NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 153

EVOLUTION AND BENEFITS OF PREVENTIVE MAINTENANCE STRATEGIES

TRANSPORTATION RESEARCH BOARD
National Research Council

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EVOLUTION AND BENEFITS OF PREVENTIVE MAINTENANCE STRATEGIES

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

TRANSPORTATION RESEARCH BOARD
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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. 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.

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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 National Research Council 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 the responsibilities of the National Research Council and the Transportation Research Board.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, 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 useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on 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 these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to maintenance managers, maintenance engineers, and others concerned with the implementation and evaluation of preventive maintenance strategies. Detailed information is presented on the formulation, use, and assessment of this type of maintenance strategy.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available 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 reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Preventive maintenance strategies are viewed as a means for improving the effectiveness of state highway maintenance programs. This report of the Transportation Research Board describes the preventive maintenance (PM) practices of several states, along with the rationale for these practices. It covers the history of PM along with funding considerations, strategy development, and cost analysis. Recommendations regarding current practices and future funding schemes are also included.

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 researcher 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.

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Special appreciation is expressed to Louis G. O'Brien, President, SURTECH Engineering, who was responsible for the collection of the data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Gary R. Allen, Senior Research Scientist, Virginia Transportation Research Council; Dorothy L. Andres, Maintenance Engineer, New Jersey State Department of Transportation; Kenneth A. Brewer, Professor of Transportation Engineering, Department of Civil Engineering, Iowa State University; Byron N. Lord, Chief, Pavements Division, Office of Engineering and Highway Operations Research and Development, Federal Highway Administration; Michael J. Markow, Principal Research Associate, Massachusetts Institute of Technology; George P. Romack, Highway Engineer, Program Management, Federal Highway Administration; Michael M. Ryan, Director, Bureau of Maintenance and Operations, Pennsylvania Department of Transportation; and Robert G. Sorcic, Pavement Management, City of Salt Lake Public Works.

Adrian G. Clary, Engineer of Maintenance, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

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

EVOLUTION AND BENEFITS OF PREVENTIVE MAINTENANCE STRATEGIES

SUMMARY

Road maintenance has evolved from being the responsibility of owners of property located adjacent to the road in 19th century agrarian society, to a national program accounting for approximately 25 percent of the total expenditures for roads of a complex industrialized society. Maintenance has developed into an intricate, large-scale function that is still plagued with doubts about effectiveness and funding.

Today's highway and bridge maintenance programs require a professionally managed, highly skilled, well-trained work force to execute effective maintenance activities efficiently. These programs are using a more systems-oriented approach to developing resource requirements and program allocations. Improved management techniques are being applied to ensure adequate planning, programming, budgeting, scheduling, and evaluation of maintenance activities.

The results of surveys for this synthesis indicate strong support for preventive maintenance (PM) as a cost-effective measure. Seventy-eight percent of the chief executive officers (CEOs) of state highway agencies agree that "in times of limited funding, state maintenance programs should be fully funded even if some construction and administrative programs must be delayed or reduced." This might be best summed up as a policy of "maintenance first." However, this support is shown as waning when 90 percent of the CEOs would not lapse federal funding and use the state matching share to fund state maintenance programs 100 percent.

With the success of the Federal Highway Administration's Resurfacing, Rehabilitation, Restoration, and Reconstruction (3R and 4R) program in reversing the downward trend in the condition of pavements on our major highway networks and the help this program has given maintenance, the leveraging of state funds for this type of federal program should be considered an extension of the maintenance program. However, most CEOs are not interested in funding routine maintenance with federal aid.

Cost-effective preventive maintenance is largely dependent on the timing of the activity and the quality of the work performed. For a PM strategy to be successful, it must be recognized that it is cyclic and requires scheduling. It must be properly funded over a period of years to be effective. Deferring PM only increases reactive maintenance and accelerates deterioration. Nowhere is this more evident than in bridge and Interstate highway maintenance programs.

"Do it right" performance on routine and PM activities is a key element in the durability of the repairs and their cost-effectiveness. Designing PM into construction and reconstruction projects can pay big dividends when the cost of traffic delays caused by routine maintenance and PM activities on high-volume expressways and arterial highways is considered.

The emphasis on preserving our existing capital assets through a "maintenance first" policy has gained broad acceptance. It is now an accepted fact in many organizations and countries that properly timed and executed PM activities will extend the useful service life of a highway facility and delay higher-cost major rehabilitation on reconstruction projects beyond the original design life.

There is a "force for change" advocating an approach of "maintenance first," but it is important to follow up these policies with evidence that funds are effectively used. Building and improving public awareness of the need for maintenance is important. Using data from the various management systems in a coordinated effort to identify PM requirements, program PM activities, and evaluate accomplishments is essential for successful long-term PM programs.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Highway maintenance managers find it difficult to get adequate resources to meet all maintenance program needs. In many agencies this causes the deferral of some maintenance projects and reduced levels of service. Synthesis 58 (*1*) describes the scope of this problem. This 1979 report clearly documents the failure to fund maintenance and the results of deferring preventive maintenance (PM) programs to future years. The backlog of work and subsequent acceleration of structural deterioration greatly compounds the cost of correcting the problems that occur. According to the report, nationally there was only a 10 percent real growth in highway maintenance funding between 1967 and 1977, whereas the number of vehicle miles traveled increased by 50 percent.

More recent data (Table 1, *2*) indicate that the percentage of total disbursements for highway maintenance and operations has improved. However, the $8.731 billion increase between 1977 and 1986, when adjusted for inflation, represents only a 3 percent real growth in nine years. Between 1979 and 1986, vehicle miles traveled increased 20 percent nationally (*3*). Truck travel grew by 44 percent, and the number of trucks with multiple trailer combinations increased by 25 percent.

Table 1 also shows that during the 1960s, more funds were spent on capital outlays than on all of the other categories of highway expenditure combined. Between 1977 and 1982, funding for maintenance received a significant boost. However, by 1986, the data show that capital outlays had recovered at the expense of maintenance and operations funding. (It is also worth noting that administration and highway patrol and safety funding percentages have grown significantly over the past 20 years.)

Although the total disbursements for maintenance and operations did improve, there is evidence that these gains are not being maintained. Some organizations are still not completely committed to adequate maintenance funding. In some cases, the maintenance allocation is determined by subtracting the dollars for the design, construction, and overhead budgets from the total amount of funds available. The remaining amount becomes the maintenance budget. As Table 1 indicates, transportation executives, legislators, and budget analysts have become aware of the underfunding of highway and bridge maintenance and have promoted a shift toward increased funding for maintenance programs. However, recent data indicate that there is a shift away from high-level maintenance funding again.

Budget and program managers still have concerns regarding the best way to spend maintenance money. The cost-effectiveness

TABLE 1
DISBURSEMENT AND PERCENT OF TOTAL FOR HIGHWAYS BY FUNCTION (*2*)[a]

Years		Capital Outlay	Maintenance & Operations	Administration	Highway Patrol & Safety	Debt Service	Totals
1962	$	7,386	2,839	537	383	1,157	12,302
	%	60	23.1	4.4	3.1	9.4	100
1967	$	9,661	3,772	906	777	1,553	16,669
	%	58	22.6	5.4	4.7	9.3	100
1972	$	12,275	5,443	1,600	1,671	2,220	23,209
	%	52.9	23.4	6.9	7.2	9.6	100
1977	$	13,079	8,612	2,370	2,842	2,929	29,832
	%	43.8	28.9	7.9	9.5	9.9	100
1982	$	19,052	13,319	3,152	4,018	3,736	43,327
	%	44	30.7	7.3	9.4	8.6	100
1986	$	31,712	17,343	4,386	5,950	5,257	64,648
	%	49.1	26.8	6.8	9.2	8.1	100

[a]All units of government (in millions of dollars).

of preventive maintenance programs such as crack sealing, surface treatment, bridge painting, etc. is often questioned. Preventive maintenance programs are often deferred or cut back during times of fiscal restraint.

Preventive maintenance is a strategy dependent upon a manager's knowledge and experience. One benefit of scheduled PM recognized by managers is a reduction of reactive maintenance. Preventive maintenance should be a part of the "corporate culture" of transportation agencies. Belief in PM by chief executive officers (CEOs) and their staffs is an essential element for a successful long-term PM program.

There are not enough resources to perform all of the response and preventive maintenance activities in most highway agencies. Therefore, in a tight budget, there must be strong justification for reallocating funds to PM.

Figure 1 illustrates the importance of PM work programs (*4*). The dashed portion of the curve illustrates how timely PM, such as a surface treatment or thin overlays, at 15 years (the first break in the curve) and 20 years (the second break in the curve), will restore and extend the useful life of a paved surface. A Utah study indicates that for each dollar spent on 2-in. maintenance overlays before surface failures, $3 are saved on heavy overlays after failure occurs (*5*). This study and others illustrate the importance of timing and proper execution of PM activities. Appendix A shows one agency's approach to planning PM activities.

THE PROBLEM

Highway maintenance managers recognize the value of timely PM. However, because the benefits are often poorly defined, PM programs are, in many cases, not able to compete with other programs. Historically, great emphasis has been placed on highway improvements and pavement surfacing. Maintenance was somewhat relegated to "quick fixes" and emergency responses. Positive changes have occurred within many agencies with the advent of maintenance, bridge, and pavement management systems. Increased awareness of the importance of maintenance and the completion of Interstate construction has focused attention on the need to preserve and extend the useful life of existing highways and bridges. However, there still are highway agencies that defer maintenance. The fact that PM programs require timely execution to be cost-effective is still called into question by some budget analysts and executives who wish to reduce maintenance funding. However, delays caused by malfunctioning traffic signals, poor pavements, and bridge load limitations add to user and agency operating costs. The problems of moisture-induced weakening, corrosion, soil instability, materials durability, management of vegetation, personnel motivation, and design and construction standards have been identified as important factors affecting a comprehensive maintenance program. How can budget analysts, executive and legislative staffs, and the industry as a whole be persuaded to adopt the "maintenance first" corporate culture?

In a survey conducted for this synthesis, state highway organization CEOs are shown to support, up to the point of lapsing federal funds, a substantial shift in program emphasis toward maintaining the existing investment. Evidence that the Federal Highway Administration's (FHWA's) Resurfacing, Rehabilitation, Restoration, and Reconstruction (3R/4R) program is having a positive impact on reducing the miles of road rated as fair and poor should encourage more resources into this program. The ever-increasing use of highways for the movement of goods and people requires appropriate maintenance and rehabilitation strategies to meet this demand.

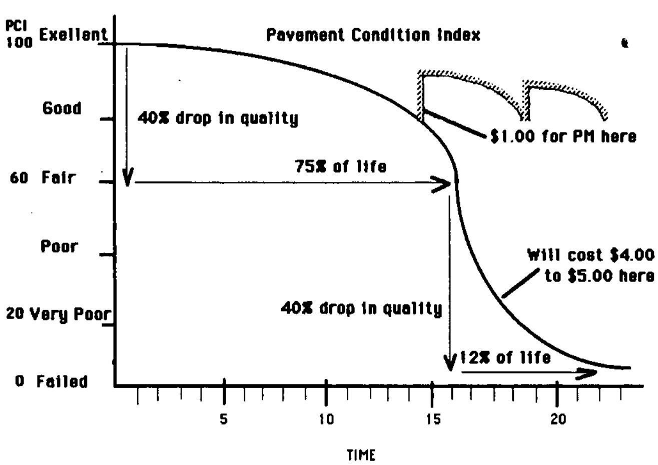

FIGURE 1 Typical pavement life-cycle.

APPROACH

Information for this synthesis was obtained from:

- Extensive literature search.
- Personal contacts and interviews.
- Survey of chief executives of state transportation departments.
- Survey of state, provincial (Canadian), city, and county maintenance and public-works managers.

OBJECTIVE AND SCOPE

The objective of this synthesis is to assist highway maintenance managers to broaden the acceptance of and communicate the value of timely preventive maintenance programs to transportation executives and legislative members. The benefits of PM are sometimes overlooked or are not well defined. Preventive maintenance programs are not always politically attractive. They often have difficulty competing for adequate funding. While addressing significant PM activities, this synthesis will look at other factors affecting the success of maintenance programs.

Common sense and experience must be used in evaluating PM benefits. Placing an objective value on PM benefits is most difficult because there are many variables involved (see Chapter 6). Looking at the perceived results of doing PM and the unintended consequences of deferring or canceling PM activities may help to define the benefits more clearly. Costs of PM activities are somewhat easier to obtain from accounting systems. However, lowest unit costs do not always ensure an effective PM activity. Quality assurance of the materials being used and their placement during construction and maintenance activities may be one of the most cost-effective PM programs an agency has or can adopt. Training personnel to "do it right" may be the key to what is a cost-effective PM activity, because quality usually determines the life of a repair or the effect of a PM activity.

This synthesis will also examine highway maintenance from a historical perspective, comment on the need for more maintenance input during the design phase of construction and reconstruction projects, and address the costs and benefits of PM. Some PM practices and subjective opinions on their cost-effectiveness will be discussed. The use of PM strategies, development of funding requirements, and implementation of programs will be addressed. The scope is limited to pavements, shoulders, bridges, drainage facilities, roadsides, some traffic services, and equipment areas.

HISTORICAL PERSPECTIVE

The concept of PM is rooted in the practices of the 18th century English military. Preventive maintenance was used to ensure firearms reliability. The incentive was simple: A gun that fails to fire may mean the difference between life and death and battles won or lost. Manufacturing and processing industries have been practicing scheduled maintenance to preserve functional performance for many decades.

In road maintenance, PM is of more recent vintage. Adequate attention to maintenance has been difficult to achieve since roads were first built in the United States. It has evolved from a strictly local problem for landowners adjacent to the road to a program of national concern (*6*). The years between 1850 and 1900 have been called the "dark ages of the rural road system" (*7*). During this period 1 ½ million miles of rural roads were built; most were unimproved, at best only ditched and graded. Local money was the main source of funding for roads. The first state road convention was held in 1883 in Iowa City, Iowa, to try to improve the poor conditions of rural roads. This was the beginning of "the good roads movement." The Office of Road Inquiries was established in the Department of Agriculture in 1893 to collect and disseminate information about good roads. In 1918, the Bureau of Public Roads conducted a study of maintenance and recommended:

- Stronger road surfaces and better drainage.
- Continual adequate maintenance with well-equipped year-round crews assigned to patrol specific sections of roads (*7*).

The automobile was first introduced in the United States in 1892, when agriculture was the principal economic activity. American industrialization was just beginning. In 1883, a Texas constitutional amendment provided a county tax for road work of $0.15 on each $100 of property valuation (*8*). In looking at the early history of modern highways in Texas and Pennsylvania (*8, 9*), it is readily apparent that the good roads movement was a national one. Similarities of action by these two states are listed here:

1879—Pennsylvania bicycle riders demand better roads, which results in the creation of the Side Path Commission.

1883—Texas institutes a county tax of $0.15 for each $100 of property valuation for road work.

1903—Pennsylvania establishes a Road Department to construct various types of roads in cooperation with townships and counties.

Texas passes a law authorizing counties to issue bonds for public roads and begins investigating a Bureau of Public Highways.

1905—Texas creates the Office of State Expert Engineer.

Pennsylvania increases the state share of road costs to 75 percent.

1909—Texas establishes a Commission of Highways.

1911—Texas starts a State Highway Department with state aid for construction and maintenance.

Pennsylvania sets up a system of state roads to be built and maintained at the sole expense of the state by a new Department of Highways.

1916—Federal Road Act of July 11 provides federal funding to aid states in the construction of rural post roads.

1921—Federal Highway Act requires states to handle the highway construction program and to establish maintenance programs for any roads built with federal funds.

1924—Texas creates a maintenance division to assume responsibility for maintenance of all state highways.

This illustrates how road responsibility evolved from a strictly local problem of landowners located adjacent to the roadway to a program of national importance.

In *The History of Public Works in the U.S.A.*, published by the American Public Works Association (APWA) (*6*), it states, "In the horse and buggy days, road maintenance usually failed to get adequate attention, except in the largest and best managed cities." As late as 1915, a convention of the American Society of Municipal Improvements concluded that "many cities spend large sums on roads and then do nothing to keep them in order, thereby losing outright a large part of their original investment." Discussions at this convention centered on the difficulty of obtaining an understanding of and support for a maintenance budget. From a historical perspective, it is evident that the underfunding of maintenance and its negative results are not new.

Maintenance in most states did not become a state function until the mid 1920s, when proper maintenance became a requirement for participation in the Federal-Aid Highway Program (*7*). Maintenance of state highways was not considered to require any special skills until the middle of the 20th century. In many states, a change in the governor would result in the replacement of existing highway maintenance crews with personnel whose qualifications were based on political party affiliation. The advent of an Interstate expressway system made skilled and experienced workers increasingly important. Proper maintenance of high-speed, high-volume highways is an expensive operation requiring up-to-date resources and management skills (*6*).

In 1948, the American Association of State Highway Officials (AASHO) published a policy on the maintenance of roadway surfaces, which became a valuable guide. This provided a major step in improving the technical base of highway maintenance.

Intensive research on the materials, equipment, methods, and management techniques used in maintenance has paralleled the growth of highway use. The Iowa Highway Department's Comprehensive Maintenance Study (*10*) in 1959–60 initiated a major change in management's approach to maintenance. This study objectively evaluated road maintenance, methods, materials, organizational techniques, resource allocation, and cost distribution. It also documented the need to improve the management of highway maintenance. Later, studies in Louisiana, Minnesota, Virginia, and the province of Ontario expanded the scope and molded the requirements for highway maintenance management systems (MMS). These systems focused on the establishment of standards, annual work programs, evaluation of performance, and improved budgeting techniques. In 1972, the French government initiated a research study into carriageway maintenance (*11*). The study concluded that:

> . . .the effect of a chronic pavement maintenance deficiency can be catastrophic over a long period and more so if the traffic is both intense and heavy and the climatic conditions unfavorable. France experienced such a situation during the 1960's and it was necessary to renew the entire main road network, affected by irreversible deterioration. . . .For all these reasons, the renewal and maintenance of the existing road substructure has today become the first priority road policy in most countries.

This study resulted in a comprehensive maintenance and rehabilitation strategy that places maximum efforts on preventive maintenance and pavement strengthening in France.

Recent History Affecting the Funding of Maintenance Programs

Some references have already been made to the problems of underfunded maintenance programs. In the 1960s and early 1970s, the Interstate highway construction program ran in high gear. Thousands of miles of expressways were opened. It was soon learned that these roads required greater maintenance efforts because of high truck use, heavier than anticipated truck loads (*12*), and the requirements of higher road standards for signing, lighting, roadside services, and landscaping. Truck travel doubled between 1970 and 1985 (*13*). In general, maintenance funding and programs did not keep up with the system's needs.

The full impact of this did not become clearly evident until the mid-1970s, when the older Interstate pavements, approaching their anticipated design life, started to deteriorate rapidly. Interstate pavements were designed for 20 years of heavy axle loading by a fixed percentage of truck traffic; however, with higher percentages of truck traffic than were originally anticipated, many highways were experiencing severe pavement distress in the 12th to 15th year.

In 1975, the average cost of Interstate maintenance was $1837/lane mile, or 26 percent higher than the average maintenance cost for primary roads. Although the Interstate network accounted for only 10 percent of the primary and Interstate mileage, 21 percent of the total maintenance dollars spent were directed at preserving the Interstate system (*14*). During this period, while nationwide maintenance expenditures rose from $3.8 billion in 1967 to $8.4 billion in 1977, the value of the dollar decreased by 50 percent. In terms of 1967 dollars, only $4.1 billion were spent for maintenance activities in 1977, or about 10 percent more than in 1968. Between 1979 and 1986 maintenance expenditures grew by only 3 percent. During this same period the number of truck combinations increased by 25 percent. In addition, in 1982 Congress increased the size and weight of trucks allowed on Interstate highways.

As stated earlier, inflation has limited the real growth in maintenance spending to meet increasing needs. Other factors contributing to inadequate maintenance funding and the backlog of work were:

- Insignificant highway or bridge construction was performed during World War II, so large sums of money were spent on new construction after the war (*7*).
- Many roads, streets, and bridges were not designed to carry today's traffic loadings.
- Early Interstate routes were built using the results of the AASHO Road Test, and it was a common belief that these roads would be fairly free of maintenance needs.
- Decline in the railroad systems of the Northeast, and the shift to heavy trucks, accelerated pavement deterioration.
- Because of increased traffic volumes and truck loading on rural primary and secondary networks, construction of low-cost seal coats and thin overlays was deferred in many areas. These PM activities were deferred or replaced with fewer miles of higher-cost thick hot-mix overlays required to meet new loading conditions.
- Substantial investments of resources in traffic control facilities, signing, and highway illumination required additional maintenance and operational funding.
- High traffic densities made performance of routine and preventive maintenance on urban commuter routes very difficult if not impossible. Restricting the hours of operation to daytime off-peak (9 a.m. to 3 p.m.) or nighttime periods reduced productivity and required more resources. In many cases extra funding was not allocated to urban areas to meet added expenses. It is still true today that many highway maintenance managers in urban areas complain about underfunding for their special needs.

CHAPTER TWO

MANAGEMENT PHILOSOPHY

For this synthesis, state highway CEOs and state, provincial, and municipal maintenance engineers were surveyed to obtain information on their attitudes toward PM, its funding, and its cost-effectiveness. The survey questions are shown in Appendixes B and C, and summaries of the replies are used throughout this synthesis. The state highway CEOs were asked about the cost-effectiveness of PM. Maintenance engineers were also asked to reply to questions on the cost-effectiveness of some typical PM activities. Both groups were asked for their opinions on additional funding for maintenance based on the following definitions.

DEFINITIONS

The division of activities between routine and preventive maintenance is not easily defined. It is acknowledged that some activities could fall into both categories. However, for this synthesis the following definitions were developed:

Routine Maintenance—A program to keep pavements, structures, drainage, safety facilities, and traffic control devices in good condition by repairing defects as they occur. It provides snow and ice control, and mowing services on an as-needed basis. Routine maintenance is generally "reactive maintenance." Typical activities include: pothole repair; shoulder grading; pipe, ditch, and inlet cleaning; blowup repair; spall repair; erosion repair; guardrail and attenuator repair and replacement; traffic control device repair and replacement; salting, sanding, and plowing; mowing; the operation and maintenance of roadside rest areas; and debris removal.

Preventive Maintenance—A program strategy intended to arrest light deterioration, retard progressive failures, and reduce the need for routine maintenance and service activities. Preventive maintenance is generally cyclic in nature. It is planned maintenance. Preventive maintenance activities do not significantly improve the load-carrying capacity of pavements, shoulders, or structures but extend the useful life and improve the level of service. Typical activities may include: crack and joint sealing; joint repair or rehabilitation; limited slab replacement; under sealing and mudjacking; base repair; surface treatment (fog seals, rejuvenators, slurry seals, oil and chips, thin plant-mix overlays); grinding; machine-laid patching; shoulder cutting or turfing; herbicide spraying; snow fence erections; thermoplastic striping;

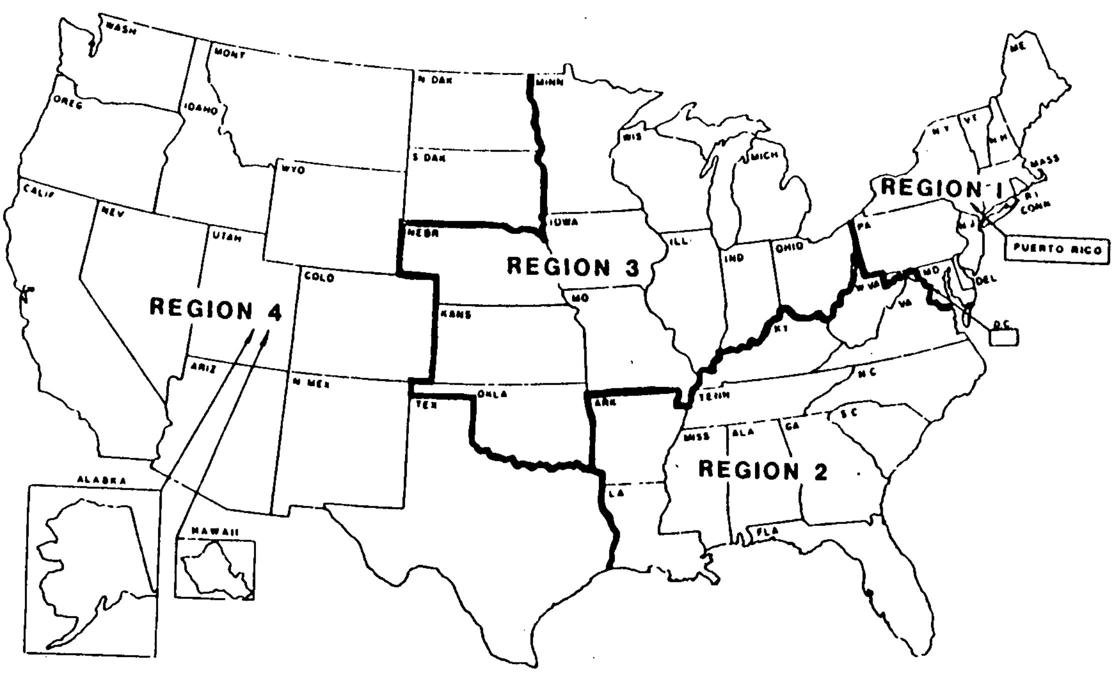

FIGURE 2 Map of AASHTO regions.

