Timely Preventive Maintenance for Municipal Roads — A Primer

A Best Practice by the National Guide to Sustainable Municipal Infrastructure

National Guide to Sustainable Municipal Infrastructure
Guide national pour des infrastructures municipales durables

Canada

NRC · CNRC

Federation of Canadian Municipalities
Fédération canadienne des municipalités

Timely Preventive Maintenance for Municipal Roads — A Primer
Issue No 1.1
Publication Date: April 2003

TABLE OF CONTENTS

TABLES

FIGURES

FOREWORD

In spite of recent increases in public infrastructure investments, municipal infrastructure is decaying faster than it is being renewed. Factors such as low funding, population growth, tighter health and environmental requirements, poor quality control leading to inferior installation, inadequate inspection and maintenance, and lack of consistency and uniformity in design, construction and operation practices have impacted on municipal infrastructure. At the same time, an increased burden on infrastructure due to significant growth in some sectors tends to quicken the ageing process while increasing the social and monetary cost of service disruptions due to maintenance, repairs or replacement.

With the intention of facing these challenges and opportunities, the Federation of Canadian Municipalities (FCM) and the National Research Council (NRC) have joined forces to deliver the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices*. The Guide project, funded by the Infrastructure Canada program, NRC, and through in-kind contributions from public and private municipal infrastructure stakeholders, aims to provide a decision-making and investment planning tool as well as a compendium of technical best practices. It provides a road map to the best available knowledge and solutions for addressing infrastructure issues. It is also a focal point for the Canadian network of practitioners, researchers and municipal governments focused on infrastructure operations and maintenance.

The *National Guide to Sustainable Municipal Infrastructure* offers the opportunity to consolidate the vast body of existing knowledge and shape it into best practices that can be used by decision makers and technical personnel in the public and private sectors. It provides instruments to help municipalities identify needs, evaluate solutions, and plan long-term, sustainable strategies for improved infrastructure performance at the best available cost with the least environmental impact. The five initial target areas of the Guide are: potable water systems (production and distribution), storm and wastewater systems (collection, treatment, disposal), municipal roads and sidewalks, environmental protocols and decision making and investment planning.

Part A of the *National Guide to Sustainable Municipal Infrastructure* focuses on decision-making and investment planning issues related to municipal infrastructure. Part B is a compendium of technical best practices and is qualitatively distinct from Part A. Among the most significant of its distinctions is the group of practitioners for which it is intended. Part A, or the DMIP component of the Guide, is intended to support the practices and efforts of elected officials and senior administrative and management staff in municipalities throughout Canada.

It is expected that the Guide will expand and evolve over time. To focus on the most urgent knowledge needs of infrastructure planners and practitioners, the committees solicited and received recommendations, comments and suggestions from various stakeholder groups, which shaped the enclosed document. Although the best practices are adapted, wherever possible, to reflect varying municipal needs, they remain guidelines based on the collective judgements of peer experts. Discretion must be exercised in applying these guidelines to account for specific local conditions (e.g. geographic location, municipality size, climatic condition).

For additional information or to provide comments and feedback, please visit the Guide Web site at www.infraguide.gc.ca or contact the Guide team at infraguide@nrc-cnrc.gc.ca.

ACKNOWLEDGEMENTS

The dedication of individuals who volunteered their time and expertise in the interest of the *National Guide to Sustainable Municipal Infrastructure* is acknowledged and much appreciated.

This best practice was developed by stakeholders from Canadian municipalities and roads specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. The following members of the National Guide's road Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff and Eres Consultants, a division of Applied Research Associates Inc.

Mike Sheflin P.Eng., Chair	Former CAO, Regional Municipality of Ottawa-Carleton
Brian Anderson	Ontario Good Roads Association, Ontario
Vince Aurilio P.Eng.	Ontario Hot Mix Producers Association,
Don Brynildsen P.Eng.	City of Vancouver, British Colombia
Al Cepas P.Eng.	City of Edmonton, Alberta
Brian E. Crist P.Eng.	City of Whitehorse, Yukon
Michel Dion ing. M.Sc.	Axor Experts-Conseils, Quebec
Cluny Matchim C.E.T.	Town of Gander, Newfoundland
Abe Mouaket P.Eng.	IM Associates, Ontario
Tim J. Smith P.Eng. M.Sc.Eng	Cement Association of Canada, Ontario
Sylvain Boudreau M.Eng., P.Eng.	Technical Advisor, NRC

In addition, the roads Technical Committee would like to thank the following individuals for their participation in working groups and peer review:

Al Cunningham P.Eng.	City of Moncton, New Brunswick
Bill Larkin P.Eng.	City of Winnipeg, Manitoba

This and other best practices could not have been developed without the leadership and guidance of the Project Steering Committee and the Technical Steering Committee of *the National Guide to Sustainable Municipal Infrastructure*, whose memberships are as follows:

Project Steering Committee:

Mike Badham, Chair	City Councillor, Regina, Saskatchewan
Bill Crowther	City of Toronto, Ontario
Jim D'Orazio	Greater Toronto Sewer and Watermain Contractors Association, Ontario
Glen Everitt	Mayor, Dawson City, Yukon
Derm Flynn	Mayor, Appleton, Newfoundland
David General	Cambridge Bay, Nunavut
Ralph Haas	University of Waterloo, Ontario
Barb Harris	Whitehorse, Yukon
Robert Hilton	Office of Infrastructure, Ottawa, Ontario
Dwayne Kalynchuk	City of St. Albert, Alberta
Marie Lemay	Canadian Council of Professional Engineers
Wayne Motheral	City Councillor, Louise, Manitoba
Saeed Mirza	McGill University, Quebec
Lee Nauss	City Councillor, Lunenburg, Nova Scotia
Ric Robertshaw	Region of Halton, Ontario
Dave Rudberg	City of Vancouver, British Columbia
Van Simonson	City of Saskatoon, Saskatchewan
Basile Stewart	Mayor, Summerside, Prince Edward Island
Serge Thériault	Department of Environment and Local Government, New Brunswick
Alec Waters	Alberta Transportation
Wally Wells	Dillon Consulting Ltd., Ontario

Stakeholder Liaison:

Joan Lougheed	City Councillor, Burlington, Ontario

Technical Steering Committee:

