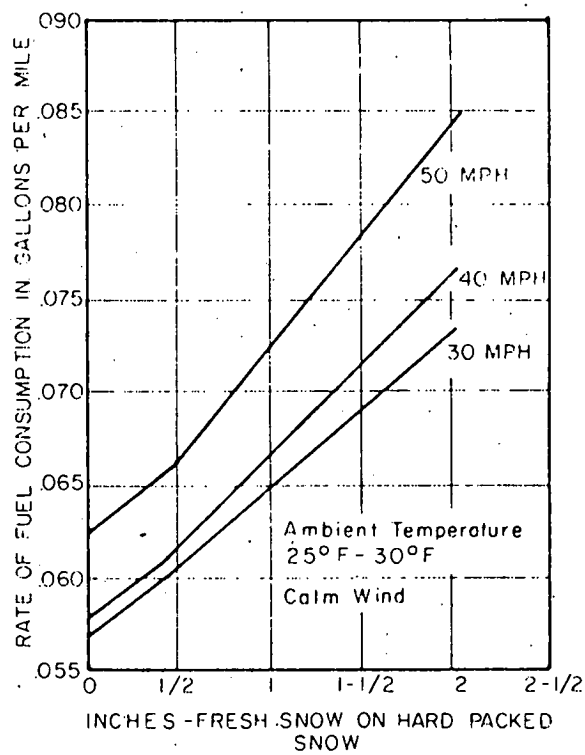
- Snow and ice control, storage, and melt run-off.
- Accessibility to drainage features and structures.
- Minimizing use of appurtenances such as guardrail, delineators, and barriers.
- Mechanization of maintenance operations such as pavement and drainage cleaning, mowing, and litter removal.
- Reduction in isolated, inaccessible areas which trap litter or require mowing.

Under an FHWA research project in 1974, an attempt was made to develop a rational approach to the establishment of warrants for the use of "premium" pavements permitting reduced maintenance. As a part of that study, the influence of maintenance and rehabilitation work (roadway occupancy) on the motorist was assessed. Using field data collected under a wide range of roadway closure conditions, motorists costs as determined by lost time, accidents, and pollution were computed.

Fuel consumption rates of a passenger car for various ice and snow conditions.



Relationship between snow depth and rate of fuel consumption of passenger cars



Correction factors to ajust passenger car fuel consumption for ice and snow conditions.

Speed (MPH)	Dry Pavement	Very Slippery Hard - Packed Snow	Hard - Packed Snow On Ice With Bumpy Surface	New Snow On Hard - Packed Snow (in)				
				1/2	3/4	1	1-1/2	2
20	1.00	1.33	1.30	1.36	1.43	1.47	1.51	1.60
30	1.00	1.16	1.20	1.28	1.32	1.35	1.45	1.54
40	1.00	1.11	1.14	1.20	1.23	1.28	1.40	1.48
50	1.00	1.06	1.10	1.12	1.18	1.24	1.34	1.45
60	1.00	1.04	1.08	1.10	—	—	—	—

NOTE: Correction factors are designed to be applied to values in Table 6 of NCHRP Report 111. They may however also be applied to any valid passenger car fuel consumption rates for operation on dry pavement.

Figure 16. Fuel consumption for automobiles by road surface condition (12).

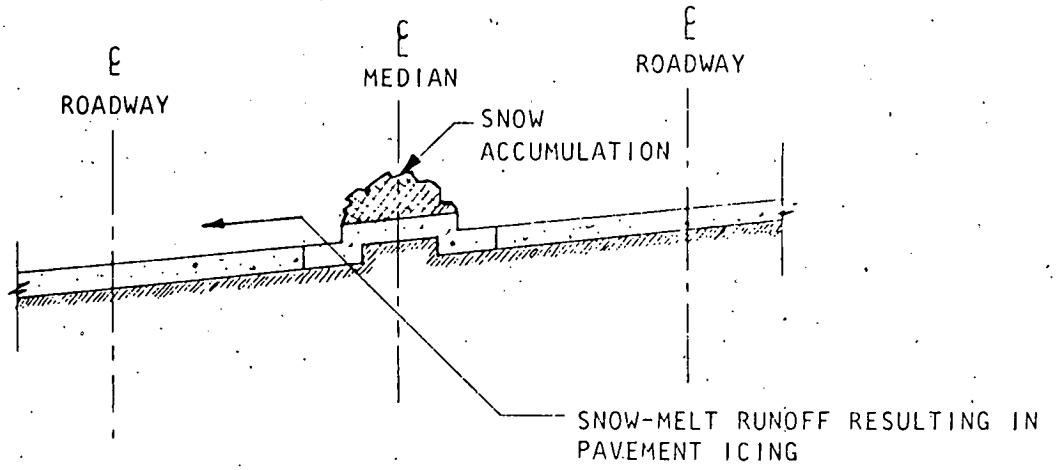


Figure 17. Raised median or gore area resulting in pavement icing.