TABLE 2
CEO'S REPLIES TO QUESTIONS 1, 2, AND 3

AASHTO Regions	and No. of Replies	Question 1 - Fully Fund Routine Maintenance SA	A	U	D	SD	Question 2 - Fully Fund PM SA	A	U	D	SD	Question 3 - PM Is a Good Investment SA	A	U	D	SD
1	11	10	1				8	3				9	2			
2	10	5	5				3	7				4	6			
3	11	8	3				5	6				7	3	1		
4	14	8	6				6	8				6	8			
Totals	46	31	15				22	24				26	19	1		
Percentage		67	33				48	52				57	41	2		

bridge-deck sealing; cathodic protection; bridge painting; periodic traffic signal and street light servicing; and scheduled equipment maintenance.

SURVEY DESCRIPTION

The surveys were sent to 50 states, Puerto Rico, and the District of Columbia. Forty-six of the 52 CEOs surveyed replied to the questionnaire. In the survey of state maintenance engineers, 44 of the same 52 agencies replied; 25 of 46 municipal maintenance engineers polled replied. [In many cases the survey replies were also analyzed by AASHTO region (Figure 2).] Eleven Canadian agencies were polled and 10 replied. Of the six toll road agencies contacted, five answered the survey for maintenance engineers. A total of 84 of 115 maintenance engineers (73 percent) who were polled replied.

As earlier stated, funding and belief in the effectiveness of PM by CEOs is important. Questions 1, 2, and 3 addressed this area, and a summary of replies is shown in Table 2. Questions 4, 5, 6, and 7 of the CEOs' survey address funding, and replies are shown in Table 3.

The following code was used to interpret the entries in many of the tables in this synthesis: (SA) strongly agree, (A) agree, (U) undecided, (D) disagree, and (SD) strongly disagree.

Replies to question 1 indicate very strong support for funding routine maintenance. Also, fully funding PM received good support. The CEOs also thought that PM is a good investment, with 45 of the 46 replies being positive. The strongest agreement came from region 1 (Northeast) and region 3 (Missouri Valley).

Although CEOs feel PM is a good investment, their replies to question 4 indicate that 70 percent are undecided about or against making federal funds available for Interstate maintenance. However, 78 percent would agree to fully fund maintenance even if construction and administration is cut. This could be viewed as strong support for maintenance. However, when it comes to lapsing federal funding, 90 percent of the group said no. Their responses to question 6 set the limits for "maintenance first," and a majority (52 percent) would not spend federal funds

TABLE 3
CEO'S REPLIES TO QUESTIONS 4, 5, 6, AND 7

AASHTO Regions	and No. of Replies	Question 4 - Federal Funds Available Int. Maintenance SA	A	U	D	SD	Question 5 - Fully Fund Maint., Cut Const., etc. SA	A	U	D	SD	Question 6 - Lapse Federal Funds Yes	No	Question 7 - Use Federal Funds Yes	No
1	11	3	3	1	2	2	2	9	0	0	0	1	10	7	4
2	10	0	2	1	7	0	2	6	0	2	0	1	9	3	7
3	11	1	0	4	5	1	1	6	3	0	1	1	10	5	6
4	14	1	4	3	3	3	1	9	0	4	0	2	12	7	7
Totals	46	5	9	9	17	6	6	30	3	6	1	5	41	22	24
Percentage		10	20	20	37	13	13	65	6	13	3	10	90	48	52

TABLE 4
SUMMARY OF REPLIES TO QUESTION 7

Respondent	No. of Replies	SA	A	U	D	SD
State Chiefs of Maintenance	44	8	31	1	4	0
Local Chiefs of Maintenance	25	2	11	2	5	5
Totals	69	10	42	3	9	5

for maintenance programs. Factors influencing the decision not to lapse federal funds or spend them for maintenance could be:

- A large amount of federal funds are going to Resurfacing, Rehabilitation, Restoration, and Reconstruction (4R)-type projects that have a positive impact at state levels on reducing maintenance backlogs. The 4R funding is not new money, but comes out of the normal state apportionment.
- Capital projects are in the planning stage for years, and it is difficult not to honor commitments to build when federal funding is available.
- States often have a "grantsmanship policy" that tries to obtain as much federal funding as possible.
- Lapsing or losing federal funds is not politically popular.
- The majority opinion not to use federal funds may reflect the desire to avoid the paperwork and detailed documentation that may accompany the use of federal funds in force-account work (*15*).

By 1976, the FHWA had recognized that the backlog of deferred maintenance was reaching crisis proportions on many Interstate and primary highways. It was also evident that routine and preventive maintenance programs were unable to meet this need and correct structurally deficient pavements. A statement that the rate of pavement deterioration was 50 percent greater than the rate of reconstruction was quoted time and time again (*14*). Congress acted to reverse this trend by incorporation of the Restoration, Rehabilitation and Resurfacing (3R) program in the 1976 Federal-Aid Highway Act. This program was later expanded to include bridges and was termed the 4R program.

Question 7 in the survey of chiefs of maintenance (Appendix C) was aimed at evaluating the impact of 3R on maintenance needs. Table 4 summarizes the answers.

The data in Table 4 indicate that for states, 3R programs are seen as having a positive impact on their maintenance programs. This program allowed federal funds to be used for activities formerly 100 percent state funded. This allows states to leverage state funds with their allocated federal funds and to correct major deficiencies, thus reducing stopgap maintenance measures.

Local (municipal and county) chiefs of maintenance split on how much help 3R funding has been in aiding their maintenance programs. This is not unexpected because the Interstate and primary networks have been the major benefactors of 3R programs.

The physical conditions of our nation's principal highways (Figure 3) show that there has been progress in reversing the trend in declining pavement conditions on the nation's arterial system (*16*). On the Interstate system, the portion of total mileage rated in poor and fair condition has decreased from 27.3 percent in 1982 to 25.3 percent in 1985. Similarly, for other arterials, the portion of total mileage in poor and fair condition has decreased from 46.0 percent in 1982 to 41.8 percent in 1985 (*16*).

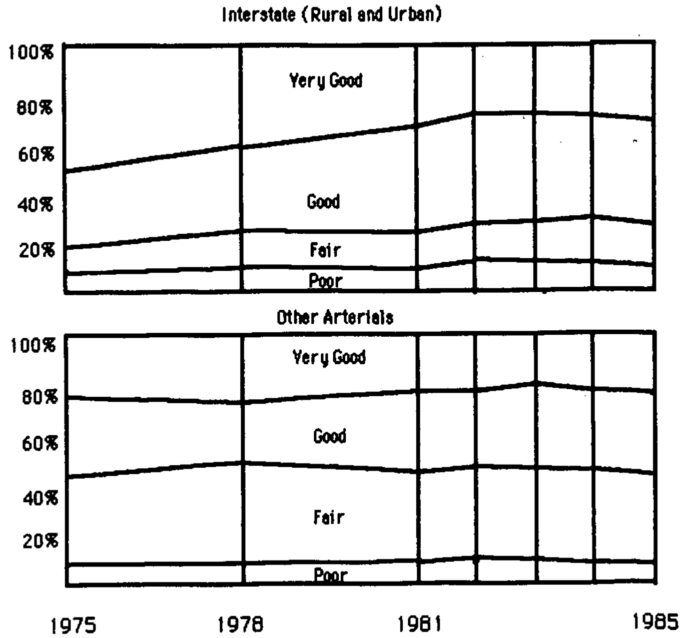

FIGURE 3 Pavement conditions of principal highways.

These data would tend to verify the state maintenance engineers' views that the 3R program has had a positive impact on their maintenance programs. Roads that are in good and very good condition usually require less maintenance than poor or fair pavements.

Increased Interstate and arterial 4R authorization in the 1982 Surface Transportation Act has prevented further pavement deterioration. The downward trend in pavement conditions on Interstates and arterials has been reversed. But additional funding will be required to eliminate the backlog of poor roads.

In addition to properly managing the maintenance program and effectively using the 3R/4R programs, adequate funding must be provided to preserve the existing pavements that are in good or very good condition. The 44 percent growth in all truck traffic, with the 25 percent growth in truck combinations between 1979 and 1986 (*3*), illustrates the ever-increasing demands placed on our highway network that maintenance must address. If deterioration of roads and bridges is to be significantly delayed, deferral of scheduled PM may not be the best budget option.

Managers should keep in mind that 3R/4R is not a panacea for all maintenance problems. First, 3R/4R programs do not receive additional funding but are financed from a state's normal allotment.

Second, if good PM is not practiced, roads will deteriorate faster, thus requiring more 3R/4R money. This will subtract from capital construction programs. Putting off PM and letting roads deteriorate until they qualify for 4R may not be the best way to optimize construction dollars.

Third, it may be more cost-effective to beef up the design standards for high-volume expressways and eliminate or reduce the need for PM on these facilities.

The replies to the questionnaires appear to indicate that the value of PM is recognized. However, lapsing federal funding appears to be the limit on this commitment. Maintenance programs should have an easier time competing with other programs for funding. However, the value of PM is still not recognized by some who control the purse. Requests for funds should be documented on a rational needs basis.

CHAPTER THREE

THE PREVENTIVE MAINTENANCE FUNCTION

It should be emphasized that PM activities share three common elements that determine the effectiveness of the activity. These elements are:

- Timing—Activities must be performed when their application would be effective in preventing deterioration, correcting weaknesses, restoring ridability, or extending useful life.
- Crew Training—The proper performance of PM activities has a direct effect on the life of the repairs.
- Planned Programs—PM is a cyclic, multiyear program that must be planned, programmed, and funded.

The definition of PM established for this synthesis spelled out certain items identified as typical PM activities. The questionnaires answered by chiefs of maintenance addressed some of these activities and requested opinions on cost-effectiveness and frequency of use. An indicator of frequency was included to help evaluate the replies. The survey data were analyzed on a regional basis to see if there would be differences between regions. The activity description statements gave non-PM alternatives. A clear choice was presented to the respondents.

Question 8a deals with pothole repairs, which is not a PM activity per se, but pothole repair is a maintenance activity that can be influenced by the PM position of the agency. The cost-effectiveness of "do it right" repairs (repairs done according to established procedures, which is considered a PM strategy) is still an open question for some. Therefore, this question was included to obtain a more definite answer as a follow-up to question 6. (See Table 19, Chapter 6.)

To evaluate their relative ranking, numerical weights based on the relative cost-effectiveness were assigned to each answer, and a numerical value, for ranking purposes only, was calculated by adding the products of the number of answers in each cost-effectiveness category by assigned weight value of that category.

The weight values were :

Very cost-effective (VCE) = 2
Moderately cost-effective (MCE) = 1
Undecided (U) = 0
Moderately ineffective (MI) = −1
Not very cost-effective (NVCE) = −2

Listed in Table 5 in numerical value ranking order are the eight activities evaluated. The highest possible score would be

TABLE 5
RANKING OF PM ACTIVITIES USED IN SURVEY OF CHIEFS OF MAINTENANCE

Ranking	Question and Topic Description	Total No. VCE & MCE	% of Total	Av. Freq. Score	Calculated Numerical Value	
1	"Do It Right" 8a Pothole Repair	79 of 84	95	5.92	119	
2	8f Herbicide Weed Control	66 of 81	81	6.27	113	
3	8e Surface Treatment	71 of 82	86	6.00	111	
4	8b Crack Sealing	67 of 84	80	5.76	96	
5	8c Joint Sealing	60 of 77	78	4.90	88	VCE
6	8g Elimination Tree Overgrowth	59 of 82	72	5.17	82	MCE
7	8h Spot Bridge Painting	59 of 82	72	4.09	78	
8	8d Spray or Skin Patching	61 of 84	73	5.40	74	

TABLE 6
RESPONSE SUMMARY TO QUESTION 8a

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	7	3	0	0	1	6.45	68
Local	3	1	2	0	0	0	4.66	67
Totals	14	8	5	0	0	1	6.07	68
2 State	10	7	3	0	0	0	6.20	85
Local	5	4	1	0	0	0	8.60	90
Totals	15	11	4	0	0	0	7.00	87
3 State	9	4	4	1	0	0	4.44	67
Local	9	3	5	1	0	0	3.55	61
Totals	18	7	9	2	0	0	4.00	64
4 State	14	5	8	1	0	0	5.00	64
Local	8	4	3	0	0	1	7.00	69
Totals	22	9	11	1	0	1	5.73	66
State Tot.	44	9	11	1	0	1	5.52	72
Local Tot.	25	12	11	1	0	1	5.80	68
Canadian Provinces	4	4	0	0	0	0	6.25	100
Local	6	3	3	0	0	0	7.00	75
Totals	10	7	3	0	0	0	6.88	85
Toll Rds.	5	2	3	0	0	0	8.60	70
Grand Totals	84	44	35	3	0	2	5.92	73

168 [84 (the total number of respondents) responses in the very cost-effective category $\times$ 2 = 168]. The lowest possible score would be -168 if all of the respondents felt that the activity was not very cost-effective. Although all eight activities received more than 70 percent positive (VCE or MCE) ratings, "do it right" pothole repair was given the highest ranking.

A frequency rating was an attempt to gather data on how frequently each activity is done. The chiefs of maintenance were requested to indicate on a scale from 1 to 10 the frequency of doing the subject activity. A value of 1 would indicate seldom if ever done. Ten would indicate a major activity using significant resources. The individual frequency ratings for each activity were averaged, and the results are in Table 5. Assuming that maintenance chiefs are scheduling effective PM activities more frequently, average frequency values above 5.00 and a high score of the activity's cost-effectiveness could indicate high professional support for a specific PM activity.

The 79 of 84 positive replies to question 8a (Table 6), the highest positive rating of cost-effectiveness, indicate that chiefs of maintenance feel very strongly that "do it right" pothole repairs are cost-effective. Frequency information would indicate that pothole repair is a major maintenance effort. However, responses by the chiefs of maintenance (Question 6, Table 19) indicate that in 50 of the 84 agencies a "dump and run" technique was generally used for pothole repairs. Conversely, the 5.92 frequency average, calculated from the responses from the maintenance chiefs, would indicate that the "do it right" technique was the dominant way of repairing potholes. Eighteen agencies that answered "yes" to question 6 gave frequency ratings greater than 5 in question 8a. The other 32 positive responses to question 6 gave low frequency ratings in 8a, as would have been expected. Scofield's lament (*17*), "How can you repair potholes by 'do it right' in a pothole riddled secondary road that is beyond repair and needs rehabilitation. . .," along with the replies to question 8a, may reflect the frustration generally associated with spring breakup.

Herbicide spraying for growth control was ranked second. However, in the West and Middle West regions and Canada, it received lower values than in other areas (Table 7). These three regions had larger percentages of replies from cities and counties

TABLE 7
SUMMARY OF RESPONSES TO QUESTION 8f

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	10	1	0	0	0	7.27	95
Local	3	1	0	2	0	0	4.67	33
Totals	14	11	1	2	0	0	6.71	82
2 State	10	7	3	0	0	0	7.50	85
Local	5	3	0	2	0	0	5.20	60
Totals	15	10	3	2	0	0	6.73	77
3 State	9	4	3	1	1	0	5.33	56
Local	8[a]	5	1	2	0	0	6.00	69
Totals	17	9	4	3	1	0	5.65	62
4 State	14	10	2	1	0	1	6.50	71
Local	8	4	1	1	2	0	4.75	44
Totals	22	14	3	2	2	1	5.86	61
State Totals	44	31	9	2	1	1	6.68	77
Local Totals	24	13	2	7	2	0	5.25	54
Canadian Provinces	4	4	0	0	0	0	5.25	100
Local	4[b]	1	1	2	0	0	5.75	38
Totals	8	5	1	2	0	0	5.50	69
Toll Roads	5	3	2	0	0	0	8.80	80
Grand Totals	81	52	14	11	3	1	6.27	71.8

[a]Milwaukee, Wisconsin did not reply to this question.
[b]Winnipeg and Toronto, Canada did not reply to this question.

where undesirable growth may not generally be a significant problem. Also, in many areas where crop protection and groundwater quality control are necessary, local environmental controls affect the use of herbicides. The high ranking of this activity is somewhat surprising with so much emphasis being placed on bridge and surface maintenance.

Because of its environmental impact, this activity must be very carefully planned and executed. Also, herbicide spraying is much less labor intensive than the presented alternative of manual or mechanical control. Labor cutbacks in many agencies may help explain its high ranking. This activity also received the highest average frequency score, 6.27.

Surface treatments (question 8e) was ranked third. Although its percentage of agreement was higher than that for question 8f (86 percent versus 81 percent), the calculated maximum values for 8f were slightly higher (113 versus 111). In Region 4 (West) there appears to be a very strong regional bias favoring this activity (Table 8). This is supported by a high average frequency score. However, toll road administrators did not place as strong a value on this activity as did state, Canadian, or local agencies. Toll road frequency scores indicate that this activity is conducted infrequently. It would appear that toll road administrators place a higher value on crack sealing and other PM activities. Because toll roads are generally very heavily traveled, the administrators may prefer more extensive and higher-cost surface rehabilitation done less frequently. Also, toll roads have higher revenues per mile for funding such repairs. It is evident that, with few exceptions, maintenance engineers value the effectiveness of surface treatments.

Crack sealing, traditionally a high-visibility PM activity, ranked fourth. This activity received very high approval from Region 1 (75 percent) and high approval from Region 4 (64 percent), Canadian provinces (65 percent), and toll road administrators (60 percent). As measured by the percentage maximum calculated numerical value, Regions 2 and 3 placed relatively lower values on this activity. They had low frequency values,

TABLE 8
SUMMARY OF RESPONSES TO QUESTION 8e

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	5	5	0	1	0	5.72	63
Local	3	1	1	1	0	0	6.67	50
Totals	14	6	6	1	1	0	5.93	61
2 State	10	5	5	0	0	0	6.10	75
Local	5	3	1	0	1	0	5.20	60
Totals	15	8	6	0	1	0	5.80	70
3 State	9	1	6	2	0	0	5.00	44
Local	9	6	1	1	1	0	7.56	67
Totals	18	7	7	3	1	0	6.28	56
4 State	14	11	3	0	0	0	7.57	89
Local	8	8	0	0	0	0	7.88	100
Totals	22	19	3	0	0	0	7.68	93
State Totals	44	22	19	2	1	0	5.64	70
Local Totals	25	18	3	2	2	0	7.08	74
Canadian Provinces	4	2	1	1	0	0	6.00	63
Local	4[a]	1	2	1	0	0	5.75	50
Totals	8	3	3	2	0	0	5.88	56
Toll Roads	5	1	2	1	1	0	4.00	30
Grand Totals	82	44	27	7	4	0	6.00	57.6

[a]Toronto and Winnipeg did not reply to this question.

especially at the local level, which supports this evaluation (Table 9). It should be noted, however, that Region 2 gave surface treatment high priority. Because surface treatment also addresses sealing out water from the pavement structure, the crack seal may not be as effective in this region.

"Value Engineering Study of Crack and Joint Sealing" (*18*) and Synthesis 98 (*19*) address the benefits of crack and joint sealing in preventing or retarding raveling or spalling of joints and cracks. The average life of joint and crack sealing was reported to be three to five years. The weighted average cost per lane mile of pavement for crack and joint sealing was reported to be $414 for rigid pavements and $147 for flexible pavements.

Experience has shown that several rules of thumb can be applied to crack sealing (*20*):

- If you can stick a pencil in the crack, fill it.
- Ninety percent of the reflective cracks will appear by the end of the third year in the life of a new surface.
- Use a high-quality product with a quality-minded crew.
- Wet weather is not crack sealing weather.
- Most sealant failures are bond failures. Over banding can reduce this type of failure.

It should be noted that Canadian agencies at the local level gave crack sealing the highest average frequency rating, 9.30, and the second highest average frequency total, 8.00. However, two provinces were unsure about its cost-effectiveness even though they indicated a 6.00 frequency rate.

Joint sealing, like crack sealing, is a high-visibility item that is perceived as essential PM. There has been considerable discussion on the cost-effectiveness of this activity in the research community (*21–23*). Eight responding organizations did not reply to this question; all but one were local agencies. The maximum numerical value was adjusted to reflect the number of responding agencies for the percent of maximum value calculation.

Region 4 and Canadian agencies placed high rankings on the cost-effectiveness of this activity. Conversely, toll road adminis-

TABLE 9
SUMMARY OF RESPONSES TO QUESTION 8b

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	6	5	0	0	0	6.18	77
Local	3	1	2	0	0	0	5.67	67
Totals	14	7	7	0	0	0	6.07	75
2 State	10	2	5	3	0	0	4.70	45
Local	5	2	1	2	0	0	2.80	50
Totals	15	4	6	5	0	0	4.07	47
3 State	9	3	3	1	1	1	4.11	33
Local	9	5	1	1	1	1	5.89	44
Totals	18	8	4	2	2	2	5.00	39
4 State	14	5	6	2	0	1	5.07	50
Local	8	6	2	0	0	0	6.88	88
Totals	22	11	8	2	0	1	5.73	64
State Total	44	16	19	6	1	2	5.07	52
Local Total	25	14	6	3	1	1	5.56	62
Canadian Provinces	4	1	1	2	0	0	6.00	38
Local	6	4	2	0	0	0	9.30	83
Totals	10	5	3	2	0	0	8.00	65
Toll Roads	5	2	2	1	0	0	7.60	60
Grand Totals	84	37	30	12	2	3	5.71	57

trators indicated a lower value, even though the average frequency rate is above 5.00, at 5.80. The agencies that agreed it was cost-effective had very high frequency rates. The other three regional areas were near the average frequency for the entire sample (4.90) for this activity. This may be expected because rigid pavements make up less than 4 percent of the total paved roads in the United States. However, 51 percent of the Interstate mileage is rigid pavements (*24*). Therefore, state highway agencies would have need for this activity on high-volume roads, where benefits could be more clearly observed (Table 10).

Question 8g may be viewed by some as stretching the concept of PM as defined for this synthesis. However, the scope addressed the control of moisture and vegetative management. Poor vegetation control can impede proper drainage. Shaded pavements stay wet longer. Because moisture penetration and high moisture content weaken the pavement structure, eliminating shaded pavements should improve pavement performance by reducing the duration of high-surface moisture conditions. Although mowing still accounts for more than half of the average roadside maintenance budget, 39 states reported reductions in mowing, whereas 30 states reported increases in their use of selective herbicides (*25*).

An analysis of the answers to questions 8g indicates that there are regional differences. These differences reflect the variation in the type and density of trees and brush. Toll road administrators, as with question 8f, put high priority on vegetation management and its value in a PM program (Table 11).

With all that has been written about the bridge crisis, one would assume that bridge spot painting would be a high-priority item. Although 59 of 82 respondents (72 percent) considered it cost-effective to spot paint, the frequency average of 4.09 would indicate that spot painting is not a big activity. It would appear that spot painting is considered very cost-effective in Region 2. Region 3 and toll road administrators are less enthusiastic about spot painting (Table 12). Because structure maintenance is so important, additional data on bridge painting strategies were obtained in question 9 (Table 13).