Don Brynildsen	City of Vancouver, British Columbia
Al Cepas	City of Edmonton, Alberta
Andrew Cowan	City of Winnipeg, Manitoba
Tim Dennis	City of Toronto, Ontario
Kulvinder Dhillon	Regional Municipality of Halifax, Nova Scotia
Wayne Green	City of Toronto, Ontario
John Hodgson	City of Edmonton, Alberta
Bob Lorimer	Lorimer & Associates, Yukon
Betty Matthews-Malone	City of Hamilton, Ontario
Umendra Mital	City of Surrey, British Columbia
Anne-Marie Parent	Councillor, City of Montréal, Quebec
Piero Salvo	WSA Trenchless Consultants Inc., Ontario
Mike Sheflin	Former CAO, Regional Municipality of Ottawa-Carleton, Ontario
Konrad Siu	City of Edmonton, Alberta
Carl Yates	Halifax Regional Water Commission, NovaScotia

EXECUTIVE SUMMARY

This part B best practice describes the main features of a preventive maintenance program for municipal pavements and the steps required for its implementation. Since preventive maintenance applies to both flexible and rigid pavements, types of treatments are described for both. This includes waterproofing pavement surfaces, draining the pavement structure and subgrade, strengthening deficient pavement sections and slowing the rate of deterioration.

This best practice also describes basic premises for performing preventive maintenance, the expected benefits, identification of the most deserving pavement sections, the need for ongoing support and assessment, and the importance of dedicated funding.

To succeed, a preventive maintenance program requires long-term commitment, ongoing improvements, and documented and reported program benefits. Life-cycle cost analysis plays a pivotal role in selecting pavement preservation treatments and in evaluating any trade-off between the initial pavement structure and the subsequent need for maintenance and rehabilitation. Indeed, many agencies have found that applying a series of low-cost preventive treatments extends the service life of pavements. This translates into a better investment, better ride quality and increased customer satisfaction and support.

For a preventive maintenance program to be cost effective, it is necessary to apply the right treatment to the right pavement at the right time. The objective is to identify the sections that would benefit most from preventive maintenance, perform this identification in a timely manner, and select the most beneficial treatment. However, preventive maintenance does not mean other pavement preservation treatments are not required. All types of maintenance treatments (including preventive, emergency and holding maintenance) and rehabilitation treatments are needed as part of a comprehensive, cost-effective, preservation program.

To develop and implement such a program often requires substantial managerial and technical change. For some agencies, these changes may affect staff, funding priorities, the contracting industry, and the public. A preventive maintenance program should be assembled and implemented in a collaborative manner, supported by training and educational activities, and the development of specific guidelines, technical manuals, and best practice guides.

With the increasing use and awareness of pavement management systems and the growing emphasis on asset management of municipal infrastructure, it is important to strengthen the maintenance components of these systems, particularly, preventive maintenance. A successful program also has other elements that require support: a pavement inventory and condition assessment, performance predictions, and a framework to identify needs and set priorities for pavement preservation treatments. To ensure that funding is available for preventive maintenance when required, many practitioners advocate establishing adequate, dedicated funds.

Preventive pavement maintenance is intended to treat small problems before they require more expensive repairs. By slowing the rate of deterioration, treatment can effectively increase the useful life of pavement. However, the practice of systematically identifying pavements that would benefit most from preventive maintenance, and of implementing treatments in a timely manner, is often neglected.

1. GENERAL

1.1 INTRODUCTION

This best practice document is part of the *National Guide to Sustainable Municipal Infrastructure*. The Guide aims to assist municipalities with the management of all components of the municipal infrastructure, including transportation, wastewater collection and water distribution systems, and with all activities involved with infrastructure management, including planning, design, financing, and maintenance. This document is concerned with the maintenance of pavement infrastructure, particularly with preventive pavement maintenance.

Preventive maintenance, like the proverbial stitch-in-time that saves nine, has instinctive appeal to those responsible for maintaining our municipal infrastructure. The potential benefits for pavements have been recognized in Canada for over 20 years. For example, in the late 1970s, the Ontario Ministry of Transportation implemented a pavement management program that systematically used the concepts of preventive pavement maintenance (Blum, W.E. and W.A. Phang, 1980). In the early 1980s, the Regional Municipality of Ottawa-Carleton recognized the importance of timely pavement maintenance programs (Sheflin, M.J.E, 1985). Recently, several U.S. agencies, including the Federal Highway Administration, the Foundation for Pavement Preservation and the American Association of State Highway and Transportation Officials (AASHTO), initiated a joint effort to promote preventive pavement maintenance. Nevertheless, the practice of preventive pavement maintenance is a relatively new concept for many Canadian municipal agencies.

1.2 SCOPE AND OBJECTIVES

Even though the concept of preventive maintenance is reasonable and not new, there are still uncertainties and misunderstanding over what preventive maintenance is and is not (U.S. Federal Highway Administration, 2000). The recent definition of preventive maintenance, advanced by the AASHTO Standing Committee on Highways, states that preventive maintenance is "…the planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional conditions of the system (without increasing structural capacity)" (U.S. Federal Highway Administration, 2000).

Because preventive maintenance is a planned pavement preservation strategy and not a single specific treatment, it needs to be viewed in the context of the overall management of municipal infrastructure. This best practice document describes the main features of a preventive maintenance program and the steps required for its implementation. Other topics include:

- benefits of preventive maintenance;

- relationship with other planning and engineering tools such as asset management, pavement management and life-cycle cost analysis;
- types of maintenance treatments used in preventive maintenance;
- identification of suitable candidates for preventive maintenance; and
- ongoing support and assessment.

1.3 GLOSSARY OF TERMS

Preventive maintenance is not a single pavement maintenance or rehabilitation treatment. Rather it is defined as a planned strategy of cost-effective treatments. There is a difference between preventive maintenance (a strategy) and a preventive maintenance treatment (an action). The following key words provide background information to facilitate the understanding of preventive maintenance concepts.