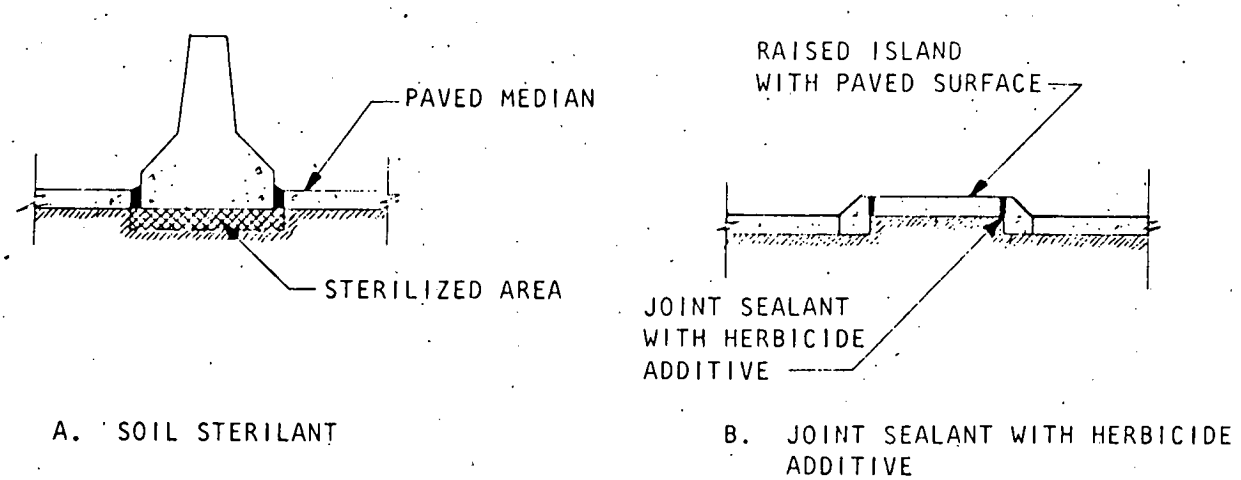


Figure 18. Techniques for preventing vegetation growth in joints.

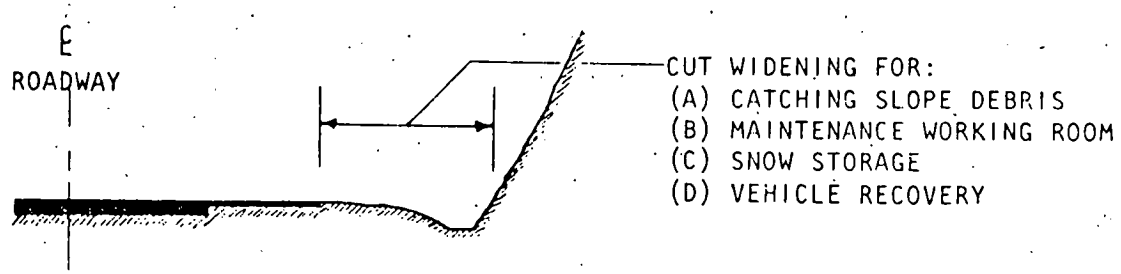


Figure 19. Cut section widening.