Question 9 asked the chiefs of maintenance to select which bridge-painting philosophy they used (maintain appearance, pre-

TABLE 10
SUMMARY OF RESPONSES TO QUESTION 8c

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	10[a]	4	6	0	0	0	4.30	70
Local	3	0	1	2	0	0	4.70	17
Totals	13	4	7	2	0	0	4.40	58
2 State	10	5	4	1	0	0	5.10	70
Local	4[b]	0	2	2	0	0	2.25	25
Totals	14	5	6	3	0	0	4.29	57
3 State	9	4	2	2	1	0	4.56	50
Local	8[c]	2	3	3	0	0	4.62	94
Totals	17	6	5	5	1	0	4.59	47
4 State	14	7	5	1	0	1	5.21	61
Local	4[d]	4	0	0	0	0	3.50	100
Totals	18	11	5	1	0	1	4.83	69
State Totals	43	20	17	4	1	1	4.84	61
Local Totals	19	6	6	7	0	0	3.89	50
Canadian Provinces	4	2	1	1	0	0	6.75	63
Local	6	4	1	1	0	0	6.50	75
Totals	10	6	2	2	0	0	6.60	70
Toll Roads	5	0	3	1	1	0	5.80	20
Grand Totals	77	32	28	14	2	1	4.90	57

[a]Vermont did not reply to this question. The state has no RC pavement.
[b]Orlando, Florida did not answer this question.
[c]Franklin County, Ohio did not answer this question.
[d]Four local agencies did not answer this question.

vent metal loss, maintain structural capacity only, or whatever can be done with money available).

The summary of answers to question 9 on bridge-painting philosophy indicates that 55 percent of the agencies paint only to prevent metal loss, 11 percent paint to maintain structural ratings, and 24 percent do whatever they can with the available funds. Only 10 percent used appearance as a criterion. There does not appear to be any significant regional differences among agencies that try to prevent metal loss. However, 37 percent of the agencies using a "money available" criterion are in Region 4. It would appear that although 76 percent of the responding agencies have a philosophy of maintenance painting, 24 percent report that money available is still the criterion. As suggested by one bridge engineer, "The cost of new environmental regulations for capturing lead chips and blasting materials on repainting projects makes repainting of old, functionally obsolete trusses not very cost effective" (*26*).

Today, bridge-deck maintenance is a major problem receiving much attention. Chemicals, moisture, overloading, fatigue, freeze-thaw cycles, and shallow cover of rebars are major factors contributing to this problem. Frequently, by the time the deck surface starts to show signs of serious problems, low-cost solutions are not very cost-effective.

Addressing these problems during design has become a national priority. Incorporating epoxy-coated rebars, requiring more cover over deck steel, and reducing live load deflections are cost-effective design steps for new and replacement decks. Some sealing treatments show promise if applied early enough (*27*). Cathodic protection shows great promise for some deck and substructure problems, particularly on large structures or in

TABLE 11
SUMMARY OF RESPONSES TO QUESTION 8g

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	5	4	2	0	0	6.09	64
Local	3	0	1	2	0	0	4.33	17
Totals	14	4	5	4	0	0	5.71	53
2 State	10	4	6	0	0	0	6.00	70
Local	5	1	2	2	0	0	3.60	40
Totals	15	5	8	2	0	0	5.20	60
3 State	9	4	4	1	0	0	5.10	67
Local	8[a]	3	1	4	0	0	4.12	44
Totals	17	7	5	5	0	0	4.65	56
4 State	14	3	6	4	0	1	4.86	36
Local	7[b]	3	2	0	1	1	5.43	36
Totals	21	6	8	4	1	2	5.05	36
State Totals	44	16	20	7	0	1	5.48	57
Local Totals	23	7	6	8	1	1	4.43	37
Canadian Provinces	4	4	0	0	0	0	5.25	100
Local	6	1	1	3	0	1	4.33	8
Totals	10	5	1	3	0	1	4.80	45
Toll Roads	5	3	0	2	0	0	6.60	60
Grand Totals	82	31	27	20	1	3	5.17	50

[a]Milwaukee, Wisconsin did not reply to this question.
[b]Phoenix, Arizona did not reply to this question.

combination with low-slump or latex-modified concrete (*28*). Perhaps the most cost-effective first step is to develop a bridge-deck maintenance and rehabilitation policy.

Cady suggests that this policy includes a decision-making strategy. He also suggests that applying a thin bituminous overlay after minimal patching with or without a membrane (depending on the age of the deck) is a cost-effective method of providing the traveling public with a good riding surface (*29*).

To reduce moisture and salt penetration, state agencies in Oregon, Michigan, and New Hampshire and others are using a thin (1-in. maximum thickness) polyester fiber-reinforced hot-asphalt concrete membrane that is designed with less than 1 percent air void. This membrane is immediately overlaid with a 1-in. standard hot-mix asphalt surface course. Some surface courses are reinforced with polyester fibers to retard rutting. Other agencies are using preformed polyester-reinforced modified asphalt membrane sheets that are overlaid with a thin surface course of hot mix.

The spray patch or skin patch addressed in question 8d received a relatively low score. Still, 61 of the 84 (73 percent) felt it was cost-effective. Toll road administrators and local Canadian agencies accounted for 80 percent of those who strongly disagreed in their evaluation. For toll road administrators, this response is consistent with their evaluation of surface treatment (question 8e). It does appear that Regions 3 and 4 favor this activity more than other areas and also give it high frequency ratings (Table 14).

The greatest differences of opinion appear to be among Canadian agencies. Although this activity received relatively high frequency scores, indicating wide use, it received lower numerical evaluations of its cost-effectiveness.

A word of caution about this item, which is very often used to correct localized failures. Taking corrective action to eliminate any drainage problems before or immediately after the skin patching operation is vital to the cost-effectiveness of this activity. It is highly probable that localized pavement distress is directly related to poor drainage or poor base material, which should be corrected if thin surface skin patching is to have significant longevity and be cost-effective.

In the area of equipment maintenance, question 10a asked, "Do you have a formalized equipment PM program?" Sixty-nine of the 84 respondents (82 percent) said yes (Table 15). Question 10b asked those who had a formalized equipment PM program "Was it cost-effective?" Twenty-six rated MCE and 38 had VCE for equipment PM (Table 15). With 64 of the 69 agencies (93 percent) responding positively about the cost-effectiveness of equipment PM, it appears that this program is beneficial.

The replies to these questions reveal that there are differences in the perceived cost-effectiveness of some PM activities between regions and types of agencies. The relatively high value placed on herbicide spraying was somewhat surprising when one considers all of the national emphasis that is placed on pavement and bridge maintenance. The differences reflect maintenance engineers' changing priorities to meet perceived needs. This also implies that there is not a standard formula for developing a cost-effective maintenance program across all regions and in all agencies. It is apparent that most managers recognize the value of the PM program concept but differ on priorities.

TABLE 12
SUMMARY OF RESPONSES TO QUESTION 8h

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	3	6	1	1	0	3.45	50
Local	3	1	1	1	0	0	5.33	50
Totals	14	4	7	2	1	0	3.86	50
2 State	10	4	6	0	0	0	4.80	70
Local	4[a]	2	1	1	0	0	3.25	63
Totals	14	6	7	1	0	0	4.36	68
3 State	9	3	4	1	0	1	4.89	44
Local	9	1	3	4	0	1	3.00	17
Totals	18	4	7	5	0	2	3.94	30
4 State	14	6	4	2	2	0	4.43	50
Local	8	3	3	2	0	0	2.75	56
Totals	22	9	7	4	2	0	3.82	52
State Total	44	16	20	4	3	1	4.36	53
Local Total	24	7	8	8	0	1	3.25	42
Canadian Provinces	4	4	0	0	0	0	5.25	100
Local	6	1	1	3	0	1	4.50	17
Totals	10	5	1	3	0	1	4.80	45
Toll Roads	4[b]	2	0	1	0	1	4.50	25
Grand Totals	82	30	29	16	3	4	4.09	48

[a]Orlando, Florida did not reply to this question.
[b]Illinois Toll Road did not reply to this question.

TABLE 13
RESPONSES TO QUESTION 9

AASHTO Regions	No. of Replies	Painting Philosophy: Maintain Appearance	Prevent Metal Loss	Maintain Structure Capacity	Money Available
1 State	11	0	7	0	4
Local	3	1	1	0	1
Totals	14	1	8	0	5
2 State	10	1	6	2	1
Local	5	1	1	1	2
Totals	15	2	7	3	3
3 State	9	0	5	3	1
Local	7[a]	1	3	1	2
Totals	16	1	8	4	3
4 State	14	2	7	0	5
Local	8	0	6	0	2
Totals	22	2	13	0	7
State Total	44	3	25	5	11
Local Total	23	3	11	2	7
Canadian Provinces	3[b]	1	2	0	0
Local	6	1	2	2	1
Totals	9	2	4	2	1
Toll Roads	4	0	4	0	0
Grand Totals	80	8	44	9	19

[a]Two agencies did not reply to this question.
[b]One agency did not reply to this question.

TABLE 14
SUMMARY OF RESPONSES TO QUESTION 8d

AASHTO Regions	No. of Responses	VCE	MCE	U	MI	NVCE	Av. Freq.	% Max. Value
1 State	11	3	5	2	1	0	3.90	45
Local	3	1	0	1	1	0	4.00	17
Totals	14	4	5	3	2	0	3.93	39
2 State	10	5	4	1	0	0	5.50	70
Local	5	0	2	0	3	0	3.80	-10
Totals	15	5	6	1	3	0	4.93	40
3 State	9	5	2	2	0	0	5.78	67
Local	9	3	4	1	1	0	5.11	50
Totals	18	8	6	3	1	0	5.44	58
4 State	14	9	5	0	0	0	7.78	82
Local	8	3	2	1	1	1	5.50	31
Totals	22	12	7	1	1	1	6.77	64
State Total	44	22	16	4	2	0	5.89	66
Local Total	25	7	8	3	6	1	4.68	28
Canadian Provinces	4	1	2	0	1	0	6.25	38
Local	6	1	2	1	0	2	5.17	17
Totals	10	2	4	1	0	2	5.60	15
Toll Roads	5	1	1	1	0	2	4.40	-10
Grand Totals	84	32	29	9	9	5	5.40	50

TABLE 15
SUMMARY OF RESPONSES TO QUESTIONS 10a AND 10b

	No. of Responses	Question 10a Do you have equipment PM?		Question 10b How cost-effective is equipment PM?				
		Yes	No	VCE	MCE	U	MI	NVCE
State Total	44	35	9	22	11	2	0	0
Local Total	25	21	4	8	11	2	0	0
Canadian Provinces	4	4	0	3	1	0	0	0
Local	6	4	2	2	1	1	0	0
Totals	10	8	2	5	2	1	0	0
Toll Roads	5	5	0	3	2	0	0	0
Grand Totals	84	69	15	38	26	5	0	0

CHAPTER FOUR

BRINGING ABOUT CHANGE

A POLICY OF "MAINTENANCE FIRST"

The 1960 Iowa maintenance study (*10*) was an important step in achieving a national focus on the highway maintenance problem. Between 1960 and 1976 there were many other maintenance management studies and pavement and bridge maintenance research projects initiated in the United States and Canada that provided a more objective insight into highway and bridge maintenance needs and funding requirements. Establishment of the 3R Program in the 1976 Federal-Aid Highway Act was another important milestone toward making "maintenance first" a reality.

In April 1986, a survey of maintenance officials (*30*) from 31 states, two Canadian provinces, and the District of Columbia identified "low funding of maintenance" as a significant barrier to improved highway maintenance management. In Pennsylvania, the Fiscal Review Task Force of the Pennsylvania Transportation Advisory Committee completed a study (*31*) of future highway needs to meet the challenge of the 1990s and beyond. In this study "maintenance forever" was given the highest priority. The report points out that Pennsylvania's $50 billion capital investment in roads and bridges must be maintained at a high level of service to provide the mobility necessary for maintaining economic growth and the safety of the traveling public.

Replies by CEOs discussed in Chapter 1 indicate that maintenance is given a high priority. A strategy of "maintenance first" appears to be receiving acceptance.

As further evidence of the shift to maintenance of existing highways, *ENR* (*32*) claimed more states were preparing to repair:

> Until the mid 1980's, close to two-thirds of federal aid went for new construction, FHWA figures show. But as federal aid construction fades, state DOT's are concentrating on upgrading a deteriorated road system and generating more money to fund their own programs. Of total contracts planned for 1988, 67 percent will go for 4R work compared to 62 percent this year. As planned, a 14 percent rise in 4R work would offset a nine percent decline nationwide in new road and bridge projects.

In the 1987 *AASHTO Maintenance Manual* (*33*), the definition of construction has been revised to include pavement and shoulder work "that would seal pavement surfaces to prevent water intrusion; that would substantially extend the service life of pavements; that would improve or restore adequate skid resistance; that would improve or restore the profile or cross slope of a pavement. . . ." The manual also includes a new definition of construction betterments: "Resurfacing of hard surfaces with bituminous material ¼" thick or more for a length of 500 continuous feet or more. . . ." This revised definition, which recognizes a ¼-in. seal as an improvement, is further evidence that surface treatments, as noted in question 8e, are viewed as effective in extending the useful life of pavements.

FUNDING MAINTENANCE PROGRAMS

For the maintenance program to be "first" it must receive adequate funding to accomplish routine and preventive maintenance programs. In addition to the funding views of CEOs, it was important to obtain opinions on this subject from the chiefs of maintenance (see Appendix C).

Question 1 asked if the maintenance program is funded by legislative appropriation. Thirty-six of the 44 states (82.0 percent) said legislative appropriation is required.

Question 2 determined that 35 of the 44 states (79.5 percent) receive the majority of maintenance funding from restrictive receipts or trust fund sources.

It would appear that if adequate funding is to be maintained or improved to keep up with maintenance needs, state legislatures will have to be convinced that there is a need. The use of a systems approach, as discussed in Chapter 5, could help document these needs.

To obtain the opinions of chiefs of maintenance concerning how they view four alternatives for maintenance funding, question 11 (Appendix C) was included in their questionnaire. Table 16 summarizes the replies to questions 11a through 11d.

The data in Table 16 show that 46 agencies (55 percent of the total responding) did not agree to fund maintenance through bonds. These 46 agencies included 28 states (64 percent of the responding states) and 15 local agencies (60 percent of the local respondents). Sixty of the respondents (72 percent of the total) favored raising state taxes to finance additional maintenance. Thirty-five states responding (80 percent) and 20 local governments (80 percent) agreed to this method. Using federal funds was favored by 50 agencies (60 percent of the total), but only 22 state maintenance chiefs (50 percent of that group) favored this option. However, this is significantly more than the 14 state CEOs (31 percent of that group) who favored federal funding of maintenance, as discussed in Table 3. Twenty of the 25 local agencies (80 percent) favored using federal funding.

Fifty of the 84 respondents (60 percent) rejected collecting tolls on high-volume Interstates as a way of funding maintenance. Not unexpectedly, four of the five toll road administrators favored this as an option. They also favored using federal funds for this purpose. Thirty-five of the 44 states (80 percent) did not see tolls as a way to get additional funding.

Twelve of the 25 local agencies (48 percent) objected to placing tolls on high-volume Interstates. Generally, Canadian provinces

TABLE 16
REPLIES TO QUESTIONS 11a THROUGH 11d

AASHTO Regions	No. of Replies	11a Bond Funding					11b Raise State Tax					11c Use Federal Funds					11d Place Tolls				
		SA	A	U	D	SD	SA	A	U	D	SD	SA	A	U	D	SD	SA	A	U	D	SD
1 State	11	0	4	2	3	2	3	4	2	2	0	1	5	1	3	1	0	1	2	6	2
Local	3	0	2	1	0	0	0	2	0	1	0	1	1	1	0	0	0	2	1	0	0
Totals	14	0	6	3	3	2	3	6	2	3	0	2	6	2	3	1	0	3	3	6	2
2 State	10	1	2	1	5	1	2	5	2	1	0	1	5	1	3	0	1	1	1	5	2
Local	5	1	1	0	3	0	0	5	0	0	0	1	3	1	0	0	0	2	0	3	0
Totals	15	2	3	1	8	1	2	10	2	1	0	2	8	1	3	0	1	3	1	8	2
3 State	9	0	1	1	4	3	2	6	0	1	0	0	3	2	1	3	0	0	1	5	3
Local	9	0	0	1	3	5	4	3	2	0	0	2	5	0	1	1	0	0	3	2	4
Totals	18	0	1	2	7	8	6	9	2	1	0	2	8	2	2	4	0	0	4	7	7
4 State	14	0	2	2	5	5	1	12	0	1	0	2	5	5	1	1	0	1	1	10	2
Local	8	0	3	1	3	1	2	4	2	0	0	1	6	1	0	0	0	1	4	2	1
Totals	22	0	5	3	8	6	3	16	2	1	0	3	11	6	1	1	0	2	5	12	3
State Totals	44	1	9	6	17	11	8	27	4	5	0	4	18	9	8	5	1	3	5	26	9
Local Totals	25	1	6	3	9	6	6	14	4	1	0	5	15	3	1	1	0	5	8	7	5
Canadian Provinces	4	0	0	3[a]	0	1	0	0	3[a]	0	1	0	1	3[a]	0	0	0	0	2[a]	1	1
Local	6	0	2	3[b]	1	0	0	3	2[b]	1	0	0	3	3[b]	0	0	1	1	3[b]	1	0
Totals	10	0	2	6	1	1	0	3	5	1	1	0	4	6	0	0	1	1	5	2	1
Toll Roads	5	1	2	1[c]	0	1	0	2	1[c]	2	0	1	3	1[c]	0	0	3	1	1[c]	0	0
Grand Total	84	3	19	16	27	19	14	46	14	9	1	10	40	19	9	6	5	10	19	35	15
% of Total	--	3	23	19	32	23	17	55	17	11	-	12	48	23	10	7	6	12	23	42	17

[a]One province did not reply to these questions.
[b]Three cities did not reply to these questions.
[c]One toll road did not reply to these questions.

and cities indicated that the questions on financial options did not apply to their situation, but most expressed a preference.

The message received is that the way of doing things has to change, that "maintenance is forever," and that "maintenance first" is perceived by many as an effective strategy. The challenge for maintenance administrators is to take advantage of the shift in emphasis to obtain sufficient funding and execute the programs needed to preserve the existing highway systems.

BUILDING PM IN TO DESIGN AND CONSTRUCTION STANDARDS

It is important that maintenance engineers and managers have an opportunity for input during the development of 4R and construction standards. Whenever possible, there should be a positive effort made to build in minimal maintenance features. This is particularly true in the case of urban expressways, where, ideally, vegetation management, snow and ice control, striping, sweeping, and litter pickup are the only significant maintenance items performed routinely. Maintenance activities on high-average-daily-traffic (ADT) roads usually cause considerable traffic delays and add significantly to user costs. Required PM activities such as spot painting and joint sealing, which extend the highway's life, should be avoided, if possible, by the specification of high-type coating systems and joint sealers on high-volume expressways. Preventive maintenance activities reduce future user costs by delaying major reconstruction to sometime in the distant future.

In the early 1970s multidisciplinary design teams were used by many states to plan and establish work items for safety improvement projects (scoping). Some agencies routinely include safety, maintenance, and construction personnel as participants in the design scoping and review process.

In 1978, FHWA published a report, "Integration of Maintenance Needs into Preconstruction Procedures" (*34*). This benchmark report provides details for reducing highway maintenance through the design process. Some examples of features that contribute to reducing maintenance are:

- High side shoulder superelevation of roadways and bridges, rolled over in a well-rounded cross vertical curve so that rainwater and/or snowmelt will not flow down across travel lanes. (See "AASHTO Policy on Geometric Design of Highway and Streets 1984," Figure IV-3, pp. 368, 391.)
- High-type performance concrete joint sealer, such as preformed neoprene joint seal or high-performance silicone joint filler.
- Saw and seal bituminous overlays of jointed concrete pavement.
- Incorporation of permanent pavement markings (hot or cold) during resurfacing operations.
- Specification of high-type aggregates (granite, trap rock, etc.) or life-extending additives such as polymers, fibers, antistripping agents, etc. for use in pavement surfaces on high-volume urban expressways, where surface repair maintenance usually causes major traffic delays. (See Appendix D for photos of PM designed into new construction.)

To most, the incorporation of maintenance concerns in the design process is not considered a part of PM. Knowledgeable designers and construction specification writers are aware of maintenance problems and try to prevent them when it is possible operationally and economically. However, in today's large organizations awareness does not always translate into desired actions or results.

Communication, coordination, and cooperation are the "three C's" to success. The formal use of multidisciplinary teams in project development and the development of standards and specifications should help to have more maintenance features included in construction projects. The book *In Search of Excellence* (*35*) is replete with examples of implementing the "three C's". For instance, ". . .at 3M and Texas Instruments they don't seem to have these problems. People simply talk to each other on a regular basis." Highway design, construction, and maintenance personnel should talk to each other on a regular basis.

To make the force for change permanent, management of public-works and transportation departments should be organized to promote the "three C's" among program, design, materials, construction, and maintenance engineers and field managers. The data collected in the surveys and evidence that timely PM activities can extend the useful life of capital investments demonstrate the need for adequate long-term funding and execution of PM programs.

CHAPTER FIVE

THE SYSTEMS APPROACH

MAINTENANCE MANAGEMENT SYSTEMS

Chapters 2 and 4 show that "maintenance first" has gained some acceptance. The challenge is to realistically define the maintenance program needs, estimate the budget to meet these needs, monitor performance, and evaluate results. This can be accomplished by using a systems approach. System does not mean that everything has to be on a computer. It does entail using an organized approach for planning, budgeting, scheduling, reporting, and evaluating work programs. An MMS is one approach to meeting these requirements.

Using the MMS approach, the manager:

- Quantifies maintenance needs.
- Identifies resources to meet these needs.
- Determines standards to measure accomplishments and set priorities.
- Monitors performance.
- Exercises program, budget, and expenditure controls.

The MMS can provide an improved rationale for maintenance funding and management of resources. Improvements in production through greater mechanization and employee training are important adjuncts to the MMS process. Better management information helps administrators to document needs and accomplishments and identify problems and training requirements.

In one state these systems were used to justify additional maintenance funding and win legislative and user support of a "maintenance first" program (*36*). Another state uses the results of its Maintenance Quality System to monitor the condition of key roadway elements such as pavements, shoulders, drainage structures, vegetation, etc. (*37*). Bar charts are developed annually that plot cost versus recordable conditions. These data are used to support program funding and to show the benefits of increased funding in terms of reductions in "reportable conditions" (see Appendix E).

In 1982, the AASHTO *Maintenance Aid Digest* (MAD) Number 26 (*38*) tallied replies from the 50 states to a survey on MMS. It indicated 41 states operated under MMS. Seven of nine that did not have MMS reported that they planned to develop a system.

The survey of maintenance managers for this synthesis indicates that 34 of the 44 states responding have MMS. A follow-up phone survey of five states that in 1982 had MMS but did not respond to this survey found that all five have kept MMS. A comparison of results state by state indicates that only two states have dropped MMS. It appears that 43 states (86 percent of all states) now have MMS, a net gain of 2 since 1982. Based on the data in Table 17, MMS is being used by a significant number of the maintenance organizations surveyed.

The chiefs of maintenance were asked about MMS in question 3a and 3b. Question 3a asked, "Does your organization have MMS?" and 3b asked, "Do you develop an annual work plan for PM activities?"

In Synthesis 110 (*39*) MMS is defined as

> controlling resources to accomplish a predetermined level of service through:
>
> Planning of work requirements.
> Budgeting to meet work requirements.
> Scheduling to achieve budget objectives.
> Reporting of accomplishments and resources used.
> Evaluating of accomplishments compared to work objectives.

The systems approach should improve:

- Budget development and documentation.
- The accuracy of cost information.
- The reporting of work program accomplishments and the provision of these data to other systems (i.e., pavement and bridge management, accounting, etc.).
- The identification of problem areas and unmet needs and provide an estimate of the required resources to meet these needs.

Maintenance administrators can use an MMS to evaluate the results of work activities in terms of work accomplished versus needs and maintenance deferred. Also, it can be used to predict the unintended consequences of not fully funding the maintenance program. At the systems level, accomplishment of surface maintenance work activities can be evaluated in terms of pavement conditions for a macroanalysis [e.g., Maintenance Quality Systems of Ohio DOT (*37* and Appendix E)].

The Strategic Highway Research Program (SHRP) has identified a technical research area (TRA) addressing maintenance effectiveness (TRA-3) (*40*). It is hoped that research efforts in this area, along with the SHRP Long-Term Pavement Performance Study (TRA-2), will give maintenance administrators and engineers more objective criteria for evaluating maintenance effectiveness.

In Table 18, shifts from routine to preventive maintenance are noted to illustrate what has happened over a long time span when an agency established a PM policy. Table 22 also illustrates how outputs from MMS can be used to evaluate the results of a PM policy.

Synthesis 80 (*41*) shows various methods used by states to formulate and justify budgets.