Preventive maintenance treatment – treatment is performed to prevent premature deterioration of the pavement or to retard the progress of pavement defects. The objective is to slow down the rate of pavement deterioration and effectively increase the useful life of the pavement. The key is to apply the treatment when the pavement is still in relatively good condition with no structural damage (U.S. Federal Highway Administration, 2000). Examples of preventive maintenance treatments include:

- routing and sealing cracks to prevent water from entering the pavement structure;
- stitching cracks in Portland concrete cement (PCC) pavement to restore load transfer; and
- applying a thin overlay to protect open and porous pavement surfaces from accelerated deterioration.

Typically, preventive pavement maintenance treatments are applied to pavement in good or very good condition. Once structural damage occurs, preventive maintenance is no longer a viable option.

Corrective maintenance treatment – maintenance actions are taken to correct deficiencies that are potentially hazardous and to repair defects that seriously affect serviceability. Corrective maintenance is also referred to as “reactive” maintenance. Examples of corrective maintenance treatments include:

- filling potholes to retain safe driving conditions;

- removing and replacing cracked PCC slabs; and
- re-grading gravel shoulders to remove shoulder drop-off.

Emergency maintenance treatment ─ treatments are performed during an emergency situation, such as immediate repair of a severe pothole or a shoulder washout. Emergency repairs may be necessary for both old and new pavements.

Holding maintenance treatment ─ holding maintenance is also called "temporary" maintenance (or "solution d'attente" in French). It includes maintenance actions designed to hold the pavement surface together until more permanent or substantial rehabilitation takes place. Holding maintenance may be necessitated by the timing of future rehabilitation or reconstruction activities or by lack of funds.

Rehabilitation treatment ─ actions are taken to restore initial pavement serviceability such as by pavement overlay or insitu recycling. Pavements may receive several rehabilitation treatments (or undergo several rehabilitation cycles) before they are reconstructed.

Reconstruction ─ this covers actions that include the removal of all surface layer materials and possible substantial changes to base and subbase layer materials.

Pavement preservation treatments ─ preservation treatments encompass all types of maintenance and rehabilitation treatments.

Asset management ─ this is the systematic process of maintaining, upgrading and operating physical assets effectively, combining engineering principles with sound business practice and economic theory, providing tools to facilitate a more organized, logical approach to decision making (Transportation Association of Canada, 1999).

Pavement management ─ this includes the tools or methods that assist decision makers in finding optimum strategies for providing, evaluating and maintaining pavements in a serviceable condition over a period of time (AASHTO, 1993).

Life-cycle costing ─ in the context of pavement management, it is an economic analysis procedure used to compare alternative pavement structures over an extended period of time (often 30 years or more) taking into account the agency costs (initial construction costs as well as all subsequent maintenance and rehabilitation costs). Some agencies might include user costs.

A preventive maintenance treatment, as defined above, is not determined by the type of treatment, but by the reason for the treatment. For example, a micro-surfacing treatment applied to seal an open and slightly porous asphalt concrete surface is a preventive maintenance activity; micro-surfacing applied to counteract moderate rutting is a corrective maintenance activity. An overlay applied to pavement sections (that are below an average or required strength due to poor local soil conditions or unforeseen traffic loads), before major pavement distresses appear, is a preventive maintenance treatment; an overlay applied to restore pavement serviceability is a rehabilitation treatment.

The construction technology of pavement maintenance treatments (e.g., micro-surfacing, or routing and sealing) is similar whether the treatments are considered preventive or corrective. There are also no clear boundaries between preventive and corrective maintenance treatments. Often, when a treatment is initially planned, it may be preventive; when it is finally implemented it may be considered corrective.

The anticipated effect of a preventive maintenance treatment is illustrated in Figure 1. The curve that shows the change in pavement condition with time is referred to as the "pavement performance curve." Typically, preventive pavement maintenance treatments are applied while the pavement is in a relatively good condition. Usually, on the scale of 0 to 100, where 100 represents a new pavement, the first preventive maintenance treatment is applied before the pavement condition drops below 70. Figure 1 also shows the effect of a preventive maintenance treatment on extending the life span of the pavement.

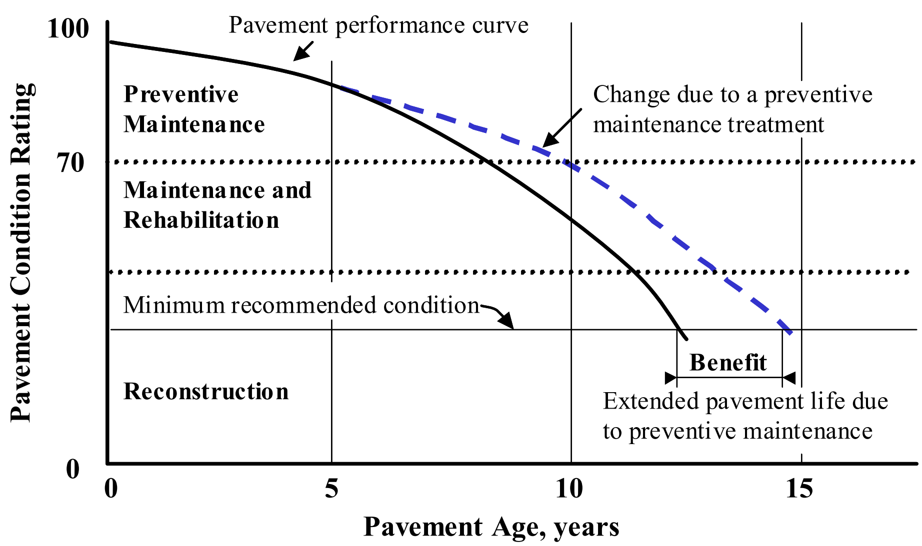


Figure 1: Benefits of Preventive Maintenance for Extended Pavement Life

2. RATIONALE

2.1 ROLE OF PREVENTIVE MAINTENANCE

Considering the definitions of asset management and pavement management systems provided above, it is obvious that both asset management and pavement management systems explicitly recognize the importance of maintenance. These systems also recognize the importance of costs in decision making, be it in terms of sound economic theory, optimum strategies or cost-efficiency. Consequently, preventive maintenance can be viewed as part of pavement management, and pavement management can be viewed, in turn, as part of asset management. The linkage between asset management, pavement management and preventive maintenance is illustrated in Figure 2.