TABLE 7

EXAMPLES OF LEVELS OF SERVICE, SNOW ACCUMULATION, AND PLOWING FREQUENCY *(12)*

State	Level of Service	In. Snow Accumulation	Plowing Frequency
Michigan	1	1/2	-
	2	1	-
	3	2	-
	4	-	-
	5	-	-
Minnesota	1	1	120 min.
	2	1-1/2	180 min.
	3	3	240 min.
	4	-	-
	5	-	-
New Hampshire	1	1	60 min.
	2	1-1/2	90 min.
	3	3	120 min.
	4	-	180 min.
	5	-	-
Virginia	1	1	-
	2	2	-
	3	6	-
	4	-	-
	5	-	-

A computer program was developed to perform an economic analysis of roadway occupancy for maintenance and rehabilitation. The user specifies the pavement design and traffic. The problem then generates hourly traffic volume by (a) trip purpose, direction, and year; (b) vehicle operational cost as a function of vehicle weight, speed, and project design alignment; (c) value of time by trip purpose, income level, and time loss; and (d) annual workload by activity. The influence of roadway occupancy on the motorist is executed hourly for each activity and lane closure. The resulting operational, time, accident, and pollution impacts are combined for all feasible closures including traffic detours and crossovers.

Using this computer program, a 10-mile section of 8-lane portland cement concrete was analyzed for a 20-year life. Applying an 8 percent interest rate, the present worth of maintenance, rehabilitation, and motorist costs was $1,061,000. This was composed of 38 percent for maintenance and rehabilitation, 25 percent for motorist operation cost increases, 35 percent for the value of time losses, and 2 percent for increased accident costs.

Thus, in the example, an additional $1,061,000 could be spent on the initial construction of a "premium" pavement, if this investment would yield a maintenance-free pavement for 20 years.

CHAPTER THREE

CONCLUSIONS AND RESEARCH NEEDS

CONCLUSIONS

In summary, there is a significant trend toward deferring maintenance on U.S. highways today. The impact of this deferment is not fully understood, but it is being studied.

Three areas of study show promise. The first is a study of techniques for measuring the level of maintenance being achieved on the highways. Currently, condition surveys and some instrumented measurements on pavements are being used for this purpose.

Second, studies are being made of techniques for evaluating alternative levels of maintenance. Methods are being developed to quantify the impact of each maintenance activity on safety, service life of the facility, rideability, and esthetics. Trade-off analyses are being developed to weight impacts and alternatives.

Third, studies have been made to establish methodologies for quantifying the life-cycle costs of highway maintenance as a basis for evaluating the alternative investment in highways that are maintenance-free, that reduce the need for maintenance, or that accommodate efficient and low-cost maintenance procedures.

None of the available management techniques is free of variables that depend on judgment. But the management decision process is being structured through evolution. Out of that structure, managers can achieve a better understanding of the impact that their decisions will have on highway systems, highway users, and upon the economy, society, and environment.

RESEARCH NEEDS

The pronounced absence of quantitative data and specific evaluation procedures for many aspects of maintenance impact provides an open field for research. Several specific areas of study need to be considered.

Maintenance vs. Reconstruction Evaluation

Several agencies have probed the questions of costs and benefits that can be assigned to high maintenance levels vs. minimum maintenance levels and earlier reconstruction. By deferring maintenance, as many agencies are doing today without choice, the reconstruct option is being exercised without full knowledge of the costs. A research

program is needed on a regional or nationwide basis in which carefully selected sections of highway are maintained under controlled conditions with complete reports on resources expended and resulting physical and operational conditions of the highway. An analysis of such data may permit the correlation of maintenance level, cost, and service life in reliable models that can be used by maintenance managers.

Service Level Measurement

The quantitative measurement of maintenance service levels is a capability badly needed for managing, controlling, and evaluating maintenance programs. Without this tool, the evaluation of the impact of deferred maintenance is dependent, in part, upon judgmental values. The measuring of service levels must permit a practical, consistent, economical, field measurement procedure to be used. Sampling concepts need to be considered, as do automated data collection devices and techniques.

Service Level-Maintenance Effort Relationship

Many maintenance programs have been predicated on the assumption that there is a direct and simple relationship between the maintenance effort expended and the maintenance service level achieved. These assumptions may not be valid if maintenance service levels are defined to express both physical and operational conditions of the highway.

The Caltrans study to optimize traffic lane delineation suggests that, in some areas, reduced maintenance effort may not result in reduced maintenance service levels. The Queensland, Australia, study, on the other hand, shows that some reductions (i.e., no edgelines on narrow pavements) may have more than one effect in lowering service levels (i.e., reduced lane delineation and increased pavement edge deterioration).

The relationships of all major maintenance activities to maintenance service levels under sets of condition variables need to be studied. This will probably require a series of individual research projects.

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