TABLE 17
REPLIES TO QUESTIONS 3a AND 3b

Agencies	No. of Replies	Questions 3a Have MMS?		3b Plan PM?	
		Yes	No	Yes	No
State Tot.	44	34	10	36	8
Local Tot.	25	14	11	20	5
Canadian Provinces	4	4	0	4	0
Local	6	6	0	6	0
Totals	10	10	0	10	0
Toll Roads	5	4	1	4	1
Grand Totals	84	62	22	70	14

One benefit of a systems approach is the identification of other organizational functions that may affect the maintenance program. Thus, materials inventory systems (MIS), pavement management systems (PMS), bridge management systems (BMS), accident analysis systems (AAS), equipment management systems (EMS), construction program management systems (CPMS), and payroll and accounting systems have data elements that affect maintenance programs. Coordinating maintenance management with these other systems should improve program coordination and functional cooperation, encourage multidisciplinary approaches to problem solving, and improve intra-agency communications.

Thus, interaction among executive management and functional program administrators and their staffs during the development and use of MMS should improve everyone's knowledge about and support for an adequate maintenance program.

A major benefit of the systems approach is the identification of principal work functions and significant highway elements that require maintenance work. An inventory of these elements organized by functional classification (Interstate, arterial, etc.) and operational unit (region, district, county, or subdivision) is the essential first step. Then it is possible to identify what routine and preventive work functions will be required. The general rule that 20 percent of the work generates 80 percent of the costs has application to the identification of major work activities. When one is overwhelmed by data, it becomes difficult to set priorities among work activities and to analyze performance. By identifying those activities that account for 80 percent of the maintenance budget, managers can typically focus their attention on the top 10 or 15 items. These items generally represent the areas in which significant improvements in cost-effectiveness can be made. Also, the effects of changes in policy and program emphasis can be evaluated over time.

Table 18 is a comparative ranking of the Pennsylvania Department of Transportation's (PennDOT) work activities for fiscal years 1974–75 and 1986–87 based on the expenditure for each activity expressed as a percentage of the total maintenance expenditure. Only 24 of 145 activities accounted for 79.9 percent of the expenditure in 1974–75, whereas 25 activities accounted for 81.7 percent in 1986–87.

Comparisons of the rankings and percentage of expenditure 12 years apart indicates that snow and ice control and pavement maintenance continue to be dominant activity areas. Principal snow and ice activities in 1974–75 were 25.5 percent of expenditures, whereas they accounted for only 20.9 percent in 1986–87. Significantly, the virtual elimination of erecting and dismantling 12 million lin ft of snow fence and the hauling of antiskid materials to stockpiles by 1986–87 accounts for 2.3 percent of the 4.6 percent difference between 1974–75 and 1986–87. Most antiskid material is now purchased delivered to the stockpiles, and snow fence is only erected at selected critical points. Because of a reduction in forces, cost analysis, and the application of value engineering, these items were decreased and emphasis was shifted to fall PM activities, such as crack sealing and shoulder cutting.

Two important PM activities on major roadways and one maintenance activity not ranked in 1974–75 were ranked in 1985–86. The PM activities are paved road liquid bituminous spray patching, ranked 8th (3.5 percent), and paved road crack sealing, ranked 16th (2.0 percent). The unranked maintenance activity, base/subbase repair, ranked 15th (2.3 percent) in 1985–86. The rankings of these items are the result of this agency's policy to emphasize pavement PM and "do it right" pothole repairs, including repair of base, where required, to prevent future potholes. Additional comments on the effects of this policy and program shift are listed here:

Snow and ice control (ranked first for both years)—Significant training and monitoring of winter salt use, through spreader calibration and use application rates, reduced winter material use by 30 percent, or an average of 150,000 tons of salt per year.

Manual patching (reactive maintenance) (ranked second in 1974–75 and third in 1986–87)—A 34 percent relative reduction,

TABLE 18
COMPARISON RANKING OF WORK ACTIVITIES FOR FISCAL YEARS 1974-'75 AND 1986-'87 (PERCENT OF TOTAL EXPENDITURE)[a]

Work Function Activities	Ranking 1974-75	% Total	Ranking 1986-87	% Total
Apply antiskid or chemicals and other for snow/ice control	1	19.8	1	17.0
Manual pothole patching	2	11.5	3	7.5
Liquid bituminous surface treating	3	8.1	4	5.7
Mechanized patching	4	6.1	2	10.5
Line painting	5	4.2	13	2.4
Surface treating plant mix	6	3.8	9	3.1
Grading shoulders	8	2.8	28	0.8
Ditch and drain cleaning	9	2.7	20	1.5
Shoulder-cutting	12	1.8	14	2.4
Vegetation management--brushing and trimming	13	1.8	18	1.6
Hauling antiskid to stockpile	14	1.5	No ranking	
Bridge-deck repair	24	0.8	37	0.005
Paved road liquid bituminous spray patching	No ranking		8	3.5
Paved road base/subbase	No ranking		15	2.3
Paved road crack sealing	No ranking		16	2.0

[a]This is only a sample of the work activities that make up 80 percent of the expenditures.

from 11.5 percent to 7.5 percent, while mechanical patching (a planned PM activity) moved from fourth to second, with a 72 percent increase in expenditure. This increase in mechanized patching also affected surface treatment.

Surface treatment (ST), liquid bituminous (ranked third in 1974–75 and fourth in 1986–87) and plant-mix surface treatment (ranked sixth in 1974–75 and ninth in 1986–87)—A 30 percent reduction in expenditures for liquid ST and 18 percent reduction for plant-mix ST reflected the effects of increased mechanized patching, liquid spray patching, and the 3R/4R resurfacing program. Also, a portion of the reduction in expenditures was caused by improved productivity and lower asphalt prices.

Shoulder grading (ranked eighth in 1974–75 and 28th in 1986–87)—A 71 percent relative reduction, from 2.8 percent to 0.8 percent, was achieved over 12 years. This documents the cost benefits of a 1969 policy change that required high-type paved shoulders (designed in PM) on all resurfacing and new-construction projects, which demonstrated the positive effects of building PM into design standards.

Shoulder cutting (ranked 12th in 1974–75 and 14th in 1986–87)—A 33 percent increase (1.8 percent to 2.4 percent) in this activity is a direct result of management's policy to place greater emphasis on improving roadway and shoulder drainage as a PM initiative.

Table 18 illustrates how MMS data can be used for analysis. It also shows the relatively few work activities (24 of 145, or 17 percent) that account for 80 percent of the maintenance program expenditure. The effects of policy changes, training, etc. can be broadly monitored and the impact on performance evaluated. The goal of maintenance management and preventive maintenance is to reduce reactive maintenance and increase the use of scheduled PM maintenance activities.

The use of MMS has resulted in (*42*):

- Improved standards.
- Increased use of automated data processing to speed up the handling of cost and performance data.
- Better pavement maintenance data that promote improved understanding of pavement performance.
- Increased use of system components to analyze performance of field units and measure effects of PM activities.
- The redefinition and redistribution of maintenance activities.
- The definition of areas for contract maintenance.
- A new focus on equipment use and requirements.
- Improved work program development and adjustments.

A criticism of the systems approach is that managers and administrators sometimes get carried away with numbers and do not always recognize the need to maintain and update the MMS and audit data reporting. Numbers should not drive management. Annual goals are just that, goals, and adjustments should be allowed. Quarterly goals are a necessary fine tuning of an annual program, and a reasonable percent of planned accomplishment should be expected. Setting requirements for 90 to 100 percent planned goal achievement for 90 to 100 percent of the time in all highway maintenance programs is unrealistic. Overemphasis on rigid performance objectives could result in poor-quality workmanship or doctoring of the data to make them fit the boss's perception of how good things are.

ACCIDENT ANALYSIS SYSTEMS

Accident analysis systems can supply important accident cluster data about locations where accidents may have involved maintainable features or services. These data, if properly used, can eliminate unsafe conditions and reduce exposure to tort liability. Some agencies have AAS that provide maintenance organizations with annual reports showing accident cluster data for several preceding years. This information can be used by maintenance personnel to schedule corrective or PM activities to reduce the chances of future accidents. One agency supplies its maintenance districts with annual listings of accidents for the following categories and criteria:

Shoulder dropoffs—three or more accidents in 3000 ft.

Nighttime curve accidents—four or more accidents in 3000 ft.

Fixed object (trees)—three or more accidents in 1000 ft.

Slippery snow and ice conditions—five or more accidents in 3000 ft.

Slippery wet conditions—five or more accidents in 3000 ft.

The AASHTO *Maintenance Aid Digest* (MAD) Number 8 (*43*) details how states use accident data in their maintenance programs. This MAD report encourages the use of multidisciplinary review teams to develop recommendations for corrective improvements and assign action program responsibilities. Thus, maintenance forces may be required to improve signing or remove trees, and construction may be required to implement surface friction improvements and paved-shoulder projects. Major roadway realignments, reconstruction, and intersection improvements usually require capital funding.

PAVEMENT AND BRIDGE MANAGEMENT SYSTEMS

The Ontario Ministry of Transportation and Communications in 1980 published *Pavement Maintenance Guidelines* (*44*) as a practical "down to basics" method of communicating a pavement maintenance policy. Other agencies use the results of pavement condition surveys, bridge reportable condition surveys, pavement serviceability indexes etc., in conjunction with work method standards, to communicate pavement and bridge conditions and recommended repair procedures.

Formalized pavement and bridge management systems provide:

- An inventory of pavements and bridges by type, size, and location, including data on shoulders, water tables, and foundations.
- A uniform agency-wide condition evaluation data base.
- A uniform method of monitoring conditions over a period of years to evaluate remedial program effectiveness.
- A data base for assessing future needs and establishing county or subdivision rankings.
- Information to assist in the allocation of maintenance funding by program and management areas or counties.
- Information for selecting and ranking candidate projects for major 4R or capital improvements.
- A listing of maintenance district pavement sections and bridge structures that should be considered for major maintenance work.

These systems have become very important in some agencies in the planning of major bridge replacements or rehabilitation and in the allocation of maintenance and resurfacing funds. They are valuable sources of objective data that are needed to justify maintenance and rehabilitation budgets and to quantify benefits of maintenance, rehabilitation, and capital programs. County and city highway agencies are also developing these systems for their own use. Several counties in Washington State have modified the state's pavement management system for county and city use (*45*). The APWA Micro Paver package is used by many cities, counties, and airport agencies to evaluate pavement needs and program surface maintenance activities.

Proper timing of preventive maintenance is a key factor in the success of a PM program. Both PMS and BMS provide the data base and information summaries to assist in developing programs and projects that focus the appropriate maintenance or rehabilitation activities at the network and project level. Proper timing of PM will help ensure reductions in more costly repairs and future maintenance costs (*46*).

Pavement deterioration curves (Figure 1) depict pavement life-cycles as consisting of two phases (*4*). During the first phase, 40 percent of the of pavement deterioration occurs over 75 percent of the life of the pavement. The rate of pavement deterioration increases sharply in the second phase, where it takes only 12 percent of the pavement's life to drop its condition another 40 percent. Pavement maintenance and rehabilitation costs at this point, in phase two, are four to five times greater then those in phase one (*47*). So it is evident that pavement maintenance activities should be performed in phase one of the typical life-cycle. Several states, as part of their PMS, have developed "typical" pavement maintenance planning schedules for network analysis and projection of system maintenance and rehabilitation activities. (Appendix A shows one for Idaho developed in 1984.)

Pavement and bridge management systems can provide important inventory information on such items as lane miles of road by base and surface type, bridge-deck area by type, etc., and changes in reportable conditions (shoulder dropoffs, potholes, cracks, clog drains, etc.). Cost estimates of major corrective action, or increases or decreases in the number of lane miles of road and number of bridges that fall below an established serviceability index or performance rating threshold, can provide objective data for estimating resource requirements. This type of analysis can be used to establish budget needs and document the ability of present maintenance programs to reduce the backlog of highways and bridges that have approached unacceptable conditions.

QUALITY CIRCLES

A logical extension of the MMS concept is the quality circle or productivity team. Quality circles were developed in Japan with help from Juran and Deming (*48*) to improve the quality of workmanship and production. New management approaches include worker participation in the decision-making process.

The basic principle of a quality circle or productivity team (PT) (*49*) is that workers and their immediate supervisors are very knowledgeable about assigned work activities. These employees can use this knowledge to develop improvements in quality or production. A productivity team is not another form of cost reduction or a suggestion box. Like value engineering, (see Chapter 6), PT must be structured to facilitate communications, coordination, and cooperation. (See Appendix F for details of a state maintenance PT system.)

One maintenance organization that implemented PT was PennDOT (*50*) in 1981. This Productivity Improvement Program had three goals:

- Greater involvement of employees in decisions affecting their work activities.
- Creating a shorter chain of command for implementing changes.
- Improvement in performance.

Although work circles are targeted at improved quality and production, employee input can be used in analyzing the effectiveness of PM activities. Details on this program are in Appendix F.

CHAPTER SIX

COST AND BENEFITS

COST-EFFECTIVENESS

The cost-effectiveness of preventive maintenance activities is very dependent on:

- Planning
- Budgeting
- Programming
- Scheduling
- Training
- Performance of the work activity

Joint and crack sealing is a classic example. Some administrators and maintenance managers do not feel that joint and crack sealing is cost-effective. New York DOT's Bugler (*21*) has convincing evidence that crack sealing is cost-effective when "done right" by contract. The Ontario Ministry of Transportation and Communications (*51*) has also done extensive work on evaluating this activity and the performance of materials at 20°C. The ministry concluded that, for it, a need still exists to:

Quantify benefits of crack sealing and
Improve the technology through:

- the development of more suitable cold area sealants,
- the development of application methods that better recognize requirements of high bond and extensibility,
- the development of equipment that is more productive and consistent, and
- the provision of adequate training and guidance to crews.

Communicating recommended maintenance is a key element in achieving cost-effective PM. In 1980 the ministry published *Pavement Maintenance Guidelines: Distresses, Maintenance Alternatives, Performance Standards* (*44*). The manual contains photographs of different types of pavement distress, methods of classification, lists of suitable treatments or maintenance alternatives, performance standards, and a method of evaluating the most cost-effective action by calculating equivalent annual costs of each alternative. The manual promotes the concept that timing and degree of severity play an important role in what maintenance activity should be scheduled and how cost-effective it will be. The manual is an excellent example of communicating to field personnel that pavement maintenance procedures can be used as a systematic approach to problem solving.

Cost can be affected by how work is performed and what the capabilities of the crew are. Thus the questionnaire answered by the chiefs of maintenance (Appendix C) contained items dealing with contracting maintenance, motivational and technical training, and general use of "dump and run" pothole repairs, addressing some of the elements affecting the cost of performing maintenance activities and the quality of the work accomplished.

Responses to inquiries regarding whether PM work is contracted out show that 79 percent of those responding answered yes (Table 19). Eighty-four percent of the states and 68 percent of local governments contracted PM work. Contracting of maintenance at the state level has been on the increase. According to an October 1980 AASHTO *Maintenance Aid Digest* (*52*), the growth between 1972–73 and 1978–79 was from $137 million to $376 million, a 2.75-fold increase in six years.

Preventive maintenance activities such as surface treatment, bridge painting and structure maintenance, and snow and ice control accounted for the majority of contracted work. Other work items requiring specialized or seasonal equipment also lend themselves to contract maintenance. Other factors, such as legislative limits (dollar value) on work by state forces, location of the work, availability of local contractors, union agreements, special skills required, etc., influence the final decision. For these and other reasons it is often more cost-effective to contract PM work activities.

Much has been written about motivating workers. The message that comes through is that we all want to be winners (*35*). Worker motivation affects the quality and quantity of work performed. Question 5a was targeted at getting opinions on motivational training producing high-quality work performance. Seventy-five of the 84 respondents (89 percent) affirmed that motivational training improves quality. This emphasizes the importance of planning and training as essential elements of cost-effective PM operations. Equally significant are the 78 respondents (93 percent) who believe that technical training is important in producing high-quality work performance. Taken together, there is no doubt that training is a key factor in performing cost-effective PM activities.

The FHWA, National Highway Institute (NHI), APWA, Rural Technical Assistance Program (RTAP), and state and provincial organizations are valuable, low- or no-cost sources of training materials and assistance. The NHI has an extensive library of audio-visual and other training materials for design, construction, operations, maintenance, and administration that are available to public agencies.

Fifty-nine percent of organizations responding to question 6 on "dump and run" pothole repair state that that particular type of procedure is the general rule. It is interesting to note that 65 percent of the state and local agencies replied yes. However, only 20 percent of the toll road administrators and 40 percent of the Canadian agencies replied yes. Although most maintenance

TABLE 19
SUMMARY OF REPLIES TO QUESTIONS 4, 5a AND 5b, AND 6

AASHTO Regions	No. of Responses	Questions 4 Yes	No	5a Yes	No	5b Yes	No	6 Yes	No
1 State	11	8	3	10	1	11	0	8	3
Local	3	2	1	2	1	3	0	2	1
Totals	14	10	4	12	2	14	0	10	4
2 State	10	7	3	9	1	9	1	6	4
Local	5	3	2	5	0	4	1	2	3
Totals	15	10	5	14	1	13	2	8	7
3 State	9	9	0	8[a]	0	8[a]	0	7	2
Local	9	6	3	7	2	7	2	9	0
Totals	18	15	3	15	2	15	2	18	2
4 State	14	13	1	13	1	14	0	8	5
Local	8	6	2	7	1	8	0	3	5
Totals	22	19	3	20	2	22	0	11	11
State Total	44	37	7	40[a]	3	42[a]	1	29	15
Local Total	25	17	8	21	4	22	3	16	9
Canadian Provinces	4	4	0	4	0	4	0	2	2
Local	6	4	2	5	1	5	1	2	4
Totals	10	8	2	9	1	9	1	4	6
Toll Roads	5	4	1	5	0	5	0	1	4
Grand Totals	84	66	18	75[a]	8	78[a]	5	50	34

[a]One state has no maintenance workers, so questions 5a and 5b were not answered.

engineers recognize the importance of "doing it right," the realities faced by the foremen during the spring breakup are that the public wants the holes filled immediately. One maintenance engineer asks, "How can we justify the time and effort needed to put a perfect pothole patch into a less than perfect roadway, one where the pavement is so full of alligator cracks and rutted wheel tracks. There are more potholes than there are people, patching materials, and patrol trucks to deal with them" (*17*). This conflict between "what is practiced" and "what in theory should be done" is the challenge facing administrators and managers who must maintain a road system.

Political pressure to do something—anything—to get potholes fixed is very significant during the spring breakup. A Pennsylvania State University study (*53*) recognizes this reality and concludes that top management support (including that of elected officials) is essential to the development of a comprehensive "do it right" pothole repair policy. The improvements in cold patch material and portable compaction equipment can significantly improve patch durability if such materials and equipment are made available and used properly.

CALCULATING COSTS

Determining the cost of maintenance work activities is generally dependent on the accounting system used, the type of budgeting required, and the existence of an MMS. Agencies with MMS will generally have good unit cost data for most major maintenance activities. These unit costs may also include overhead and other indirect costs. For agencies without activity cost accounting systems, estimates of costs and production will have to be made using annual costs and production information, estimated production rates, and standard crew sizes. Field studies of production and costs of work in progress are also recommended.

In developing costs for PM work activities, it is important to establish what should reasonably be included in each component of the total cost. In general, labor, materials, equipment, contract services, and overhead are the major objects that generate costs. Outlined here are what should be included in determining the costs of PM activities.

When comparing contract maintenance work with department (in-house) work, the cost of contract engineering, contract preparation, inspection, and overhead expense should be included in the contract cost. Some agencies also prorate legal services, materials purchasing, building operations, telecommunications, and computer services. When actual pay rates, rental rates, and materials costs are not readily available, average wage rates by class, area equipment rental rates, and average material costs can be used.

It is important to include the value of the significant cost generators involved. It is prudent not to waste time and money chasing down the cost of every last bolt and washer, but it is important to be consistent in cost calculations from one analysis to the next.

As a general rule, the larger the cost data population, the more reliable the data within the same management environment. Therefore, statewide or district unit costs are more reflective of the average unit costs than are crew, section, or subdivision unit costs. State or district unit costs should generally be used for analysis, except in special cases in which the activity performed is unique or dominant in a few sections or subdistricts. For example, expressway sweeping, tunnel cleaning, and traffic signal and street light maintenance may be restricted to certain districts. Each agency has its own internal accounting system, so the availability and details may vary. Also, some organizations use agency-wide or district unit costs for budgeting.

Costs are accounted for by major expenditure elements. For example, some MMS use average crew-day costs. Again, the important part is consistent and reasonable estimates of direct and indirect costs.

Two errors in logic most often made in cost analysis are:

- Accepting labor and overhead costs as fixed because they are already budgeted and paid for, and therefore concluding that only materials, equipment, and contract services will require additional cash expenditures out of budgeted dollars.
- Making judgments only on a first-cost basis, without considering the duration of the repair. This ignores annual costs, simple present worth, the time cost of money, and life-cycle costing.

As a general rule, first-cost comparisons can be used for comparative analysis between alternatives with similar short-term durations. Annual costs and simple present worth analysis are appropriate for activities with substantial differences in duration and costs.

Life-cycle cost analysis is more complex. Its accuracy is dependent on how well the maintenance costs and estimates of durability are assessed. It requires more data and resources and is generally used for major capital improvements and repairs. It should also be used to analyze alternatives for major maintenance programs such as surface treatments, thin overlays, concrete pavement repairs, etc.

Cost may be computed as follows:

First cost • Simplistic • Unit of production basis	$\text{Unit cost} = \dfrac{\text{Total work activity cost}}{\text{Production units achieved}}$
Annual cost • Recognizes differences in repair life of alternatives	$\text{Annual unit cost} = \dfrac{\text{Unit cost}}{\text{Years of expected life}}$
Single compound amount (SCA) • Recognizes the time cost of money and repair life	$p \times SCA = f$ $SCA = (1 + i)^n$ Where: i = interest rate n = number of interest payments p = present worth f = future worth (See Appendix G.)

Life-cycle cost analysis—Life-cycle cost (LCC) analysis considers the costs to the agency throughout the life of the projects under consideration. These costs include yearly maintenance costs, the date and amount of future investments, and comparison of alternatives with different economic lives. Because the value of money changes with time, interest rates must be used in life-cycle cost analysis to combine future costs with initial costs. When dealing with discount rates it is important to remember that economic analysis is independent of how a project is to be financed, by whom, and when. The interest rate is simply a device used to allow present and future costs to be compared. Only through LCC analysis can trade-offs among PM, corrective maintenance, rehabilitation,and reconstruction be evaluated.

Factors to be considered in a life-cycle cost analysis are:

- The engineering and economic issues that can be examined with respect to performing or deferring PM.
- Present costs for replacement or rehabilitation.
- Annual maintenance costs.
- Future increases to maintenance costs as a result of deterioration.
- Future rehabilitation costs.
- Analysis period.
- Interest rate.

The value assigned to the interest rate can be a major factor in the outcome.

Life-cycle cost can best be understood by illustrating its use. Synthesis 122 (*54*) presents a detailed examination of life-cycle cost analysis. (See Appendix G.)

First-cost analysis should not ignore performance and life expectancy. Attempts should be made to ensure that alternatives selected for analysis will perform equally well for the same time period. If equal performance is not expected, then that fact should be made known to the decision maker as another factor to consider in addition to the first-cost analysis. One approach might be to list all the foreseeable differences in life expectancy, maintenance costs, and future rehabilitation needs, with a discussion of each item.

A first-cost analysis does not attempt to place a dollar estimate on the effects current decisions will have on future expenditures. Highway agency funding is usually inadequate to meet all maintenance and capital needs of the agency, and it makes lower-first-cost estimates especially attractive. For these reasons, first-cost analysis can be very misleading. Choosing the lowest-cost alternative that increases annual maintenance costs may be a short-term solution and could increase the financial burden in future years. Choices of alternatives may also be dependent on pavement maintenance policies and capital programming requirements.

It is likely that the need in each category of strategies will exceed the dollars available. The strategies of base repair and seal, overlay or recycle, and major rehabilitation will need to be programmed in the system over a period of time through a 5- or 10-year program. For the purposes of economic analysis, alternative strategies may be considered for application to the section under consideration to determine the cost-effectiveness of each. Because of the time necessary to schedule and finance larger projects, it may be necessary to apply lesser strategies as alternative treatments to keep a road serviceable until a major project can be financed and developed.

Very often, the impacts of performing or not performing maintenance are not clearly defined. The development of a demand/response approach to predicting maintenance requirements, costs, and impacts (*55*) is one method of using numerical measures of maintenance levels of service, quantitative models to predict the deterioration of the road system, and their impacts of performing the specified level of maintenance on the preservation of the highway maintenance investment, user costs, and safety.