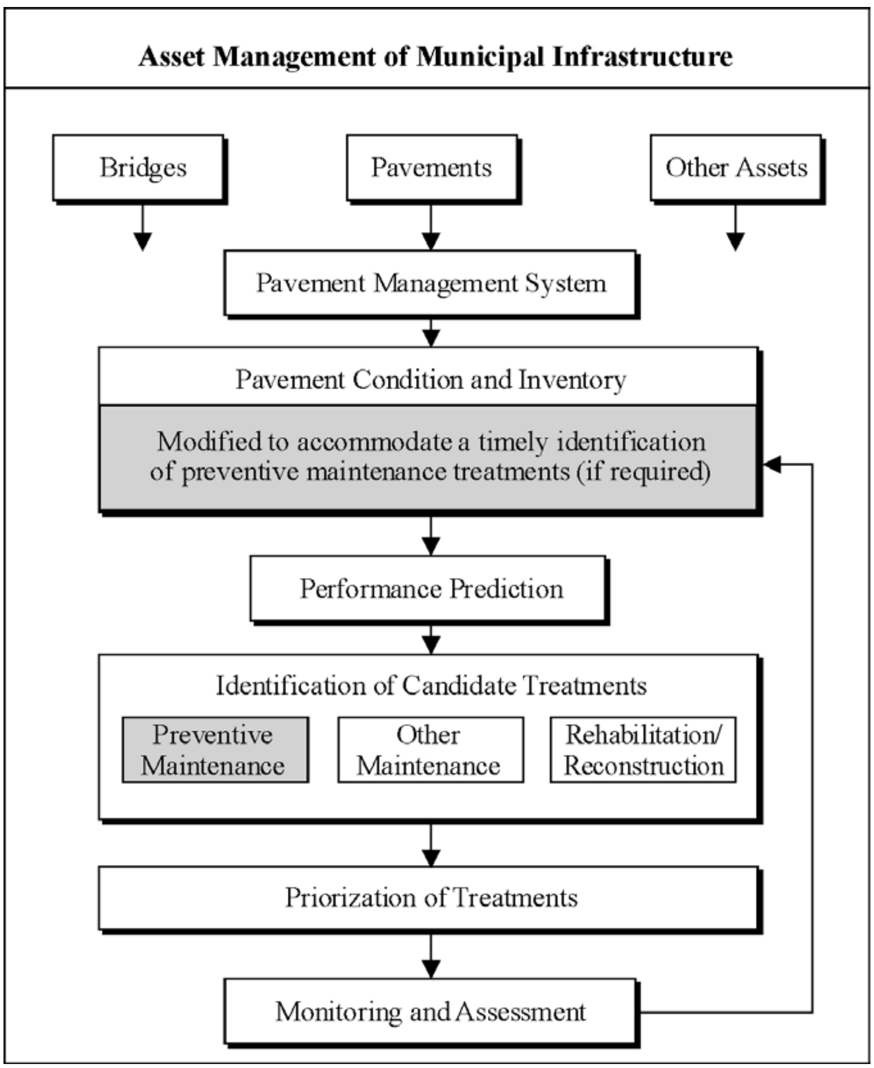


Figure 2: Role of Preventive Maintenance in Asset and Pavement Management

Figure 2 shows preventive maintenance as an integral part of a pavement management system where preventive maintenance is highlighted as a pavement management tool. Preventive maintenance also shares pavement inventory, pavement condition data and a treatment selection framework with pavement management. A recent survey of 56 Canadian municipalities revealed that 80 percent of municipalities already have, are developing or are planning to develop a pavement management system (Hajek, J.J. et al., 2002). Where a pavement management system already exists, the task is to strengthen it by adapting preventive maintenance concepts and integrating them with other pavement preservation activities. In the absence of such a system, the benefits of a preventive maintenance program should be viewed as an additional incentive for the implementation of a pavement management system.

Road agencies have found that applying a series of low-cost preventive treatments can effectively extend the service life of their pavements. This translates to a better investment, better ride quality and increased customer satisfaction and support (Foundation for Pavement Preservation, 2001). The use of preventive maintenance does not mean that other pavement preservation treatments are not required. All types of maintenance treatments (including preventive, emergency and holding maintenance) and rehabilitation treatments are needed as part of a comprehensive cost-effective pavement preservation program. The objective should be to integrate all pavement preservation strategies to obtain the best return on the investment. However, preventive maintenance has a unique feature: it is proactive and systematically looks for opportunities to eliminate small problems before they become large ones.

The basic activities and the premise for preventive maintenance include:

- waterproofing ─ preventing water from entering the pavement structure from above through cracks and joints, porous pavement surface materials and unsealed shoulders;

- drainage ─ removing water from the pavement structure and subgrade by improved drainage;

- strengthening ─ strengthening of those pavement sections that show local weakness (for example, due to poor local soil conditions or poor local construction) before major distresses appear on the pavement surface;

- resurfacing ─ protecting pavement surface from progressive ravelling and coarse aggregate loss that can lead to potholing (also related to waterproofing);

- protection from debris entering joints ─ sealing of joints and cracks in Portland cement concrete pavements not only for waterproofing, but also to prevent incompressible debris from entering joints and cracks (incompressible debris in joints can cause joint spalling with temperature variations);

- slowing down the rate of deterioration – some agencies apply preventive maintenance treatments, for example, chip seal or a slurry seal over asphalt concrete (AC) pavement, to slow the rate of deterioration regardless of specific pavement distresses (such applications are usually triggered by the age of pavement alone).

The last activity—slowing the rate of deterioration without a specific reason to waterproof or protect a weakened pavement surface—is not universally accepted. As well, premium AC surfaces (e.g., SuperPave and stone mastic asphalt mixes) are not expected to be protected by chip seals or slurry seals.

3. WORK DESCRIPTION

3.1 COMPONENTS OF A PREVENTIVE MAINTENANCE PROGRAM

The beneficial effects of preventive maintenance treatments depend on the characteristics of the pavement structure, type and extent of distresses, and other factors such as drainage and materials. For cost-effective preventive maintenance, it is necessary to apply *the right treatment to the right pavement at the right time*. Because municipalities are responsible for the preservation of many pavement sections in various stages of deterioration, procedures need to be developed to identify the sections that would benefit most from preventive maintenance (the right pavement), to identify pavement preventive maintenance needs in timely manner (the right time) and to select the most beneficial treatment (the right treatment).