The use of mathematical models to predict yearly maintenance costs has received much attention in the last decade (*56*). These models appear to be adequate for predicting various categories of maintenance cost requirements for a given network of highways. They could be used to evaluate and verify the otherwise intuitive and subjective judgments of maintenance and budget personnel made over a period of time. However, these tools will not eliminate problems of too much maintenance in some areas and not enough in others. Models should assist in developing more consistent estimates of maintenance requirements by correlating the causal factors that generate maintenance activities. For states and other organizations with reliable MMS cost and production data, modeling may be an appropriate next step in analyzing resource allocation among various field units. Because such tools require staff time and effort, they should not be implemented if top management will not use the results.

VALUE ENGINEERING

Value engineering (VE) is an inexpensive tool that can be applied to analyze work activities that account for a significant percentage of expenditure. Synthesis 78 (*57*) addresses the use of VE in preconstruction and construction. It defines VE as a process for the systematic application of recognized techniques that identify the function of a product or service, establish a value for that function, and provide the necessary function reliably at the least overall cost. Ebisch (*58*), commenting on the definition, pointed out that

> a one sentence definition of VE can sound like a fancy language for what every good designer should do as a matter of course. The problem is that VE is commonly believed to be the same as cost reduction or system analysis. Simple definitions are unsatisfying because true value engineering is a formalized and powerful methodology that must be experienced to be fully appreciated.

Value engineering, by its organization, multidisciplined participants, and methodology, enhances the commitment to the "three C's" among design, construction, material, and maintenance personnel.

Listed here are the VE steps and results as they were applied to a VE study of pothole patching (*59*) completed in 1976:

	Job Plan Phase	Phase Objective	Primary Objective
1	Selection	Select candidates	Seek Problem
2	Investigation	Investigate project	
3	Analysis	Analyze cost & function	
4	Speculation	Speculate on alternatives	
5	Evaluation	Evaluate alternatives	Solve problems
6	Development	Develop alternatives	
7	Presentation	Present alternatives	Act on solution
8	Implementation	Implement alternatives	
9	Audit	Audit results	

Appendix H shows the Function Analysis System Technique (FAST) diagram and a description of five alternatives studied in this VE.

The results of the VE audit phase are shown in Table 20. It shows that low unit costs are not always indicative of the most cost-effective methods to repair potholes.

A follow-up research project on pothole repairs conducted by Pennsylvania Transportation Institute (*53*) was initiated in 1979. This comprehensive study of 1000 pothole repairs across the state of Pennsylvania concluded that:

- Repair costs with nonstandard "throw and go" procedures were found to be greater than three times the life-cycle cost of standard "do it right" procedures.
- The emphasis on doing pothole repairs correctly with proper tools and materials had a tremendous effect on overall program costs to PennDOT. Considering the time cost of money, the cost per ton was about one-third the cost of "throw and go" ("dump and run").

This illustrates the potential benefits of applying VE to maintenance work activities. The FHWA has sponsored national VE studies using maintenance staffing from several states. Listed in Appendix I are the studies completed and published to date. (Copies of these reports are on file at regional RTAP centers, and copies may also be obtained from National Technical Information Service, Springfield, Virginia 22161.)

TABLE 20
ANNUAL UNIT COST OF FIVE METHODS OF POTHOLE REPAIR

Technique	Tons Placed	Cost Per Ton of Material	Life of Patch	Total Annual Cost per Ton[a]
Dump and run (throw and go)	18	$25.64	1 month	$307.68
Dump and run modified	12	$31.80	2 months	$190.80
Do it right vib. plate comp.	6	$63.29	No failure after 1 year	$63.29
Do it right steel roller compact.	7	$61.41	No failure after 1 year	$61.41
Same as 4 with better hole prep.	7	$65.22	No failure after 1 year	$65.22

[a]Costs are 1975-76.

Preventive maintenance strategies cannot be based on cost alone, but costs are an important element in the decision matrix. Life-cycle costs for major investment decisions are equitable, realistic, and easy to calculate. They are useful tools for good managers. The cycle times used and maintenance activities should reflect operating experiences of field personnel, outputs from MMS, and the experiences of others (*60*). Costs used should be based on local experience and long-term price trends.

BENEFITS

Benefits are much harder to evaluate in dollar terms. Some standard types of benefits are:

- Safety
- Travel time savings
- Reduced tort liability claims
- Reduced vehicle operating and maintenance costs
- Reduced disruption of adjacent business activities
- Reduced discomfort
- Preservation of the investment by deferring or reducing the high future reconstruction costs associated with a "do nothing" PM policy

Agencies could choose to place dollar values on each of the above-mentioned benefits to calculate total benefits and compare them with the cost of PM. In addition to the difficulty of expressing most benefits in dollar terms, the accrued benefits of a comprehensive PM program do not become obvious for several years. Generally, pavement management and bridge management systems perform network evaluations over time. Pavement and bridge maintenance strategies are usually based on a four- or five-year planning cycle of network and major maintenance project bases. It is hoped that the plan is coordinated with the capital construction program, urban redevelopment, and major underground utility installations and reconstruction. Most pavement PM activities are not very cost-effective if the roadway is dug up for new service connections, urban renewal utility reconstruction, or capital highway improvements shortly after a crack sealing or surface treatment activity.

Benefits could also be perceived as achieving a service level of maintenance or providing a quality level of service. This would require the establishment of network level indicators of quality maintenance. Synthesis 148 (*61*) states that quality indicators have been established in 26 of 51 agencies surveyed (states and the District of Columbia). They have established thresholds of deficiency or indicators of quality. An evaluation of the work performed in certain PM activities could be used to indicate benefits of a comprehensive maintenance program. Crack seal, surface treatment, and ditch cleaning could be evaluated against the reduction in pothole repair. If the quality indicators are associated with reportable conditions of pavement and bridge management system surveys, a numerical indicator of observed deficiencies could be established and statistical analysis used to establish ranges of conditions from poor to excellent. NCHRP Report 273 involved a very comprehensive study and the development of a rational approach to selection of optimal maintenance levels of service (*62*).

A very comprehensive treatment of performance monitoring is presented in *Performance Monitoring* by Poister (*63*). This book details how trained observers, motor vehicle owners' answers to road condition questionnaires, and PMS data were used to assess conditions and monitor the effectiveness of PM and other improvement programs. The use of PMS and other data could be used to allocate maintenance funding. In addition, Poister examined the use of tort liability claims, payments resulting from dangerous conditions, and potholes as other indicators of maintenance levels of service.

Poister developed estimates of potholes encountered per mile as a reasonable indicator of levels of service. A potholes-encountered value for each functional class (FC) is estimated by multiplying the ADT for each FC by the average number of potholes per mile obtained from trained observers for that FC. Table 21

TABLE 21
ESTIMATE OF POTHOLES ECOUNTERED PER MILE (*63*)

Functional Class	Fall '79 Cycle I	Spring '80 Cycle II	Fall '80 Cycle III
Interstate	220,699	165,642	88,887
Principal arterials	280,134	230,034	135,298
Minor arterials	106,068	99,837	50,127
Collectors	45,742	44,442	25,188
Local roads (state maintenance)	23,792	19,427	11,742

shows the estimated potholes encountered per mile during the first three cycles of the trained-observer program at PennDOT. Table 21 indicates that the estimates of total potholes encountered per mile improved over a three-cycle period. Within each cycle a comparison among the five functional classes reveals the importance of ADT in setting priorities. On each cycle the mean pothole count per mile for Interstate highways was roughly one-sixth of the count on local roads. Yet the average mile of Interstate highway had nearly eight times as many pothole encounters per day as did the average mile of local roads, even though it had only one-sixth the number of potholes per mile. Maintenance work targeted at Interstate and principal arterial pothole repairs and pavement PM will have much more impact on levels of service than will equivalent efforts on local roads. This is not to say that local roads should be ignored, but it does illustrate that getting the biggest "bang for the buck" means establishing priorities that target high-volume facilities.

Using defined levels of service in terms of deficiency counts, such as estimates of potholes encountered per mile, to measure the benefits of each maintenance activity appears to be impractical. However, such counts could be used to evaluate programs such as surface PM, bridge PM, vegetation management, line striping, and signing. Capital programs, routine maintenance, and environmental factors also have impacts on levels of service in Ohio (*37*). (See Appendix E.)

An array of unintended consequences is a method used by some agencies to communicate the results of "do nothing" or deferral of PM activities from an estimate of what is required. For example:

Activity	Unit	Annual Plan Quantity	Proposed Quantity	Unintended Consequences
Crack Sealing	Gal.	100,000	40,000	Unfilled crack will allow water to enter pavement and increase base failure and potholes.

Synthesis 58 (*1*) contains several different methods of presenting arrays of unintended consequences brought on by deferral of maintenance activities.

Benefits can also be evaluated in terms of decreases in "reactive maintenance" activities as a result of increased planned PM activities. As noted in Chapter 5, PennDOT's activity of manual patching had dropped from 11.5 percent of the maintenance budget to 7.5 percent as a result of an emphasis on PM and "do it right" repair. In terms of tons of cold patch material used, the drop was approximately 260,000 tons, from 450,000 to 190,000 tons annually. A major portion of this decrease is attributed to increased emphasis on PM activities. In addition, the benefits of doing pothole repairs right, considering the time cost of money, have been estimated by the Pennsylvania Transportation Institute (*53*) to be $40,000,000 annually for Pennsylvania road systems. Data in Table 22 show the shift over time from "reactive" maintenance to scheduled PM activities for an urbanized county.

Caltrans adopted a pavement PM strategy and program based on outputs from its PMS program. The result of a very careful study and analysis of alternatives showed that low-cost surface treatments, when applied in a timely manner, will economically extend the useful life of the pavement structure four or five years (*64*). Caltrans concluded that a properly timed surface sealing at $5,000/lane mile would significantly delay the necessity of a $100,000/lane mile pavement rehabilitation project. A $20 million budget increase for pavement PM that was targeted to address 81 percent of the needs identified by PMS in 1985–86 was approved for Caltrans in fiscal year 1986–87.

TABLE 22
ANNUAL UNITS OF PRODUCTION

Activity	Type	Units	1980-'81	1981-'82	1982-'83	1983-'84	1984-'85	1985-'86
Manual patching	Reactive	Tons	12883	15219	8293	8864	10178	9536
Bit. seal coats	Planned	Gals.	10418	34573	53072	44728	34327	42855
Ditch cleaning	Planned	Feet	55155	72381	97839	84003	81369	92193
Pipe Replacement	Planned	Feet	3195	4911	9827	12659	12787	10597
Skin patching	Planned	Gals.	145	80254	77354	289099	351314	402594
Shoulder cutting	Planned	Miles	300	757	389	331	408	355
Side dozing under guide rail	Planned	Feet	10793	77178	25980	51000	104905	123150

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on the survey data collected for this synthesis, there is a consensus that highway maintenance is an important function that should be fully funded. However, in some agencies there is a belief that maintenance can be deferred when there are funding problems. Also, there are those who are not convinced that fully funding PM is the proper option or that PM is really cost-effective, because the benefits are not always clearly defined.

In 1969, the French government started a long-range program of pavement rehabilitation and strengthening. Since 1972, it has applied a PM strategy that protects the capital investment to meet users' needs for their national road system. With 15 years of experience, the PM strategy has provided the French with very good service levels regardless of climatic conditions (*65*). They have found "the biggest bonus of the PM policy (which implies surface treatment of 1″ or 2″ asphalt overlays) is the fact, under normal conditions, it prevents the owner from repeating the original rehabilitation investment." The French have created a manual for field managers to use in implementing the most cost-effective PM treatment to address the problem. Their experience has closely paralleled many studies in the United States that support the cost-effectiveness of PM.

The support for PM is strong among the CEOs and maintenance engineers surveyed for this synthesis. Proper timing is critical to the success of PM. This fact should provide a strong argument for continuing adequate funding of a maintenance program, including additional funding to reduce the backlog of unmet PM needs.

The need to coordinate maintenance and capital programs is also a very important element in developing cost-effective PM programs and securing wide public support. There is nothing more aggravating to taxpayers than to have maintenance or contract surface work performed and then have the street dug up within weeks for some other agency's capital project, or have maintenance crews crack seal streets weeks before a mill and resurfacing project. This is not cost-effective and undermines taxpayers' support for PM. Public support is essential in getting or keeping legislative support for PM programs.

Building PM into design standards and including field maintenance personnel on design scoping teams are two important ways to limit future maintenance costs and encourage coordination of programs. This is particularly true for work on high-volume urban highways, where almost any maintenance activity causes major traffic congestion. Work on these facilities requires extensive planning and scheduling of resources. For example, contracting of innovative methods of concrete slab replacements during off-peak hours using accelerators or quick-set concrete has proved cost-effective in one major urban center (*66*). This required close coordination, planning, and proper funding.

To accomplish PM in urban areas on high-volume expressways and arterials requires greater resources than in a rural environment. Budget analysts and program managers should provide the additional funds required to cover higher costs, if urban PM programs are to be successful.

Perhaps the most cost-effective PM is "do it right" pothole repair when applied to pavement surfaces that are still in acceptable condition. This "do it right" policy should apply to all maintenance activities. Training and motivating personnel is important and should help assure cost-effective PM operations.

Somewhat surprising was the strong support for the effectiveness of herbicide spraying as a PM activity that reduces the reliance on manual or mechanical removal of undesired vegetation.

Equally surprising was the response to the survey question on bridge painting that indicated that for 24 percent of the respondents "money available" was used as a criterion for bridge painting. Fifty-five percent used "prevent metal loss" as a criterion. Although the bridge painting criteria are not the only measure of bridge maintenance efforts, the response would indicate that structure maintenance may not be adequately funded in all agencies.

There is a "force for change" and a growing recognition that "maintenance is forever." Maintenance managers should implement or continue to improve management systems to more objectively forecast their needs so that they can document benefits in terms of improved service levels and physical conditions of the capital investments.

The 3R/4R program has been helpful at the state level in reversing the downward trend in the physical condition of the Interstate and arterial networks. However, at the local level, it has had less of an impact, based on the responses to question 7 in the chiefs of maintenance survey (Appendix C).

The majority of maintenance engineers (65 percent) did not agree that bond funding was the way to raise more maintenance money. Seventy-two percent favored raising taxes to finance additional maintenance. This would indicate that the maintenance program and particularly the PM program must be "sold" to legislators and administrators if proper funding levels are to be achieved or maintained.

The overall results of the surveys in this synthesis indicate that for the sample of maintenance activities there are regional differences about which activities are considered most effective. There were also differences between levels of government. For example, most toll road administrators did not view surface treatment as being cost-effective, whereas they gave high rankings to crack and joint sealing. Most states, provinces, and local agencies gave surface treatment high marks.

It is evident that there is not one best PM strategy for all agencies, at every governmental level, in every region, or for each PM activity. The surveys indicate that a shift to a "maintenance first" program with emphasis on PM and a "do it right" attitude does reduce reactive maintenance, extends the life of capital investments, and results in improved levels of services.

RECOMMENDATIONS

It is recommended that:

- The FHWA continue to encourage multistate value engineering studies of maintenance activities; to support RTAP and other training efforts; to continue its initiatives to improve pavement, bridge, and maintenance management systems and to further the SHRP efforts in pavement bridge and materials areas that affect maintenance programs.
- The FHWA reissue report FHWA-TS-78-216, "Integration of Maintenance Needs into Preconstruction Procedures." A copy of this report was very difficult to get, and most state design engineers contacted for this synthesis could not find or did not know that this excellent report existed. (Editor's Note: This report is being updated as part of NCHRP Project 14-92, "Incorporation of Maintenance Considerations in Highway Design." The study is expected to begin in January 1990.)
- Agencies be encouraged to use multidisciplinary design scoping teams that include field maintenance engineers or managers.
- Highway maintenance agencies place additional emphasis on bridge maintenance, which still appears to lag behind surface maintenance. Findings from the required bridge inspection program should be used as a basis for a bridge repair and PM program. Inspection findings and recommendations should be communicated to field maintenance managers at the county or subdistrict level for information or maintenance program action.
- The training of personnel to "do it right" get needed emphasis.
- Highway agencies develop an illustrated pavement maintenance guidelines manual for field foremen, similar to the Ontario manual (*44*), which presents cost-effective alternatives to various problems. Such a manual can be an effective method of communicating PM policies and encouraging the participation of first-line field managers in the decision-making process of formulating corrective measures. The development of this manual may best be handled on a regional basis.
- Funding of PM programs be provided on a multiyear basis to encourage proper planning and scheduling of this cyclic activity. Adequate long-term commitment to PM should ensure proper timing of the application of PM activities and the maximizing of its benefits.

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APPENDIX A

IDAHO'S PAVEMENT PM AND REHABILITATION SCHEDULE

PREVENTATIVE MAINTENANCE FOR PAVEMENTS

to be presented at

Committee A2B04

Pavement Rehabilitation

Thursday, January 19, 1984

by

James W. Hill
Research Supervisor

Idaho Transportation Department

PREVENTATIVE MAINTENANCE FOR PAVEMENTS

The Idaho Transportation Department's Materials Section has developed a schedule of preventative maintenance to go along with pavement management, recycling, and rehabilitation for pavements. These schedules are based on the weakest material or the material having the shortest life.

The schedules also reflect, in part, the success Idaho has had in pavement design. Our overall traffic loadings may be small in number, as compared to some states, but we have been able to offer a high level of pavement service.

We are developing a pavement management information system that may make changes in the pavement management program. We believe that as we gain confidence in this new system, the preventative maintenance schedules will keep our pavement in good shape.

The schedules have been to develop budgets and monitor maintenance costs, so in a way they are operating as a small pavement management system.

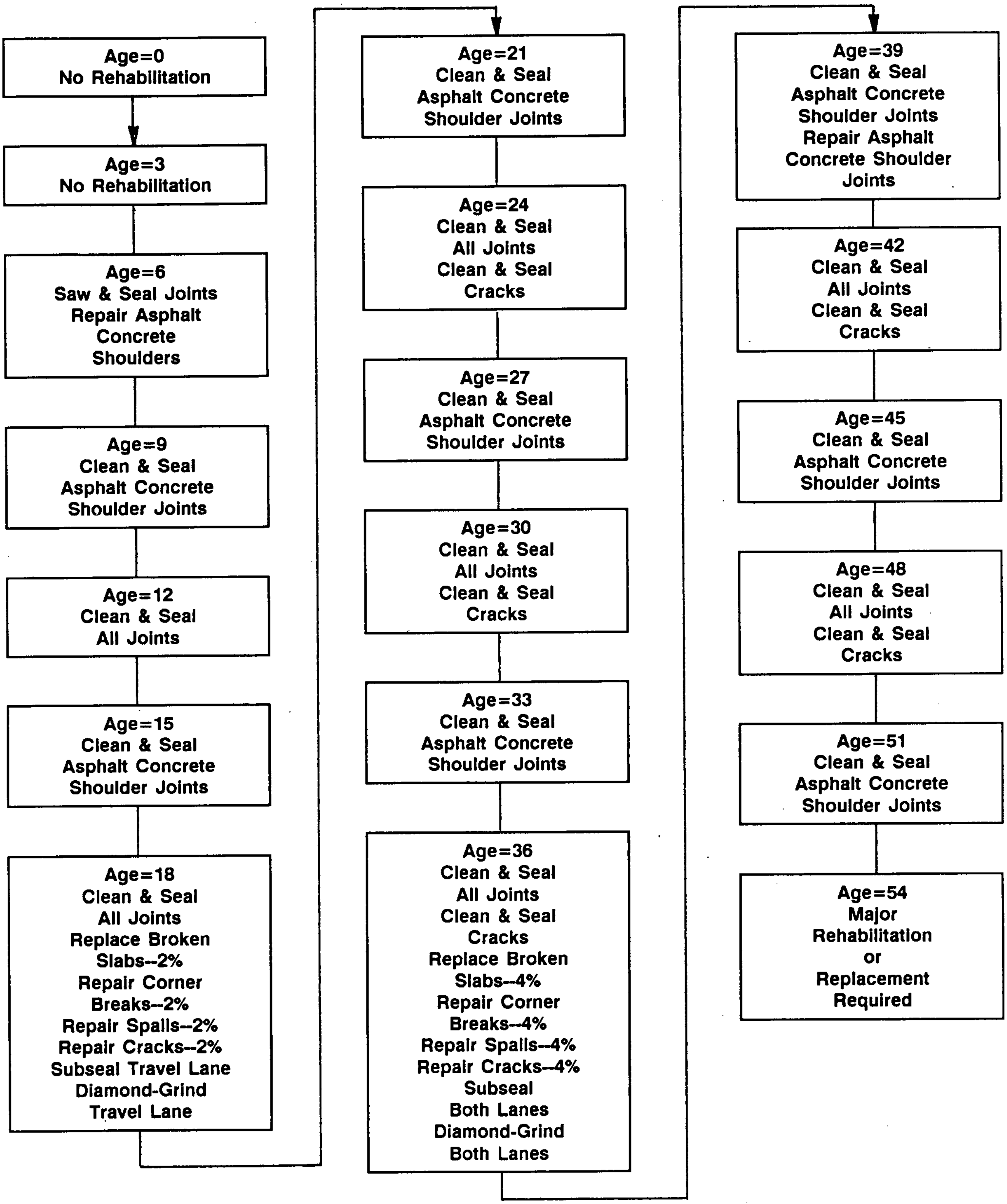


FIGURE A-1 Rigid pavement rehabilitation schedule.

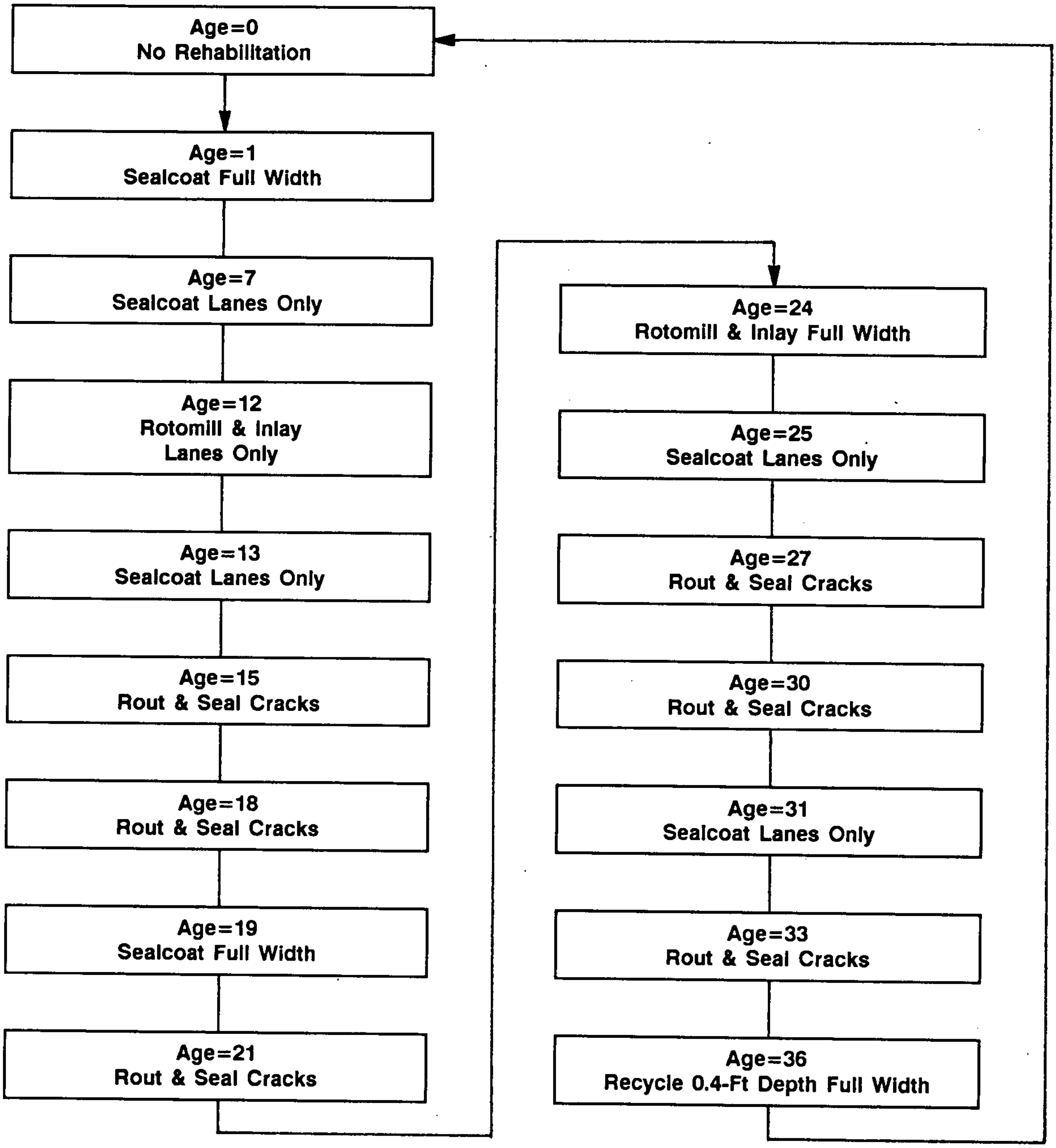


FIGURE A-2 Flexible pavement rehabilitation schedule.

APPENDIX B

CHIEF EXECUTIVE OFFICERS SURVEY QUESTIONNAIRE

Questionnaire for Chief Executive of Highway or Transportation Agency

Name of Agency ______________________________

Location ______________________________
(State, Province, City, County)
Title of Person Completing Questionnaire ____________________

Please *circle* the descriptor that expresses your opinion on the statements and questions listed below. Use enclosed definitions as a guide for what is routine and what is preventive maintenance.

1. Routine maintenance should be fully funded to meet needs.
Strongly Agree Agree Undecided Disagree Strongly Disagree

2. Preventive maintenance should be fully funded to meet needs.
Strongly Agree Agree Undecided Disagree Strongly Disagree

3. Preventive maintenance is a good investment for extending the useful life of roads and bridges.
Strongly Agree Agree Undecided Disagree Strongly Disagree

4. Federal funding should be available for maintenance and operational services on the Interstate and Defense Highway System since it requires a higher level of service and provides for national defense needs.
Strongly Agree Agree Undecided Disagree Strongly Disagree

5. In time of limited funding, maintenance programs should be fully funded ("maintenance first") even if some construction and administrative programs must be delayed and/or reduced.
Strongly Agree Agree Undecided Disagree Strongly Disagree

6. Would you lapse federal funds to free up state matching funds for 100 percent state maintenance programs?
Yes____ No____

7. If you were permitted to use some of your federal apportionment to fund Interstate maintenance would you take advantage of this funding to finance routine and preventive maintenance programs?
Yes____ No____

APPENDIX C

CHIEFS OF MAINTENANCE SURVEY QUESTIONNAIRE

Questionnaire for Chief of Maintenance (Roads, Bridges, Etc.)

Name of Agency ______________________________

Location ______________________________
(State, Province, City, County)
Title of Person Completing Questionnaire ______________

Refer to enclosed definitions of routine and preventive maintenance and place **X** next to your answer for items 1 through 6.

1. Is the highway and bridge maintenance program funded by legislative appropriation?
Yes____ No____

2. Are the majority of the maintenance programs funded from restricted receipts or trust fund sources?
Yes____ No____

3a. Does your organization have a maintenance management system?
Yes____ No____

3b. Do you develop an annual work program for highway preventive maintenance?
Yes____ No____

4. Does your organization contract out any PM activities?

5a. Do you believe that motivational training of maintenance employees produces quality work performance?
Yes____ No____

5b. Do you believe that technical training of maintenance employees produces quality work performance?
Yes____ No____

6. As a general rule, are the majority of potholes repaired by the "dump and run" method with minimum compaction (backing truck over patch or using back of shovel or hand tamper) by your maintenance crews?
Yes____ No____

7. Please circle the degree of acceptance you have for this statement:
Federal funding of restoration, rehabilitation, and resurfacing has helped the maintenance program.
Strongly Agree Agree Undecided Disagree Strongly Disagree

Instructions for 8a through 8h: Indicate your opinion on the degree of cost-effectiveness of the maintenance activities listed below by placing **X** next to the phrase that best describes your feeling. Also, on a scale from 1 to 10 indicate the frequency of doing this work activity. One (1) would be seldom if ever done, ten (10) would show it is a major activity using significant resources.

8a. Pothole patching by removal of loose material, cutting vertical sides and compacting good material with roller or mechanical compaction device rather than "dump and run."

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided

( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ________________________

8b. Crack sealing scattered cracks < 1/4 in. in width by cleaning and/or routing prior to sealing with modified, polymerized, fiberized or other high-type asphalt sealants versus dong no crack sealing.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ________________________

8c. Joint sealing concrete pavements by routing out old material, resealing with high-specification material versus doing no joint sealing.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ________________________

8d. Spray patch (oil and chip) or skin patch (thin plant mix paver patch < 500 L.F.) to repair light to moderately cracked surfaces, depressions and edge failures where severe base failure has not occurred versus doing nothing until severe base failure appears.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ________________________

8e. Surface treatment (oil and chip, slurry seal, thin ≤1 in. plant-mix overlay) placed on asphalt surfaces to seal minor hairline cracks, correct raveling, and rejuvenate and extend the service life versus doing nothing until a heavy resurfacing of ≥1 1/2 in. is required.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ________________________

8f. Herbicide spraying to control or eliminate undesirable growth from around signs, delineators, and guide rails versus manual or mechanical removal when these facilities are hidden.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ________________________

8g. Herbicide spraying and/or tree trimming to control or eliminate tree and brush overgrowth, shading, and canopying of roadways and shoulders and to improve visibility at curves and intersections versus letting nature take its course and cutting only to maintain minimum side and overhead clearances.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ____________________

8h. Spot and critical area bridge painting--maintenance painting of scattered coating failures at critical bridge areas versus doing nothing.

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

Frequency rating (1 through 10) ____________________

9. Check X which bridge-painting philosophy or objective your organization uses to program and budget the activity.
( ) Painting to maintain appearance that requires repainting at an earlier stage with minimum surface preparation.

( ) Preventing metal loss with moderate to some extensive surface preparation.

( ) Maintaining structural capacity only with extensive surface preparation in areas treated.

( ) Paint whatever can be painted when money is available.

10. Does your organization have a formalized equipment PM program that schedules inspections and/or service activities on a periodic or use basis?
Yes____ No____

If the answer to 10 is Yes, how cost-effective is this equipment PM program?

( ) Very cost-effective
( ) Moderately cost-effective
( ) Undecided
( ) Moderately ineffective
( ) Not very cost-effective

11. Please indicate your degree of support for getting additional maintenance funding by circling one of the five choices for each strategy listed below.

Additional revenue through bond funding
Strongly Agree Agree Undecided Disagree Strongly Disagree

Raise state taxes
Strongly Agree Agree Undecided Disagree Strongly Disagree

Use federal funds for maintenance of the Interstate and primary network
Strongly Agree Agree Undecided Disagree Strongly Disagree

Place tolls on high volume Interstate highways
Strongly Agree Agree Undecided Disagree Strongly Disagree

NOTE: If you wish to supplement your answers, please feel free to do so on a separate sheet of paper. Refer to each item by number.

APPENDIX D

PHOTOS OF PM DESIGNED IN TO NEW CONSTRUCTION AND REHABILITATION

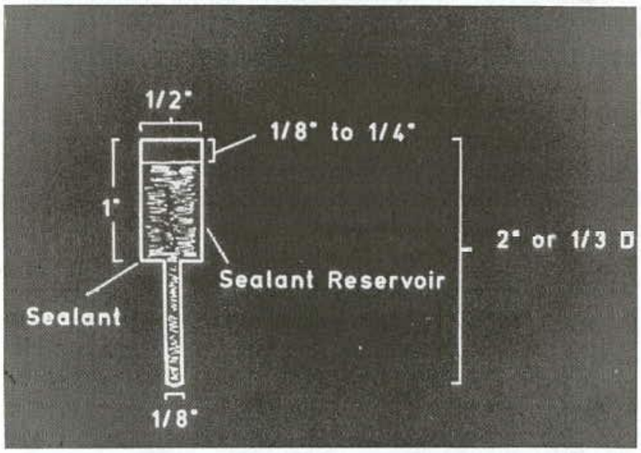


FIGURE D-1 Construction standard for saw and seal bituminous overlays of rigid pavements.

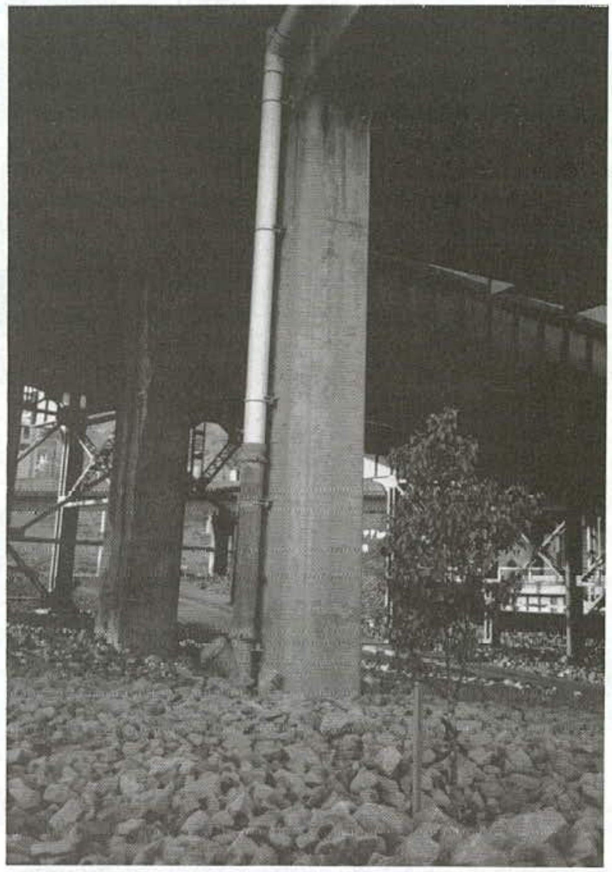
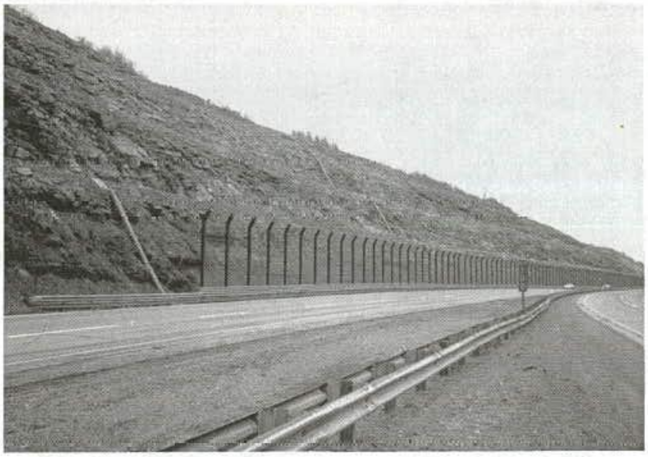


FIGURE D-3 Large-diameter (10-in.) bridge drainage pipes and plastic sheeting and stone ballast reduce maintenance at major Interstate elevated exchange (12-in. galvanized steel pipe used from ground level to 10 ft to prevent vandalism; 10-in. PVC piping used above 10 ft).

FIGURE D-2 Transverse and longitudinal joints sawed and sealed in overlay on major urban Interstate expressway.

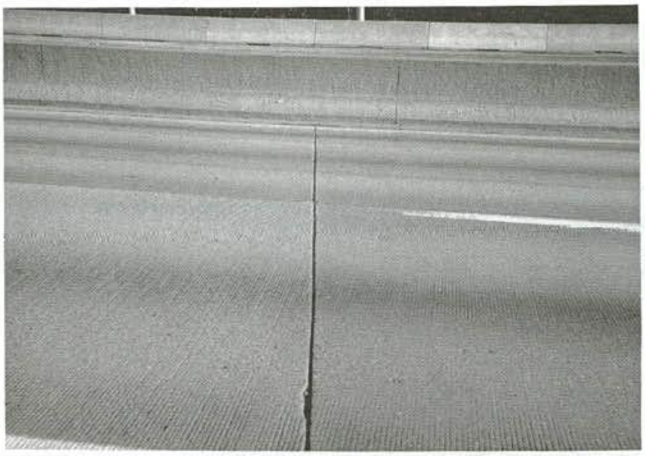
FIGURE D-4 Paved ditches prevent maintenance problems on steep slopes.



FIGURES D-5 AND D-6 Rockfall safety fencing installed during construction in known slope problem areas prevents debris-on-the-road emergencies.

FIGURE D-7 Easy access to back of sound barrier for maintenance equipment is designed in on this urban Interstate expressway.

FIGURE D-8 Drainage ditch paved behind sound barrier to facilitate the movement of equipment and reduce drainage problems.



FIGURES D-9 AND D-10 Concrete barrier and shoulders complement a thick unbonded concrete pavement overlay of existing old Interstate in Pittsburgh, Pa. Preformed joint seals were also used to reduce the need for future maintenance.

FIGURE D-11 Longitudinal surface drainage system installed on high side of superelevated curve to intercept groundwater and surface drainage from slope. This treatment prevents ice buildup during winter and was installed during I-4R upgrading of urban expressway.

FIGURE D-12 Shoulder high side of superelevation of roadway rolled over in a well-rounded cross-vertical curve. Rain and/or snow meltwater will not flow down across travel lanes but back to concrete barrier, which is slotted to facilitate drainage. (Note concrete Jersey barrier used for outside guide rail in lieu of "W" beam to reduce maintenance on this urban expressway.)

APPENDIX E

SUMMARY OF OHIO DOT'S MAINTENANCE QUALITY STANDARDS

THE QUALITY MEASUREMENT SYSTEM

The following requirements were specified by the department for the measuring system:

- The system would measure a sample of the highway system to reduce the amount of field inspection work required.
- The basis for the method was to be objective, quantitative measurements of physical conditions that could be easily understood and used by technicians and maintenance personnel.
- The data from the field inspections were to be presented in a straightforward, easily understood manner.

Except for snow and ice control, where the large number of variables encountered make evaluation difficult in a random-sample system, the activity groups selected for inclusion in the maintenance quality survey include a majority of the maintenance elements of a typical Ohio highway.

Activity Groups

Snow and ice control
Pavement maintenance, including bridge decks
Vegetation control
Shoulder maintenance
Appurtenance maintenance
Drainage maintenance
Rest area maintenance
Bridge maintenance
Roadside litter removal

Guidelines for What a Quality System Should Encompass

- The system for evaluation and inspection should be objective.
- Quantitative values should be obtained when possible and subjective judgments eliminated.
- The inspection method should be standardized to ensure statewide uniformity.
- The influence of poor design or faulty construction should be eliminated.
- Measurements should not be influenced by weather conditions to ensure uniformity.
- Maintenance activities should be weighted to reflect their relative impact on the total highway system.

Measurements

The various elements of the highway facility can be checked at intervals and their condition measured. Good condition will indicate a high level of maintenance quality and, conversely, poor condition will indicate a low quality level. Measurements of the condition of various highway elements are the quality measurements.

Because a sampling procedure was to be used, it was necessary to select conditions that occur with some frequency. The various highway conditions observed are called "recordable conditions." These conditions and their respective units of measurement are described in Table E-1, Summary of Recordable Conditions. One unit of pavement surface deterioration consists of an area of more than 24 $in.^2$ and less than 2 yd^2 of pavement where the deterioration is 2 in. or more in depth. The pavement area in the 2-mile sample section is inspected to determine the number of recordable conditions.

Field Survey Method

Each survey inspected approximately 1650 randomly selected sections. The sections are 2 miles in length, and they total approximately 19 percent of the center line mileage of the state highway system. The sections are randomly selected by computer from the road inventory, which consists of the straight line diagram sections. Sections less than 2 miles in length are not used in the survey, and those more than 2 miles in length are divided into 2-mile sections and incorporated in the sampled mileage. The total number of sections in the population is 4540.

The Ohio state highway system is classified into five route types: Interstate, major thoroughfare divided, two-lane major thoroughfare, auxiliary, and local highways. Five sections from each of the five route types are picked at random in each of the 88 counties, which would result in a total of 2200 sections. However, because many counties do not have Interstate routes and because of the numerous short sections, the sample surveyed consisted of 1650 sections.

Bar Charts

The values for each county represent the number of recordable conditions per center line mile for each route type. The values are weighted by the number of lane miles in each route type. The resulting county values are processed as input for a Calcomp plotter.

TABLE E-1
SUMMARY OF RECORDABLE CONDITIONS

Condition	Description	One Unit Count for Each	Observation Scope
Pavement			
Surface			
Deterioration	2-in. depth and 24-in.^{2} area	2 yd^2	All pavement
Obstructions	Observation or 6-in.-diameter hole	Location	All pavement
Flushing	Area 1 yd^2 or more	100 lineal ft	All pavement
Striping			
Deterioration	Stripe missing, 6 lineal ft or more	1/10 mile	All pavement
Auxiliary marking			
Deterioration	Markings do not delineate	Location	All pavement
Shoulders			
Surface			
Dropoff	2-in. depth and over 6 lineal ft	100 lineal ft	One shoulder
Obstructions	Obstruction or hole, 2 in. deep, 12 in. diameter	Location	One shoulder
Appurtenances			
Guardrail			
Appearance	Rusty, needs painting	100 lineal ft	All guardrail
Deterioration	Rotten posts, bent rail	100 lineal ft	6 runs of rail
Signing			
Deterioration	Nonfunctional sign	Sign	All signs
Roadway			
Vegetation			
Appearance	Deviation from mowing policy	1/5 mile	All medians and roadsides
Litter			
Appearance	Count of 10 or more items of litter	1/10 mile	All medians and roadsides
Drainage			
Ditches			
Obstruction	Obstruction over 50 percent	100 lineal ft	All ditches
Culverts[a] and pipes			
Deterioration	Repair required	2 yd^2	6 structures
Obstruction	Obstruction over 50 percent	Structure	6 structures

[a]Culverts are defined as pipes or structures with a clear spann of less than 10 ft.

The costs per lane mile also shown on the bar charts are direct labor, material, and equipment expenditures for the particular maintenance activity. These costs are from data reported by the Bureau of Auditing and are not available in time for immediate field use in the bar charts. For this reason, some plots are made to show labor expenditures only, which are available reasonably soon. Ideally, charts with total cost (labor, material, and equipment) should be available immediately upon completion of the maintenance quality survey.

Starting with fiscal year 1973, plots were made showing the average values per mile for surveys made during the year. The plots for various years can be compared both for recordable conditions and for expenditure per lane mile.

Bar Charts in Use

In actual use, the bar charts are plotted in two colors. The recordable conditions are in black and the cost per lane mile is in red. The two-color charts are more easily understood than the black and white bar charts included in this report. The following four types of bar charts are in current use:

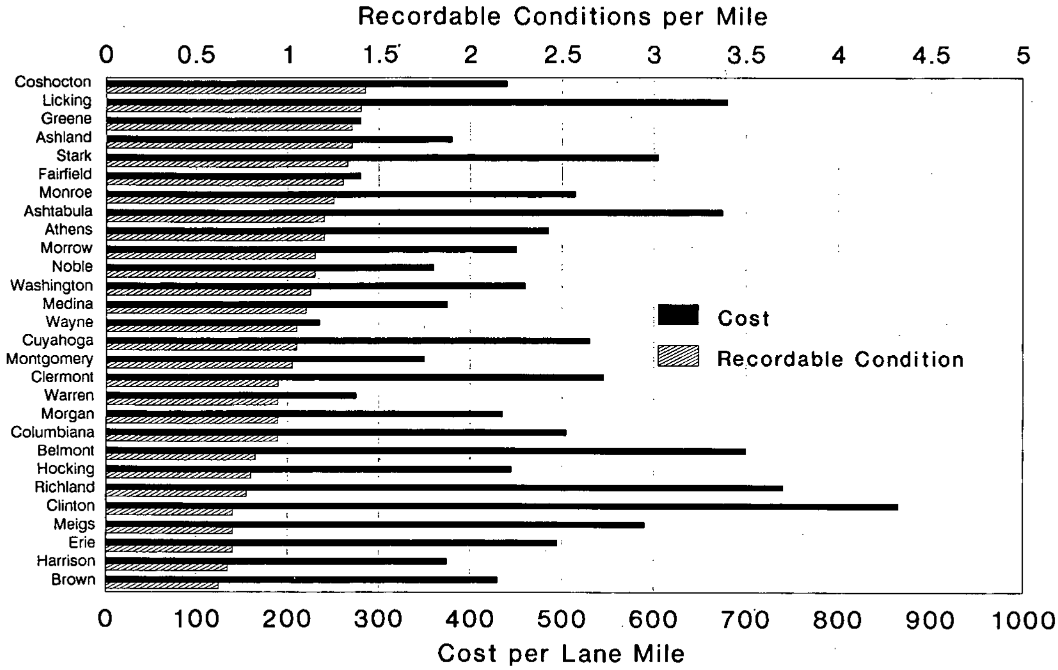


FIGURE E-1 Sample of a statewide report of recordable conditions for pavements and cost of repair per lane mile for FY 1987.

- Bar charts for individual field surveys—These charts show the recordable conditions for 13 maintenance categories and a 14th chart, which is the sum of the recordable conditions for pavement deterioration, shoulder drop-off, mowing, and litter pickup. These four categories were chosen because the recordable conditions in these categories are the result of work by county forces only, whereas in other items of work, district crews perform a part or all of the work. The costs on this chart are for direct labor only for the quarter preceding the date of the survey.
- Annual district bar charts for a fiscal year—These are the same as described in item 1 above, except that the recordable conditions are the average values of the four quarterly surveys. Further, the costs on this chart are total annual expenditures for labor, equipment, and material.

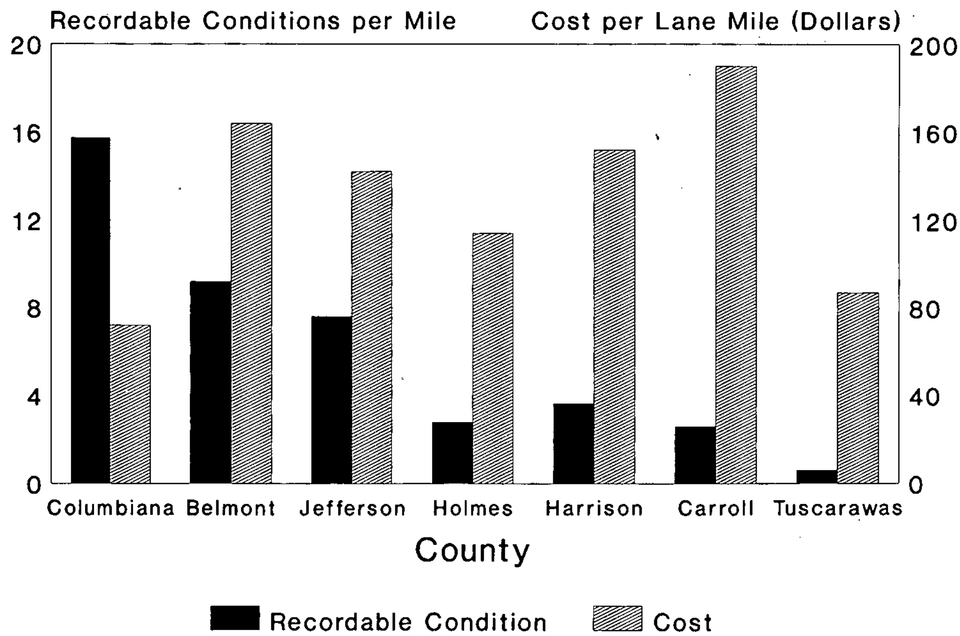


FIGURE E-2 Pavement surface maintenance quality measurement by county.

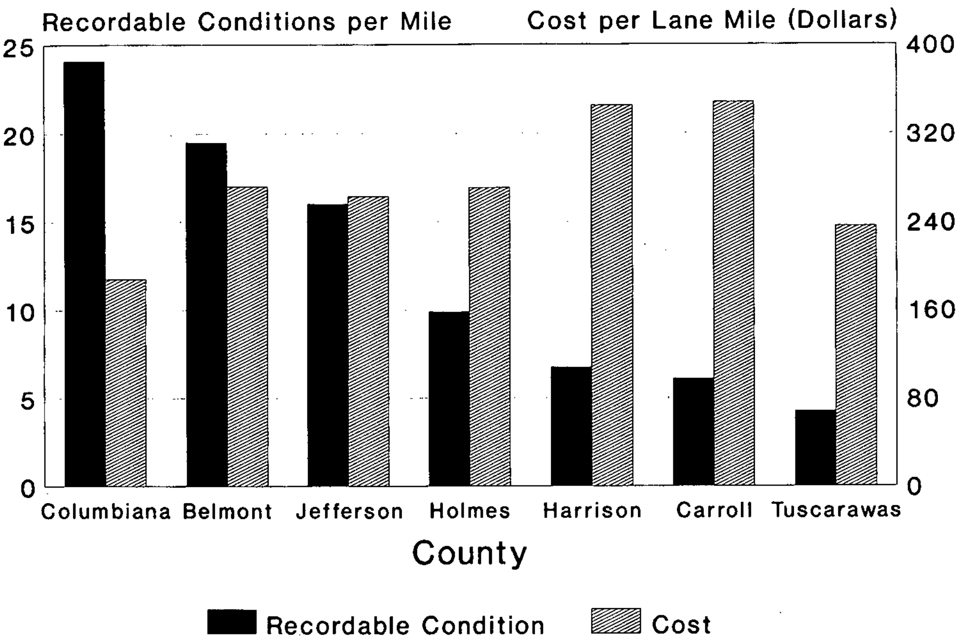


FIGURE E-3 Maintenance quality measurement for several conditions by county.