3.1.1 THE RIGHT PAVEMENT

Identification of the right pavement requires that all pavement sections are inventoried and their condition surveyed. Pavement condition surveys that determine type, severity and extent of pavement distresses are typically an integral part of pavement management systems and are also a required part of preventive maintenance programs. However, for preventive maintenance, it is also necessary to identify specific conditions and look for early indicators that trigger the need for preventive maintenance.

Pavement condition surveys must identify pavement distresses that are associated with the basic premises for the application of preventive maintenance outlined previously, and aid in identifying the sections that would benefit most from preventive maintenance.

3.1.2 THE RIGHT TIME

Preventive maintenance treatments need to be applied before distresses progress and not only affect pavement performance and life expectancy adversely, but also require more expensive corrective action. For example, routing and sealing of asphalt concrete pavement should be carried out before single transverse cracks develop into multiple cracks. As suggested in Figure 1, preventive maintenance treatments are typically carried out during early stages of pavement life.

The pavement conditions that exist at the time of the survey must be extrapolated to the future because it is not possible to apply a preventive maintenance treatment immediately. Typically, these treatments are planned from two to 18 months in advance.

To ensure that preventive treatments are applied at the right time, the following two conditions must be met.

Timely maintenance program*:* Pavement condition surveys must be carried out and translated into a preventive maintenance construction program in a timely manner.

Dedicated funding: Funding for preventive maintenance must be made available in time because it is the "stitch-in-time." Because timing is essential for achieving cost-effectiveness, many practitioners advocate the establishment of adequate, dedicated funds. Postponing preventive maintenance treatments may invalidate effectiveness.

3.1.3 THE RIGHT TREATMENT

Selection of the right treatment involves the following four phases:

- generation of possible treatments;
- treatment selection for individual sections;
- needs and priorities of other sections in the network; and
- selection of materials and construction methods.

Phase 1. Generation of possible treatments
Typical maintenance and rehabilitation treatments are listed in Table 1. The treatments that have traditionally been considered preventive maintenance are in italics and are briefly described. A more comprehensive description of pavement preservation treatments is provided in the *Reference Manual of Pavement Preservation Treatments* (Hajek, J.J. et al., 2002b) and *Concrete Pavement Restoration, Resurfacing and Reconstruction* (American Concrete Pavement Association, 1999-2000)

Machine patching – also called selective repaving, machine patching involves using a paver to place hot mix.

Sealing of cracks or joints – this usually includes routing (to clean the crack or joint and create a reservoir to hold the sealant) followed by sealing.

Slurry seal – a mixture of asphalt emulsion, fine aggregate, mineral filler and water is uniformly spread over the pavement surface. The mixture is applied cold to a pavement surface in a thin layer.

Slab stitching – holes are drilled through non-working cracks. A tie bar is then placed in the hole and cemented into place to prevent the crack from opening and to improve the load transfer capability across the crack.

Micro-surfacing – a mixture of polymer-modified asphalt emulsion, high-quality fine aggregate, mineral filler and water is uniformly spread over the pavement surface. The mixture is applied cold to a pavement surface in one or two thin layers.

Surface treatment (chip seal, seal coat) – a spray application of emulsified or liquid asphalt binder is followed by the distribution of aggregates that is subsequently rolled into the binder. If the aggregate is of uniform size, the treatment is called chip seal.

Thin hot mix overlay – hot mix is placed over the existing pavement surface. Some special mixes can be as little as 20 mm thick.

Treatments listed in Table 1 may be used in combination. For example, routing and sealing of transverse cracks can be carried out together with a micro-surfacing treatment. The line separating preventive maintenance treatments from other treatments is blurred. For example, Michigan Department of Transportation (2000) considers any hot mix overlay that is not intended to improve pavement strength (that is, non-structural overlay) to be a preventive maintenance treatment. To provide guidance and facilitate the generation of candidate treatments, agencies usually develop decision trees or matrixes. See Table 2 for an example of a decision-support matrix that identifies candidate treatments. For example, Table 2 indicates that a micro-surfacing treatment should not be used on pavements with high (severe) roughness and fatigue cracking, and may not be effective for pavements with severe rutting and transverse and longitudinal cracking, and with low fatigue cracking.

Table 1: Preventive Preservation Treatments

Asphalt Concrete	Exposed PCC And Composite Pavement	Surface-Treated	Gravel Surface
• Small area patching using hot or cold mix • Spray patching (manual chip seal) • Patching using infrared heating • *Machine patching* • *Sealing of cracks* • *Slurry seal* • *Micro-surfacing* • *Surface treatment (chip seal, seal coat)* • *Thin hot mix overlay* • Hot mix overlay • Hot in-place recycling • Cold in-place recycling • Ultrathin whitetopping (UTW) • *Drainage maintenance*	• Partial depth repairs using PCC material • Partial or full depth repairs using AC material • Full depth repairs using PCC material • *Joint/crack sealing* • Subsealing (under slab grouting) • Surface restoration by abrasion (diamond grinding or shot blasting) • *Load transfer restoration (dowel bar retrofitting and stitching of cracks)* • Slab jacking • AC overlays • *Drainage maintenance*	• Small area patching using hot or cold mix • *Spray patching (manual chip seal)* • Machine patching • Surface treatment (chip seal, seal coat) • *Drainage maintenance*	• Grading and gravelling • Dust control • *Drainage maintenance*

Notes:
1. Treatments traditionally considered to be preventive maintenance treatments are in italics.
2. Preservation treatments for composite pavements are not listed explicitly in the table. For the AC layer of composite pavements, many of the treatments listed for AC pavements apply; for the PCC base of composite pavements, some of the treatments listed for exposed PCC pavements apply.

Phase 2. Treatment selection for individual sections
The selection of candidate treatments (on the project level) is generally based on the following considerations:

- existing pavement condition
    - pavement type and pavement structure, and
    - type, extent and severity of pavement distresses, particularly cracking, utility cuts and rutting;
- time since construction or major rehabilitation;
- roadway use, volume, composition and traffic speed;
- availability of qualified contractors and construction technology;
- availability of qualified agency staff;
- availability of required materials;
- time of year of construction;
- facility downtime and associated user costs; and
- resulting pavement surface quality (noise, dust, surface friction, loose aggregate).

Table 2 : Decision-Support Matrix for Identification of Candidate Preventive Maintenance Treatments

Preventive Maintenance Treatment	**Pavement Condition for Successful Application**											
	Roughness		Rutting		Longitudinal & Transverse Cracking		Ravelling		Flushing		Fatigue Cracking	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Crack Sealing	Do not use	Do not use	Do not use	Do not use	Acceptable	Questionable	Do not use	Do not use	Do not use	Do not use	Do not use	Do not use
Chip Seal	Acceptable	Do not use	Acceptable	Do not use	Acceptable	Questionable	Acceptable	Acceptable	Acceptable	Questionable	Questionable	Do not use
Slurry Seal	Acceptable	Do not use	Acceptable	Do not use	Acceptable	Do not use	Acceptable	Acceptable	Acceptable	Questionable	Do not use	Do not use
Micro-Surfacing	Acceptable	Do not use	Acceptable	Questionable	Acceptable	Questionable	Acceptable	Acceptable	Acceptable	Acceptable	Questionable	Do not use
Thin Overlay	Acceptable	Questionable	Acceptable	Questionable	Acceptable	Questionable	Acceptable	Acceptable	Acceptable	Acceptable	Questionable	Do not use

Legend:

- Acceptable application (white)
- Questionable application (light grey)
- Do not use (dark grey)

Candidate treatments generated in Phase 1 should be ranked according to the estimated benefits and costs. Estimation of benefits should be done in terms of the extension of pavement life of the original pavement — not the expected life of the preventive maintenance treatment (Figure 1). For example, a micro-surfacing treatment may last only five years, but may extend the pavement life by nine years. Slab stitching for cracks in a concrete pavement will delay the need for more expensive pavement restoration. The basic benefit of a preventive maintenance treatment is the difference in the pavement life with and without the treatment. Some preventive maintenance treatments can create benefits beyond those that occur during a single rehabilitation cycle. For example, the installation of retrofitted subdrains may have beneficial effect on more than one rehabilitation cycle. Maintenance treatments may also create additional benefits in the form of improved pavement surface (friction, ride quality, delineation of markings, dust suppression, safety, etc.).

The two main components of treatment costs are construction costs and user costs due to construction delays. Because construction costs can vary widely depending on the location, time, quantities and the method of contracting, project-specific costs should be used.

There are several methods that can be used to select most promising treatments. These include cost-benefit evaluation, ranking and life-cycle cost evaluation.

Cost-benefit evaluation

Typically, cost-effectiveness is expressed as a ratio of costs and benefits. The costs are in terms of unit costs, for example dollars per square metre. The benefits are in terms of the additional years the pavement is expected to last (because of the preventive treatment or combination of treatments) or in terms of changes in the performance curve (the increase in the area underneath the performance curve).

Ranking

Some attributes of preventive maintenance treatments, which are important to the customer and to the agency, cannot be readily quantified. These attributes include such things as traffic disruption, surface friction, previous experience with the treatment and need for favourable weather conditions during construction. By rating the candidate treatments against these attributes, in addition to the cost-effectiveness rating, an overall score for each candidate treatment can be developed. A good example of this approach is provided in *Selecting a Preventive Maintenance Treatment for Flexible Pavements* (Hicks, R.G., S.B. Seeds and D.G. Peshkin, 2000).

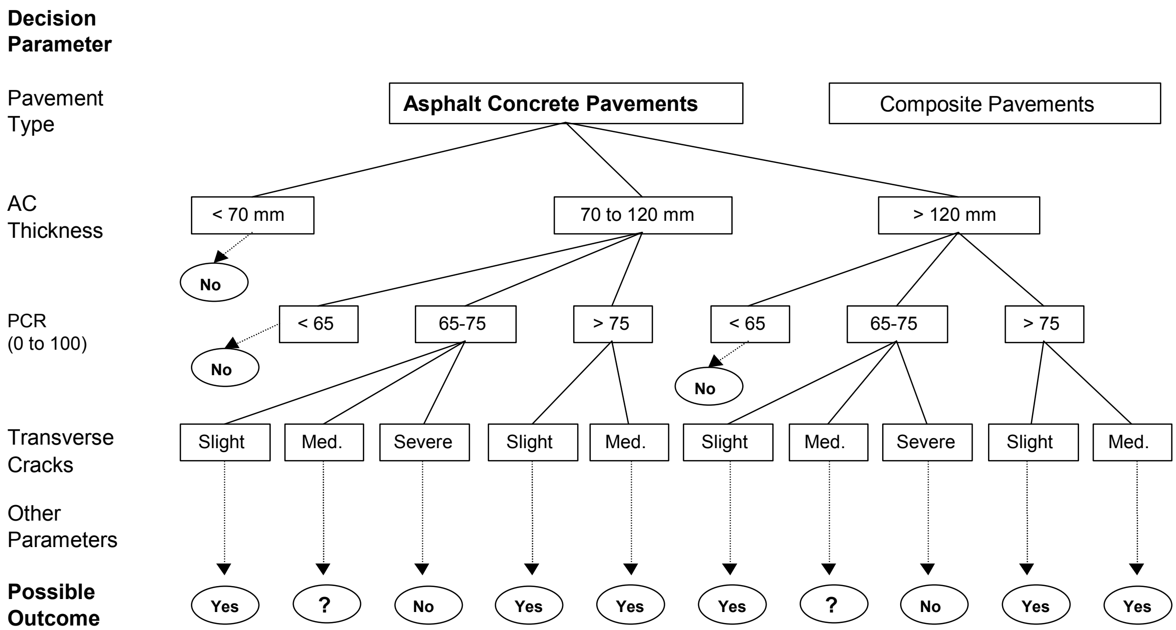
Life-cycle cost evaluation

A preventive maintenance treatment postpones the more expensive rehabilitation treatment. On the other hand, the cost for the preventive maintenance treatment must be paid now — meaning much sooner than the cost for any future rehabilitation treatment. The need to pay now rather than later must be recognized as part of the economic analysis because the same amount of money paid at different times has different economic value. There are also possible economic trade-offs between the quality of the initial construction and the need for subsequent pavement maintenance (Transportation Association of Canada, 1997). For example, the use of a high-quality polymer-modified asphalt cement during the initial construction may significantly reduce the need for subsequent preventive maintenance (e.g., crack sealing). The implementation of stringent requirements for initial construction smoothness of the pavement will significantly delay joint faulting and the need for joint load-transfer restoration. These types of analysis are best carried out within the framework of life-cycle cost analysis.