- Figure E-1—This is a portion of the 88-county bar chart for an individual maintenance category. The cost of removing shoulder obstructions is not reported separately and is included in litter-removal costs. The name of the county appears to the left of the bar chart.
- County history charts—These charts show the recordable conditions per mile and costs per lane mile on successive surveys in a particular county.

The following is a typical explanation of the bar values of the bar chart for one of the maintenance activities included in the maintenance quality survey:

Pavement Surface—The pavement surface maintenance quality measurement in Figure E-2 is the sum of the recordable conditions per mile (Table E-1) for pavement deterioration, pavement obstruction, and pavement flushing. The costs per lane mile are for (a) surface patching; (b) full-depth pavement replacement, including blowup repairs; (c) crack and joint sealing; (d) surface treatment, sealing, deslicking, etc.; and (e) pavement jacking. Although Figure E-2 appears as a separate plot, in practice the Calcomp plotter plots several on a big sheet.

Management Use of the Quality Survey Measurements

Central office management uses the statewide average values for establishing goals in the level of maintenance to be attained during a coming year. The objective of reducing or setting limits on a given number of recordable conditions for a given period can be readily measured.

The bar charts can be used to compare the performance of various counties in terms of recordable conditions and costs per lane mile (Figure E-3). They can also be used to compare the quality of maintenance being performed by a county by comparing recordable conditions between surveys.

County-level supervision monitors progress in reducing recordable conditions between surveys and notes their relative positions compared to other counties.

District office personnel compare the position of their counties and plan corrective action where appropriate. Dramatic changes in maintenance quality have been observed after changes in county supervision.

APPENDIX F

DETAILS OF QUALITY CIRCLES

First Level

Productivity Improvement Teams

This team will function in each county maintenance management organization.

Team leader	County maintenance manager
Team recorder	Appointed by county maintenance manager (HMMS coordinator or chief clerk, etc.)
Resource person	Assistant district maintenance engineer assigned to county
Member	Six to eight department employees plus one interested outside citizen
Six to eight department employees	Two to four foremen
	One assistant manager
	One equipment manager or mechanic II
	Two field employee operators HMM, etc.

All employees should be made aware of team formation and purpose. Each employee must have an opportunity to serve on team and request for volunteers should be used in the initial selection of team members.

Outside citizen: County maintenance manager and district engineer should seek out interested volunteers either from the four citizen members of selection committees or from local contractors who do maintenance contract work or equipment rentals.

Term of Service	Foremen 1 year and 4 months
	Assistants 1 year and 4 months
	Equipment manager 2 years
	Field employee 6 months
	Outside citizen 1 year and 4 months

Meetings

It is anticipated minimum one per month.

Each meeting *shall* last *no longer than 1 hour*.

Each meeting should have agenda and summary minutes (one page).

Team

It will review productivity ideas (PI), assigned by coordinating teams.

Brainstorm solutions, develop new ideas.

Draft written statement on each assigned PI, list approval, modification or rejection of proposed solutions and develop alternate solutions, with cost justification.

Develop new productivity ideas that will be passed up to coordinating committee for consideration.

It will require 80 percent yes votes by the productivity team membership to pass a productivity idea up to the productivity coordinating team.

Number of Team Members	Yes Minimum Votes Required
8	6
9	7
10	8

Second Level Productivity Coordination Teams

These teams will be organized into the following 10 maintenance functional area.

Maintenance Functional Area	Team Leaders	Team Recorders
A. Roadway-Bituminous	Paul Heise	Bob Fleegle
B. Roadway-Concrete	Wade Gramling	Serge Borichevsky
C. Shoulders	Neil Leitzel	John Logan
D. Drainage	Dave Bobanick	Fred Starasinic
E. Bridges	Norm Cochrane	Lou Robinson
F. Roadside	Bob Ross	Dwight Boyer
G. Snow & Ice Control	Hank Farrell	Al Osborne
H. Lines & Signs, Work Area Protection	Joe Wade	Larry Erdley
I. Guardrail & Safety Appurtenances	Ron Hughmanick	John Hanosek
J. Equipment Maintenance & Operator Training	Ed Kazlauskas	Bob Stull

Team Member

Productivity improvement team leaders are team members of their assigned productivity coordination teams. this means that all county maintenance managers and two equipment division managers are members.

Term of Service

It is anticipated that after (2) cycles of meetings, which will be approximately (1) year and (4) months, team makeup will be reshuffled and subject areas changed, but all members', leaders', and recorders' term of service is continuous as long as they are in maintenance management positions.

Meeting

It is anticipated that the coordination team will meet (3) times per year; near the end of summer, end of winter, and end of spring. At least one of these meetings will be held in central location at which time all teams will meet together and the other two can be decentralized and held separately.

Team Purpose

To develop cost-cutting ideas and problem statements for review and development of generalized solutions for productivity teams.

Procedure

1) Brainstorm assigned subject area.
2) Identify and list all brainstorming ideas and problems.
3) Narrow down ideas and problems listed in (2). (This can be done by voting on each idea and selecting three to six of the most important.)
4) Develop written statements for each productivity idea (PI), listing known facts, possible solutions, estimated costs and savings, and changes in current practice or policy.
5) List pros and cons of existing practice or policy and proposed changes for each productivity improvement issue (PI).
6) Assign all or some of the PI to each productivity team leader for them to take back to productivity teams at county and equipment division.
7) After review and analysis by productivity teams, coordination teams will approve, modify, or reject their recommendations and pass on to decision team a report on their actions that must include why teams approved and/or rejected productivity teams' recommendation. Copy of this report must go back to each productivity team. It will require a 80 percent yes vote by the productivity coordination team to pass productivity idea up to decision team for approval.

Third Level Productivity Decision Team

This team will function as the statewide decision team to determine which productivity idea should be implemented department wide.

Team leader	(Nonvoting) director, Bureau of Highway Maintenance
Team recorder	(Nonvoting) chief, research and studies, Bureau of Highway Maintenance
Members	All leaders and recorders of the productivity coordinating teams are voting members of the decision team. Term of service in continuous as long as employed in present job assignment.

Meeting

It is anticipated that this committee will meet (3) times a year shortly after the conclusion of the productivity coordination teams' meeting. Each meeting should not last longer than (1) day.

Team

It will review, discuss, debate, and final vote on the productivity ideas presented by each leader and recorder from the (10) coordination teams.

It will require an 80 percent yes vote of 16 members to adopt an idea for statewide implementation.

Team will also be responsible for review and debating ways to improve or modify the productivity program. If policy must be changed the approval of the Deputy Secretary for Highway Administration is also required.

Team will also be responsible for suggesting topics for coordination and productivity team action.

GROUP LEADER'S DUTIES

1) Get meeting started on time.
2) Guide meeting by gently encouraging all to participate.
3) Establish goal of meeting, which is to target in on how to improve productivity--"Do more with less."
    a) To review present standards and policies in subject area.
    b) To enumerate problem areas. Brainstorming good technique
    c) Identify the most significant items for further refinement (maybe one to five).
    d) Develop clear statement of problem and recommend solution(s).

It is important to gain consensus on what are significant items.
Don't let anyone or several individuals dominate the meeting. All group members must participate. Encourage participation by asking silent member "What do you think..."

GROUP RECORDER DUTIES

1) Get roster of who is present
2) Record principal discussion items.
3) Use easle/tablet/blackboard to list major problems.
4) Prepare and give report that summarizes discussion and present list of major recommendations for your group.

GROUP MEMBER

Group members should:

(A) Become familiar with the standards and policies of the subject area.
(B) Be constructive in critiquing standard and policies. One must keep in mind that money is a very scarce commodity and we are attempting to reduce unit cost.
(C) Come prepared to participate in a constructive discussion of problems and development of recommended solution.

Reading References:

Beck, A.C., "How to Get Commitment to Productivity," *Transportation Research Record 738: Techmology Transfer, the Research Process, and Creating a Productive Environment,* Transportation Research Board, National Research Council, Washington, D.C. (1979).

"Productivity Teams," *Small Business Report* (August 1980).

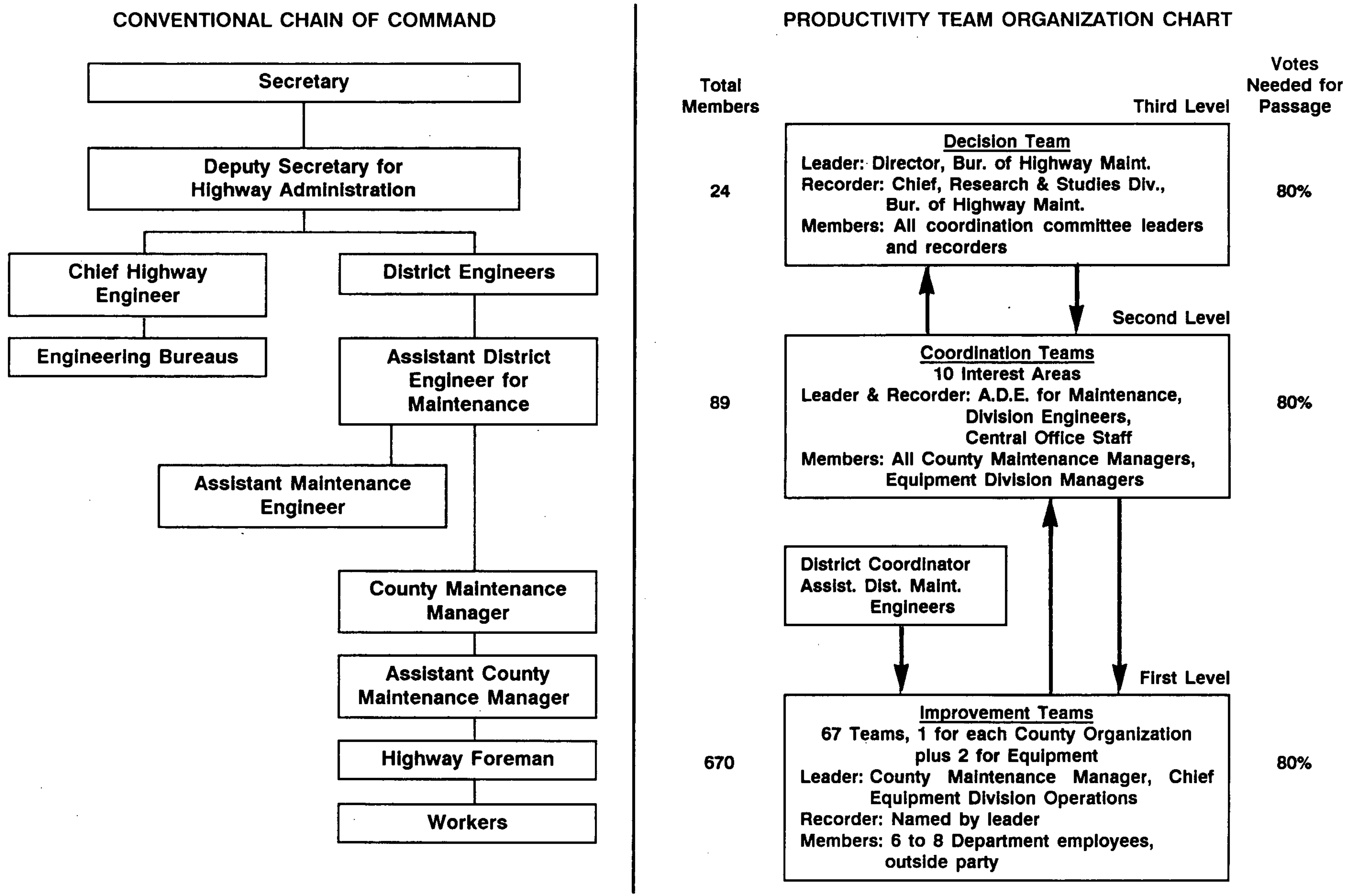


FIGURE F-1. Conventional chain of command and productivity team organization.

Productivity Idea

Panel/or Team____________________

Program Area______________________ Cost Function____________________

Description of Idea:

____

____

____

____

____

Current Procedure:

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____

____

____

____

Description of Benefits:

____

____

____

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Summary Cost Data:

Current Procedure Cost ____________

Productivity Idea Cost ____________

Cost Analysis

	Current Procedure*	Productivity Idea
Personnel Cost Add 56 percent for payroll additive to actual cost (except HMMS, which already has it built into unit costs).		
Materials Cost Should add 10% for purchasing.		
Equipment Costs		
Contract Cost Some estimate of cost for contract preparation and inspection should be used 15% to 30% depending on size of project.		
Total Cost		

*For many items, the statewide HMM unit cost can be used.

APPENDIX G

EXAMPLE OF LIFE-CYCLE COST ANALYSIS OF PAVEMENT PM ALTERNATIVES

To illustrate the use of life-cycle cost analysis, assume that two alternatives have been developed for overlaying a 1-mile section of rural road. The design life is 16 years.

The engineer has determined that a 1½-in. overlay of hot bituminous pavement is needed for strength requirements. The pavement is expected to perform satisfactorily for eight years with an average maintenance cost of $600 per year. Recent bids for similar work suggests a total contract price of $40,000. This estimate includes engineering and inspection costs. At the end of eight years, a 1-in. overlay of hot bituminous pavement will be placed at an estimated total contract price of $18,000. This overlay is expected to perform satisfactorily for the remaining eight years of the design life. The estimated average annual maintenance cost for years 9 through 16 is also $600 per year.

Because the county has the capability of placing a chip seal bituminous treatment, alternative "B" consists of substituting chip seals for the hot-mix overlays. Chip seals have performed satisfactorily for an average of four years. However, before the first seal is placed, significant pavement repairs will be required, and the estimated cost for these repairs is $9500. The average annual maintenance cost for the chip seal is expected to be $1200. Some pavement repairs are anticipated before each four-year seal: $2000 in year 4, $3000 in year 8 and $4000 in year 12. Cost of a chip seal is $10,000 per mile.

Assuming an interest rate of 7 percent and neglecting inflation, we can determine the preferred alternative.

Solution:

1. The first step toward obtaining a solution in an economic analysis is to construct a cash flow diagram. The cash-flow diagram shows all expenditures and the time at which they are made. All annual expenditures, such as annual maintenance costs, are assumed to be end-of-the-year payments. The cash-flow diagrams for alternatives "A" and "B" are shown in the cash-flow table (Table G-1).

2. Next, all expenditures must be converted to the same type of payments at the same in time. In this example all annual expenditures and future single payments will be converted to single payments at year zero. The sum of these single payments is the present worth and represents the dollar amount that must be invested at the chosen interest rate to pay all of the estimated expenditures and have a zero balance at the end of the analysis period. Engineering economy textbooks and Synthesis 122 (*54*) contain tables of factors to convert the different expenditures to the same type at the same time for particular interest rates. This appendix contains tables for 5 percent, 7 percent, and 10 percent interest.

3. Calculate the present worth of Alternative A:

a) The $40,000 for the 1½-in. overlay is a single payment at year zero and needs no conversion. Therefore, P_1 = $40,000.

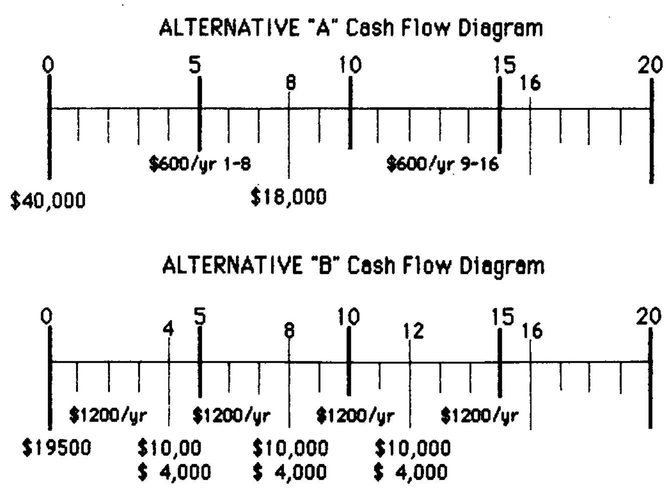
b) The $600 maintenance cost in years 0 through 16 is an annual cost, A, that must be converted to a present sum, P, at year zero. This is done by multiplying the annual cost, $600, by the uniform present worth factor, UPW, at i = 7, and n = 15 years, from the 7 percent table as shown below:

P_2 = $600 (P/A @ 7% for 16 years)
P_2 = $600 (9.44663)
P_2 = $5668

c. The $18,000 for the 1-in. overlay is a future sum, F, at year eight that must be converted to a present sum, P, at year zero. This is done by multiplying the future one-time cost, $18,000, by the single-payment present-worth factor, SPW, at i = 7, and n = 15 years, from the 7 percent table as shown below:

P_3 = $18,000 (P/F @ 7% for eight years)
P_3 = $18,000 (0.58201)
P_3 = $10,476

TABLE G-1
CASH-FLOW TABLE



d) The present worth of alternative "A" is the sum of the individual present worths.

$PW_A = P_1 + P_2 + P_3$
$PW_A = 40{,}000 + 5{,}668 + 10{,}476$
$PW_A = \$56{,}144$

4. Calculate the present worth of Alternative B:

a) Each seal is estimated at $10,000. The pavement repair necessary before the initial seal is estimated at $9500. Therefore, the year zero expenditures are:

$P_1 = 10{,}000 + 9{,}500 = \$19{,}500$

b) The four-year seal will be preceded by $2000 worth of pavement repairs; therefore, the present worth of that operation is:

$P_2 = \$12{,}000$ (P/F @ 7% in fourth year)
$P_2 = \$12{,}000\ (0.76290)$
$P_2 = \$9155$

c) The eight-year seal will need $3000 in repairs.

$P_3 = \$13{,}000$ (P/F @ 7% in eighth year)
$P_3 = \$13{,}000\ (0.58201)$
$P_3 = \$7566$

d) The 12-year seal will need $4000 in repairs.

$P_4 = \$14{,}000$ (P/F @ 7% in 12 years)
$P_4 = \$14{,}000\ (0.44401)$
$P_4 = \$6216$

e) Maintenance costs are estimated at $1200 per year for the 16-year period; therefore, the present worth is:

$P_5 = \$1200$ (P/A @ 7% for 16 years)
$P_5 = \$1200\ (9.44663)$
$P_5 = \$11{,}336$

f) The present worth of alternative "B" is the sum of the individual present worths:

$PW_B = P_1 + P_2 + P_3 + P_4 + P_5$
$PW_B = \$19{,}500 + \$9{,}155 + \$7{,}566 + \$6{,}216 + \$11{,}336$
$PW_B = \$53{,}773$

A comparison of the two alternatives shows that "B" has the lower present worth, and therefore is the preferred choice for $i = 7$ percent. The interest rate is mentioned to stress the fact that the preferred alternative is dependent on the assumed interest rate.

At 5 percent interest, alternative "A" would be just less than alternative "B." If there is concern about the assumed interest rate, additional computations should be performed to determine the effect of a higher or lower rate.

The value of the interest rate used in the analysis can be a major factor in the outcome. At first glance it may be disturbing to realize that the value assumed for the interest rate can influence the outcome of the analysis. However, this fact really increases the usefulness of life-cycle costing because it forces an organization to place values on present and future investments, and therefore to make more rational decisions. If a high value is placed on the cost of money (discount rates), investments will tend to be deferred, but an agency must then be prepared to make the necessary future investments. Low values on the cost of money will tend to result in more immediate capital investments. We also know that deferring PM can be very costly.

There are two philosophies about selecting the interest rates with the differences primarily in the handling of inflation. Some argue that the effect of inflation is extremely important and must be considered. Although future inflation rates are very difficult to forecast, they must be taken into account. This can be done by assuming an inflation rate and applying it to future costs, then discounting those costs with an interest rate close to the current rate. Another way to account for inflation is to subtract the inflation rate from the current interest rate, leaving a discount rate somewhat lower than the current interest rate to use in the computation. Then, future costs can be estimated using current dollars, and discounted at the adjusted interest rate, such as 4 percent.

The counter philosophy is that public spending takes money out of private hands, which values that money at the current rate. If public agencies cannot use the money as productively as the private sector, it should not be spent. Because future costs will be funded with future dollars and tax revenues have generally kept pace with inflation, inflation can be ignored. Also, inflation is fueled by large public expenditures, which are frequently the result of comparing large public present-day expenditures with planned future expenditures at below-market discount rates. This approach then would select a higher discount rate, approximately 2 to 4 percent below the current market rate. High interest rates tend to favor future expenditures.

Both arguments have valid points and should be considered by decision makers. For this reason an analysis should discount future expenditures at both a high and a low rate. If any alternative should come out best (or worst) in both cases, then it is clearly the best (or worst) economic choice. On the other hand, if the standing of an alternative depends upon the discount rate, then the choice is not clearly economic.

TIME VALUE OF MONEY

Money has a time value. If $1 can be invested today at a 6% annual rate it will be worth $1.06 a year from now. In other words, the present worth of the $1.06 to be received next year is $1.00. The present worth of any amount of money due in future is calculated by a process known as discounting. In the above illustration the discounting is performed by dividing the $1.06 by 1.06 (i.e. 1 + rate).

The discounting process (to be explained more fully in this chapter) is important in life cycle cost analysis because it facilitates the translation of future values to present values. If the total cost of owning an asset is its initial cost and all subsequent costs, the latter must first be discounted to present value before they are combined with initial cost to obtain the life cycle cost. It would be erroneous to ignore the timing of the future costs and merely add them to initial cost.

All life cycle cost analysis must be performed in terms of compatible dollars i.e. dollars dated as of a point in time or a period of time. The tools of life cycle cost analysis by which dollar values are shifted in time are six (6) basic interest formulas. These formulas are explained in the following pages. The symbols used are:

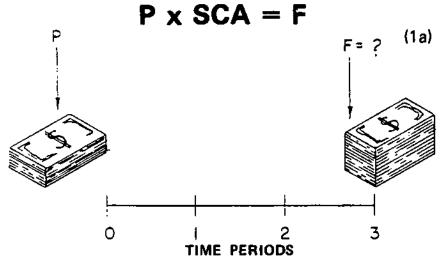
- i = interest rate per period
- n = number of interest periods
- P = present worth
- F = future worth
- A = uniform sum of money in each time period

SINGLE COMPOUND AMOUNT (SCA)

$$SCA = (1 + i)^n \qquad (1)$$

This factor is used to determine the future amount F that a present sum P will accumulate to at i-percent interest, in n years. If you know P (present worth) and want to find F (future worth), then:

$$P \times SCA = F \qquad (1a)$$



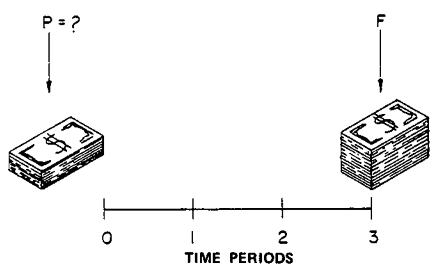
Example: Suppose you deposited $1,000 in a savings account which paid interest at the rate of 6% per annum, compounded annually. How much money would you have in the account at the end of 3 years, if you made no further deposits or withdrawals? The answer to this question is found by compounding the interest on the principal amount each year for 3 years. The result is called the "future value of a single sum." By carrying out the arithmetic, we find that the future value in 3 years of $1,000 deposited today at 6% per annum, compounded annually, is $1,191.01.