Because of the importance of life-cycle cost analysis for the selection of pavement preservation treatments, Appendix A provides additional information on life-cycle cost analysis and examples of its use.

Role of decision trees

Table 2 presents an example of a decision-support matrix that identifies candidate treatments. The actual selection of pavement preservation treatments for a specific project is more complex. It must take into account the type, severity and extent of pavement distresses, properties of the pavement structure, local experience, cost-effectiveness, etc. Figure 3 illustrates a decision tree that can facilitate the selection of a crack sealing for AC pavements. While the decision trees are useful for identifying and evaluating candidate treatments, the selection of project-specific maintenance treatments usually requires a field assessment of site-specific conditions and may not be accomplished using decision trees alone.



Note: “Other Parameters” include, for example, the presence of a cement-stabilized base, and the occurrence, severity and density of other pavement distresses such as longitudinal cracks, alligator cracks and flushing.

Figure 3: Example of Decision Tree for Selection of Routing and Sealing Treatment

Phase 3. Needs and priorities of other sections

Even if dedicated funding for preventive maintenance is in place, the amount of recommended work may exceed the available funds. Thus, listing the priorities for preventive maintenance may be necessary. It is also important to realize that maintenance and rehabilitation should not be viewed as separate and distinct delivery areas but must be coordinated within the overall pavement management system (see Figure 2). This translates into the need to list priorities not only for the preventive maintenance treatments, but also to reconcile the treatments with other maintenance and rehabilitation priorities. Agencies that practice preventive maintenance also report that, over time, money spent on preventive maintenance may free up some of the money they require for rehabilitation.

A priority listing of preventive maintenance needs may be established using the previously described selection methods (cost-benefit evaluation, ranking or life-cycle economic evaluation) and by restricting the candidate treatments to some minimum value (such as cost-benefit ratio). Further information on setting priorities and optimising selection methods for pavement preservation treatments can be found in a U.S. Federal Highway Administration Technical Bulletin (Walls and Smith, 1998).

Phase 4. Selection of materials and construction methods
Once a treatment has been selected, its application should use appropriate materials and construction methods. To ensure construction quality, appropriate specifications and warranties must be in place and enforced. Typically, preventive maintenance treatments are less forgiving and thus more demanding (e.g., in terms of material quality, adherence to construction procedures and weather condition) than the traditional hot mix overlays.

To promote and facilitate the selection of the right treatment on the right pavement at the right time, agencies that engage in preventive maintenance have developed best practice guides or manuals. These manuals are intended to provide guidance on treatment selection and timing, and on materials and construction methods.

3.1.4 Monitoring and Assessment

To succeed, a preventive maintenance program requires a long-term commitment, ongoing improvements and documentation of the benefits. It is therefore important that program monitoring and assessment be an integral part of a preventive maintenance program. Monitoring and assessment should include the following activities.

- Review of the effectiveness of treatment types used: particularly during the early program development, it is important to evaluate annually the effectiveness of individual treatments.

- Monitoring of pavement condition: annual or biennial pavement condition monitoring and assessment should be carried out both to document service life extension and to identify pavement sections that would benefit from preventive maintenance treatments in future years.

- Improvement of treatments: the experience with the program should be translated into improved guidelines and manuals of practice for treatment timing and construction.

- Promotion: to secure ongoing financial support for the program, its benefits should be documented and promoted.

4. DEVELOPING AND IMPLEMENTING A PREVENTIVE MAINTENANCE PROGRAM

This section outlines typical steps involved in the implementation of preventive maintenance by a municipal agency, and provides implementation guidance and references to manuals and standards. To develop and implement a pavement preservation program, the agency should:

- establish management aspects of the program;
- establish technical aspects of the program;
- determine maintenance needs;
- provide framework for treatment selection;
- set priorities for needs; and
- provide ongoing support, monitoring and assessment.

4.1 STEP 1. ESTABLISH MANAGEMENT ASPECTS OF THE PROGRAM

For some agencies, the development and implementation of a preventive maintenance program may be a major shift in the way the pavement preservation business is done. This shift may affect the agency staff, funding priorities, the contracting industry and the public. The necessary changes should be implemented in a collaborative manner, and should be supported by training and educational activities. The Foundation for Pavement Preservation (2001) provides useful guidelines for launching a preventive maintenance program and outlines the need to establish the overall strategies and goals of the program.

Long-term commitment and financial support from senior management are required for a successful preventive maintenance program. Preventive maintenance is more than just a set of specific pavement maintenance techniques. It is a way of technical thinking, financial planning and budgeting. Agencies that in the past used to select pavement preservation treatments using the worst-condition-first approach, have reported the need to inform the public (after the implementation of a preventive maintenance program) why relatively good pavements receive improvements while what they see as “more deserving” pavements in a worse condition do not. Figure 4 is based on the results of a recent survey of 56 Canadian municipalities (Hajek et al., 2002a). In response to the question, “How do you select projects for pavement maintenance and rehabilitation?” four options were presented: using a pavement management system (PMS), decision trees, engineering judgment and worst condition first.

Some respondents selected more then one option. However, 18 municipalities, that is one third of those surveyed, responded that they use the worst-condition-first criterion.