SINGLE PRESENT WORTH (SPW)

$$SPW = \frac{1}{(1 + i)^n} \qquad (2)$$

This factor is used to determine the present worth P that a future amount F will be at interest of i-percent, in n years. If you know F (future worth) and want to find P (present worth), then:

$$P = SPW \times F \qquad (2a)$$



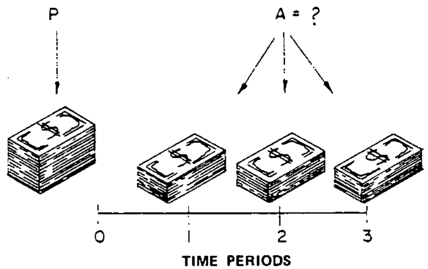
Example: How much would you have to deposit in a savings account today to receive $1,000 at the end of 3 years, if the account paid interest of 6% per annum, compounded annually? The solution is to find the "present value of a single sum." The present value of $1,000 3 years away at interest of 6% per annum, compounded annually, is $839.62.

UNIFORM CAPITAL RECOVERY (UCR)

$$UCR = \frac{i\,(1+i)^n}{(1+i)^n - 1} \qquad (3)$$

This factor is used to determine an annual payment A required to pay off a present amount P at i-percent interest, for n years. If you know a present sum of money, P spent today, and want to know the uniform payment A needed to pay back P over a stated period of time, then:

$$P \times UCR = A \qquad (3a)$$



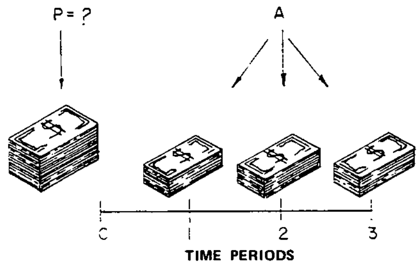
Example: Suppose you take out a $20,000, 20 year mortgage on your house, paying 8% interest, compounded annually. The uniform capital recovery factor (UCR) will tell you how much your annual mortgage payment would be. In this case, the annual mortgage payment would be $2,037.00.

UNIFORM PRESENT WORTH (UPW)

$$UPW = \frac{(1+i)^n - 1}{i\,(1+i)^n} \qquad (4)$$

This is used to determine the present amount P that can be paid by equal payments of A (uniform annual payment) at i-percent interest, for n years. If you know A (uniform annual payment) and want to find P (present worth of all these payments), then:

$$P = UPW \times A \qquad (4a)$$



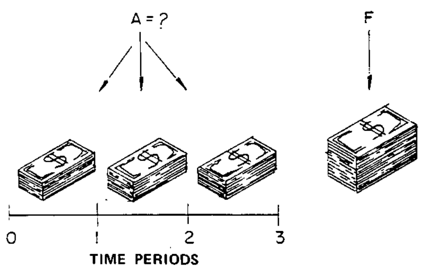
Example: What single sum, deposited today at 6% interest compounded annually, would enable you to withdraw $1,000 at the end of each of the next 3 years? In other words, we are looking for the "present value of a future annuity." The present value of a 3 year annuity of $1,000 at interest of 6% compounded annually is $2,672.98.

UNIFORM SINKING FUND (USF)

$$USF = \frac{i}{(1+i)^n - 1} \qquad (5)$$

This factor is used to determine the equal annual amount A that must be invested for n years at i-percent interest in order to accumulate a specified future amount F. If you know F (the future worth of a series of annual payments) and want to find A (value of those annual payments), then:

$$A = F \times USF \qquad (5a)$$



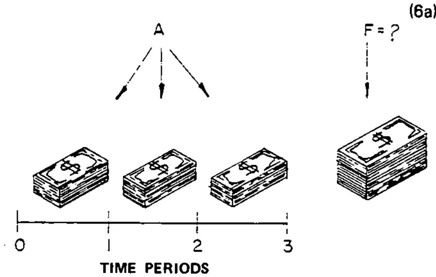
Example: The future value of a 3 year annuity of $31,411 earning interest at 6% compounded annually is $100,000. That is, in order to have $100,000 at the end of 3 years, you will have to deposit $31,411 on December 31 of each of the next 3 years in a sinking fund earning 6% interest, compounded annually.

UNIFORM COMPOUND AMOUNT (UCA)

$$UCA = \frac{(1+i)^n - 1}{i} \qquad (6)$$

This factor is used to determine the amount F that an equal annual payment A will accumulate to in n years at i-percent interest. If you know A (uniform annual payment) and want to find F (the future worth of these payments), then:

$$A \times UCA = F \qquad (6a)$$



Example: If you were to deposit $1,000 on the last day of each of 3 years in a savings account, earning interest at 6% per annum compounded annually, how much would you have at the end of the 3 years or what would be the "future value of the annuity"? The future value of a 3 year annuity of $1,000 per year at interest of 6% per annum compounded annually is $3,183.56. The word "annuity" is used to describe a series of equal payments, made at regular intervals of time.

USE OF INTEREST TABLES

To perform the necessary calculations to determine compound interest rates is a lengthy process. As a convenience, Interest Tables using one dollar as the basis of calculation have been included in this workbook to simplify the process.

The following example illustrates how the tables can be used to save time and simplify the compound interest calculation.

To find the future worth of $1,000 in 10 years at 10% per year interest rate, use the Interest Table for Single Compound Amount. The Single Compound Amount factor is 2.59373 and the future value would be calculated from Formula 1a:

F = P x SCA
F = $1,000 x 2.59373
F = $2,593.73

All the other interest values can be obtained in a similar manner from established tables. When an interest rate is not in the table, the formulas may be used or interpolation may be performed.

For example, if the uniform capital recovery factor, UCR, is desired for 7% interest rate at 10 years and only tables for 6% and 8% are available, the interpolation can be performed as follows:

n = 10 years
UCR = 0.6% = .13587 / 0.8% = .14903 → UCR @ 7% = .14245

Actual UCR @ 7% from tables, is .14233.

FREQUENCY OF COMPOUNDING

The frequency at which the interest rated is compounded has a significant effect on the true or effective interest rate. The more frequent the compounding, the greater is the effective rate. For example, if a department store has a carrying charge of 1.25% per month on the unpaid balance in an account, this will amount to an annual rate of 16%.

$(1 + i)^n = (1.0125)^{12}$
$= 1.16$
therefore $i = 16\%$

Similarly, the effective rate for money invested at 6% will depend on the frequency of compounding as follows

Nominal Rate	Frequency of Compounding	Effective Rate
6.0	Annually	6.00
6.0	Semiannually	6.09
6.0	Quarterly	6.14
6.0	Monthly	6.17
6.0	Continuously	6.19

In order to use the interest tables to find effective interest, divide the number of time periods per year into the nominal rate and multiply the periods per year by the number of years.

For example, if the annual interest rate is given as 10% compounded semiannually for 10 years and the value of a $1,000 investment is desired as of the end of 10 years, then the Single Compound Amount for 5% interest and 20 periods is used. (i.e. 10% ÷ 2 periods/yr. = 5% and 2 periods/yr. x 10 yrs. = 20 periods)

F = P x (SCA; 10 yrs., 10%) Semiannually
F = P x (SCA; 20, 5%)
F = $1,000 x 2.65326
F = $2,653.26

EXAMPLES

Example (SCA) — Column 1

If $10,000 is invested today at 10% interest per year, what would it be worth 10 years in the future?

SOLUTION:

F = P x (SCA; 10, 10%)
F = $10,000 x 2.59373
F = $25,937.30

Example (SPW) — Column 2

What is the present worth of $3,000 to be paid 10 years from today if interest is 9% per year?

SOLUTION:

P = F x (SPW; 10, 9%)
P = $3,000 x .42241
P = $1,267.23

Example (UCR) — Column 3

If $2,000 is borrowed today at 9% interest and it is to be repaid in 5 years with equal annual payments, what would these payments be?

SOLUTION:

A = P x (UCR; 5, 9%)
A = $2,000 x .25709
A = $514.18

Example (UPW) — Column 4

What is the present worth of 12 annual end of year payments of $350.00 if the interest rate is 13% per year?

SOLUTION:

P = A x (UPW; 12, 13%)
P = $350 x 5.91763
P = $2,071.17

Example (USF) — Column 5

John knows he needs $5,000 five years from today, what uniform annual payment must be made to provide it if interest is 9% per year?

SOLUTION:

A = F x (USF; 5, 9%)
A = $5,000 x .16709
A = $835.45

Example (UCA) — Column 6

What would 10 uniform end of year payments of $300.00 per year be worth in 10 years if the interest rate is 11% per annum?

SOLUTION

F = A x (UCA; 10, 11%)
F = $300 x 16.72191
F = $5,016.57

PROBLEMS

2.1 $1,000 is paid at the end of each of the next 5 years. What is the present worth of these payments if interest is computed at 8% per year?

2.2 A lender is willing to advance $30,000 on a 12% 20-year mortgage with annual payments made at the end of each year. What is the annual payment? How would this problem be solved if the payments were made monthly?

2.3 Jim Evans has the following debts:

a. 20 annual mortgage payments of $2,400,
b. 12 bi-monthly payments of $75 on his automobile,
c. $6,000 in debts due in 2 years,
d. $700 due today.

Using an annual interest rate of 12%, calculate the uniform annual amount necessary to retire all of the debts if Jim refinances the debts for 20 years.

5.00% COMPOUND INTEREST FACTORS

Periods	Single Payment		Uniform Series			
	Compound Amount Factor SCA 1	Present Worth Factor SPW 2	Capitol Recovery Factor UCR 3	Present Worth Factor UPW 4	Sinking Fund Factor USF 5	Compound Amount Factor UCA 6
1	1.05000	0.95238	1.05001	0.95237	1.00002	0.99998
2	1.10250	0.90703	0.53781	1.85938	0.48781	2.04996
3	1.15762	0.86384	0.36721	2.72321	0.31721	3.15245
4	1.21550	0.82271	0.28202	3.54589	0.23202	4.31004
5	1.27628	0.78353	0.23098	4.32942	0.18098	5.52553
6	1.34009	0.74622	0.19702	5.07563	0.14702	6.80180
7	1.40709	0.71069	0.17282	5.78630	0.12282	8.14186
8	1.47745	0.67684	0.15472	6.46313	0.10472	9.54893
9	1.55132	0.64461	0.14069	7.10773	0.09069	11.02635
10	1.62888	0.61392	0.12951	7.72165	0.07951	12.57765
11	1.71033	0.58468	0.12039	8.30632	0.07039	14.20651
12	1.79584	0.55684	0.11283	8.86315	0.06283	15.91682
13	1.88563	0.53033	0.10646	9.39347	0.05646	17.71260
14	1.97991	0.50507	0.10102	9.89854	0.05103	19.59821
15	2.07891	0.48102	0.09634	10.37956	0.04634	21.57809
16	2.18285	0.45812	0.09227	10.83767	0.04227	23.65697
17	2.29199	0.43630	0.08870	11.27396	0.03870	25.83978
18	2.40659	0.41553	0.08555	11.68948	0.03555	28.13174
19	2.52691	0.39574	0.08275	12.08522	0.03275	30.53828
20	2.65326	0.37690	0.08024	12.46210	0.03024	33.06516
21	2.78592	0.35895	0.07800	12.82105	0.02800	35.71838
22	2.92521	0.34186	0.07597	13.16290	0.02597	38.50427
23	3.07147	0.32558	0.07414	13.48847	0.02414	41.42944
24	3.22504	0.31007	0.07247	13.79854	0.02247	44.50085
25	3.38629	0.29531	0.07095	14.09385	0.02095	47.72586
26	3.55560	0.28125	0.06956	14.37508	0.01956	51.11209
27	3.73338	0.26785	0.06829	14.64293	0.01829	54.66765
28	3.92005	0.25510	0.06712	14.89802	0.01712	58.40097
29	4.11605	0.24295	0.06605	15.14098	0.01605	62.32097
30	4.32185	0.23138	0.06505	15.37237	0.01505	66.43697
31	4.53794	0.22036	0.06413	15.59272	0.01413	70.75876
32	4.76483	0.20987	0.06328	15.80259	0.01328	75.29662
33	5.00307	0.19988	0.06249	16.00244	0.01249	80.06137
34	5.25322	0.19036	0.06176	16.19281	0.01176	85.06435
35	5.51587	0.18129	0.06107	16.37410	0.01107	90.31749
36	5.79166	0.17266	0.06043	16.54675	0.01043	95.83328
37	6.08124	0.16444	0.05984	16.71120	0.00984	101.62480
38	6.38530	0.15661	0.05928	16.86780	0.00928	107.70600
39	6.70456	0.14915	0.05876	17.01695	0.00876	114.09120
40	7.03978	0.14205	0.05828	17.15900	0.00828	120.79560

7.00% COMPOUND INTEREST FACTORS

Periods	Single Payment: Compound Amount Factor SCA 1	Single Payment: Present Worth Factor SPW 2	Uniform Series: Capitol Recovery Factor UCR 3	Uniform Series: Present Worth Factor UPW 4	Uniform Series: Sinking Fund Factor USF 5	Uniform Series: Compound Amount Factor UCA 6
1	1.07000	0.93458	1.07000	0.93458	1.00000	1.00000
2	1.14490	0.87344	0.55310	1.80800	0.48310	2.06998
3	1.22504	0.81630	0.38105	2.62430	0.31105	3.21488
4	1.31079	0.76290	0.29523	3.38720	0.22523	4.43991
5	1.40255	0.71299	0.24389	4.10018	0.17389	5.75070
6	1.50073	0.66634	0.20980	4.76652	0.13980	7.15325
7	1.60578	0.62275	0.18555	5.38927	0.11555	8.65397
8	1.71818	0.58201	0.16747	5.97128	0.09747	10.25974
9	1.83845	0.54394	0.15349	6.51522	0.08349	11.97792
10	1.96714	0.50835	0.14238	7.02356	0.07238	13.81637
11	2.10485	0.47509	0.13336	7.49866	0.06336	15.78350
12	2.25218	0.44401	0.12590	7.94267	0.05590	17.88832
13	2.40984	0.41497	0.11965	8.35763	0.04965	20.14050
14	2.57852	0.38782	0.11435	8.74545	0.04435	22.55034
15	2.75902	0.36245	0.10979	9.10789	0.03979	25.12885
16	2.95215	0.33874	0.10586	9.44663	0.03586	27.88785
17	3.15880	0.31658	0.10243	9.76320	0.03243	30.83998
18	3.37991	0.29587	0.09941	10.05907	0.02941	33.99876
19	3.61651	0.27651	0.09675	10.33558	0.02675	37.37868
20	3.86966	0.25842	0.09439	10.59400	0.02439	40.99518
21	4.14054	0.24151	0.09229	10.83551	0.02229	44.86482
22	4.43037	0.22571	0.09041	11.06123	0.02041	49.00533
23	4.74050	0.21095	0.08871	11.27217	0.01871	53.43570
24	5.07233	0.19715	0.08719	11.46932	0.01719	58.17616
25	5.42739	0.18425	0.08581	11.65357	0.01581	63.24849
26	5.80731	0.17220	0.08456	11.82577	0.01456	68.67586
27	6.21382	0.16093	0.08343	11.98670	0.01343	74.48315
28	6.64878	0.15040	0.08239	12.13710	0.01239	80.69693
29	7.11420	0.14056	0.08145	12.27766	0.01145	87.34570
30	7.61219	0.13137	0.08059	12.40903	0.01059	94.45985
31	8.14504	0.12277	0.07980	12.53180	0.00980	102.07200
32	8.71519	0.11474	0.07907	12.64655	0.00907	110.21700
33	9.32525	0.10724	0.07841	12.75378	0.00841	118.93210
34	9.97802	0.10022	0.07780	12.85401	0.00780	128.25740
35	10.67647	0.09366	0.07723	12.94766	0.00723	138.23530
36	11.42382	0.08754	0.07672	13.03520	0.00672	148.91180
37	12.22349	0.08181	0.07624	13.11701	0.00624	160.33550
38	13.07913	0.07646	0.07580	13.19347	0.00580	172.55900
39	13.99466	0.07146	0.07539	13.26493	0.00539	185.63800
40	14.97429	0.06678	0.07501	13.33170	0.00501	199.63270

10.00% COMPOUND INTEREST FACTORS

Periods	Single Payment: Compound Amount Factor SCA 1	Single Payment: Present Worth Factor SPW 2	Uniform Series: Capitol Recovery Factor UCR 3	Uniform Series: Present Worth Factor UPW 4	Uniform Series: Sinking Fund Factor USF 5	Uniform Series: Compound Amount Factor UCA 6
1	1.10000	0.90909	1.10001	0.90909	1.00001	0.99999
2	1.21000	0.82645	0.57619	1.73552	0.47619	2.09998
3	1.33100	0.75132	0.40212	2.48684	0.30212	3.30997
4	1.46410	0.68302	0.31547	3.16985	0.21547	4.64096
5	1.61051	0.62092	0.26380	3.79077	0.16380	6.10505
6	1.77155	0.56448	0.22961	4.35524	0.12961	7.71555
7	1.94871	0.51316	0.20541	4.86840	0.10541	9.48709
8	2.14358	0.46651	0.18744	5.33490	0.08744	11.43580
9	2.35794	0.42410	0.17364	5.75900	0.07364	13.57936
10	2.59373	0.38555	0.16275	6.14455	0.06275	15.93729
11	2.85310	0.35050	0.15396	6.49504	0.05396	18.53099
12	3.13841	0.31863	0.14676	6.81367	0.04676	21.38408
13	3.45225	0.28967	0.14078	7.10334	0.04078	24.52246
14	3.79747	0.26333	0.13575	7.36667	0.03575	27.97469
15	4.17721	0.23939	0.13147	7.60606	0.03147	31.77214
16	4.59493	0.21763	0.12782	7.82369	0.02782	35.94933
17	5.05443	0.19785	0.12466	8.02153	0.02466	40.54424
18	5.55986	0.17986	0.12193	8.20139	0.02193	45.59863
19	6.11585	0.16351	0.11955	8.36491	0.01955	51.15848
20	6.72743	0.14865	0.11746	8.51355	0.01746	57.27428
21	7.40017	0.13513	0.11562	8.64868	0.01562	64.00168
22	8.14018	0.12285	0.11401	8.77152	0.01401	71.40179
23	8.95420	0.11168	0.11257	8.88321	0.01257	79.54193
24	9.84961	0.10153	0.11130	8.98473	0.01130	88.49608
25	10.83456	0.09230	0.11017	9.07703	0.01017	98.34561
26	11.91801	0.08391	0.10916	9.16094	0.00916	109.18010
27	13.10981	0.07628	0.10826	9.23722	0.00826	121.09800
28	14.42078	0.06934	0.10745	9.30655	0.00745	134.20780
29	15.86285	0.06304	0.10673	9.36959	0.00673	148.62850
30	17.44913	0.05731	0.10608	9.42691	0.00608	164.49120
31	19.19403	0.05210	0.10550	9.47901	0.00550	181.94020
32	21.11342	0.04736	0.10497	9.52637	0.00497	201.13410
33	23.22475	0.04306	0.10450	9.56943	0.00450	222.24750
34	25.54721	0.03914	0.10407	9.60857	0.00407	245.47220
35	28.10191	0.03558	0.10369	9.64416	0.00369	271.01900
36	30.91209	0.03235	0.10334	9.67650	0.00334	299.12080
37	34.00328	0.02941	0.10303	9.70591	0.00303	330.03270
38	37.40359	0.02674	0.10275	9.73265	0.00275	364.03560
39	41.14394	0.02430	0.10249	9.75695	0.00249	401.43920
40	45.25830	0.02210	0.10226	9.77905	0.00226	442.58270

APPENDIX H

VALUE ENGINEERING FAST DIAGRAM AND DESCRIPTION OF ALTERNATIVE POTHOLE REPAIRS

DESCRIPTION BITUMINOUS PATCHING TECHNIQUES

Number		Equipment
1	Fill hole in one lift with mixture, and compact by hitting the patch with the back of a shovel twice. No effort made to clean or shape the hole, and no tacking of the exposed surfaces of the hole.	Dump Truck Shovels
2	Same as #1, except compaction is performed with the tire of the dump truck.	Dump Truck Shovels
3	Shape the area to be patched with an axe and sledge, remove loose asphalt with mattock, sweep area clean, tack the exposed surfaces of patch area, shovel in material and level with lute. Compact the wacker (vibratory compactor) and seal edges with tack oil and #1B stone.	Dump Truck Pickup, Heating Kettle, Wacker, Axe, Sledge, Mattocks, Brooms
4	Same as #3, except a pup roller is used for compaction.	Dump Truck Pickup, Heating Kettle, Pup Roller, Axe, Sledge, Mattocks, Brooms
5	Same as method #4, except the area to be patched is shaped with a pavement breaker.	2 Pickups, Dump Truck, Heating Kettle, Air Compressor and Pavement Breaker, Pup Roller, Brooms

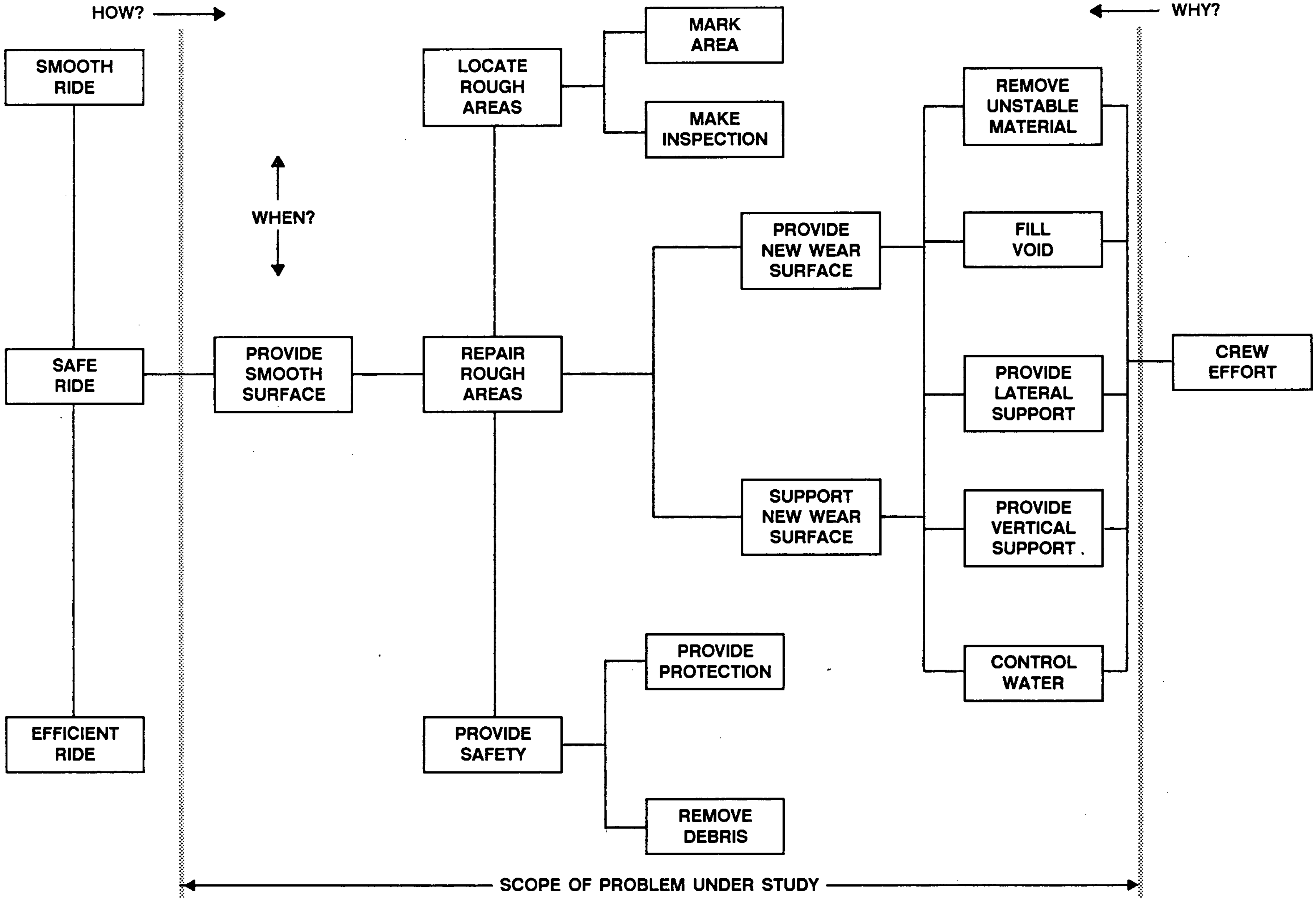


FIGURE H-1 Function analysis system techniques (FAST) diagram for bituminous patching.

APPENDIX I

LIST OF FHWA-SPONSORED VALUE ENGINEERING STUDIES

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.