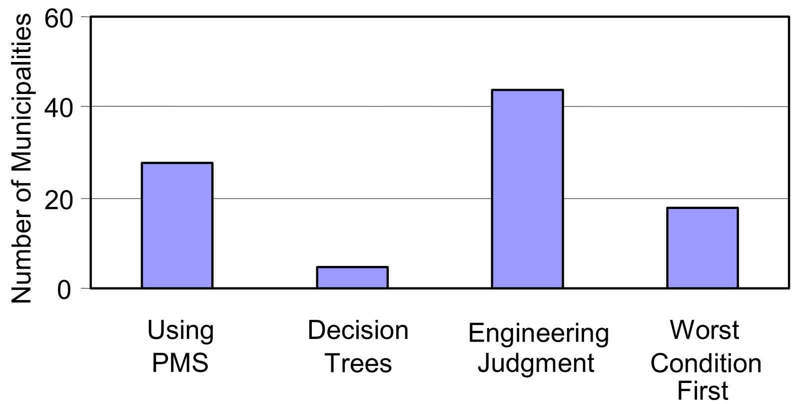


Figure 4: Methods for Selection of Pavement Preservation Treatments

4.2 STEP 2. ESTABLISH TECHNICAL ASPECTS OF PROGRAM

Technical development of a preventive maintenance program should recognize that preventive maintenance strategies are an essential element of an operational pavement management system (Geoffroy, D.N., 1996). There may be management systems without a strong preventive maintenance component. However, a preventive maintenance program without typical components of a pavement management system (including periodic pavement condition evaluation, prediction of pavement performance and setting priorities for pavement preservation needs) cannot exist. A cost-effective pavement preservation program requires that all maintenance and rehabilitation actions are coordinated and in synergy. A more detailed description of pavement management systems and their role in integrating maintenance and rehabilitation activities is provided by Blum and Phang (1980), the Transportation Association of Canada (1997) and Geoffroy (1996). The Transportation Association of Canada (1999) also outlines the role of pavement management within the framework of highway asset management.

After the integration of preventive maintenance with pavement management is resolved, technical development should include the establishment of program guidelines. These guidelines should formulate the purpose and objectives of the preventive maintenance program, describe the management structure, including the interaction with the pavement management system, and provide technical details on preventive maintenance treatments and their selection. An example of comprehensive preventive maintenance program guidelines is given in the American Concrete Pavement Association (1998-2001). Several Canadian highway agencies have developed various components of maintenance program guidelines both for flexible pavements (Saskatchewan Highways and

Transportation, 2001; Northwest Territories, Government of, 1993; Ontario Ministry of Transportation, 1990) and for rigid pavements (Quebec, 1999).

4.3 STEP 3. DETERMINE MAINTENANCE NEEDS

The success of preventive maintenance requires timely identification of pavement sections that would benefit most from maintenance actions. Existing pavement condition-rating procedures must be reviewed to ascertain whether they provide relevant information in a timely manner. Existing condition surveys may be geared to capture distresses at later stages and thus not provide early indications for preservation. For example, referring to the decision tree shown in Figure 3, the condition rating system should identify the presence of slight and very slight transverse and longitudinal cracks, as well as other decision parameters that are needed to select the crack sealing treatment.

Several provincial highway agencies have developed pavement surface condition rating manuals, including British Columbia (BC Ministry of Transportation and Highways, 1994) and Ontario (Chong, G.J, W.A. Phang and G.A. Wrong, 1989 to 1995). The Ontario Ministry of Transportation has also developed a pavement condition rating procedure specifically for municipalities (Chong et al., 1989). Other applicable pavement condition rating manuals were developed by the Transportation Association of Canada (Anderson, 1987), by the American Society for Testing and Materials (ASTM, 2000) and other organizations. Visual pavement condition surveys may be supplemented by material sampling and non-destructive testing (roughness, friction and deflection measurements).

The determination of needs is based on analysis of pavement condition and inventory data (e.g., pavement structural data and traffic data), projection of pavement condition to the time the recommended treatments are likely to be carried out (typically a year in advance) and on treatment selection guidelines. It is important to realize that preventive maintenance needs are driven by the requirement to extend pavement serviceability by early maintenance and not governed by maintenance quality standards that specify minimum (or recommended minimum) pavement performance requirements.

4.4 STEP 4. PROVIDE FRAMEWORK FOR TREATMENT SELECTION

The role of cost-effectiveness evaluation, ranking and life-cycle economic evaluation for treatment selection was outlined previously. Hicks et al. (2000) assembled about 20 different decision trees and matrices that various agencies developed to select preservation treatments for flexible pavements. While these collected decision trees and matrices are impressive, they are agency specific (applicable to a specific agency), and have only general applicability. The selection of site-specific preventive maintenance treatments typically requires a detailed engineering design.

4.5 Step 5. Set Priorities for Needs

The establishment of priorities should take into consideration both preventive maintenance treatments and other maintenance and rehabilitation treatments. Procedures for setting priorities were outlined previously and should be part of the program guidelines established in phase 2.

4.6 Step 6. Provide Ongoing Support and Monitoring and Assessment Mechanisms

Performance measures, established as part of the program guidelines, should be used to determine how well the objectives have been met. Monitoring and assessment requirements for a preventive maintenance program were discussed in phase 4 of this best practice document.

APPENDIX A: USE OF LIFE-CYCLE COST ANALYSIS FOR THE SELECTION OF PREVENTIVE MAINTENANCE TREATMENTS

The reason for choosing one pavement preservation strategy over another should be based on all relevant costs and benefits. Life-cycle cost analysis (LCCA) can effectively combine and quantify costs and benefits that are expected to occur over time or over an analysis period. For pavements, the analysis period usually exceeds 20 years.

In general, life-cycle costs include all costs and benefits anticipated over the life of the facility expressed in a way that accounts properly for the time value of money. (They are discounted using an appropriate discount rate.) A dollar that is available now (or spent now) has a higher value than a dollar that will be available in five years (or will be spent in five years). Using discounting, it is possible to evaluate the benefit of paying for maintenance now and postponing rehabilitation for later, or the trade-off between the initial cost of construction and the future cost of maintenance. In both cases, the objective is to provide pavement facilities in the most cost-effective way through the combination of initial construction and subsequent maintenance and rehabilitation treatments.

The basic formula for life-cycle economic analysis is:

$$PW = \text{Initial Cost} + \sum_{1}^{k} \text{Upkeep Cost} \frac{1}{(1 + i_{dis})^n}$$

Initial cost =	initial construction cost, $
Upkeep cost =	M&R treatments, $
i_{dis} =	Discount rate (%/100)
n =	Number of years to present
k =	number of upkeep treatments

Additional information on life-cycle economic analysis is found in the technical bulletin FHWA-SA-98-079 (Walls and Smith , 1998) and Geoffroy's synthesis of Highway Practice 223 (1996).

The application of life-cycle economic analysis is illustrated using two examples:

- evaluation of cost-effectiveness of a preventive maintenance treatment; and
- evaluation of any trade-off between the initial construction cost and the subsequent preservation costs.

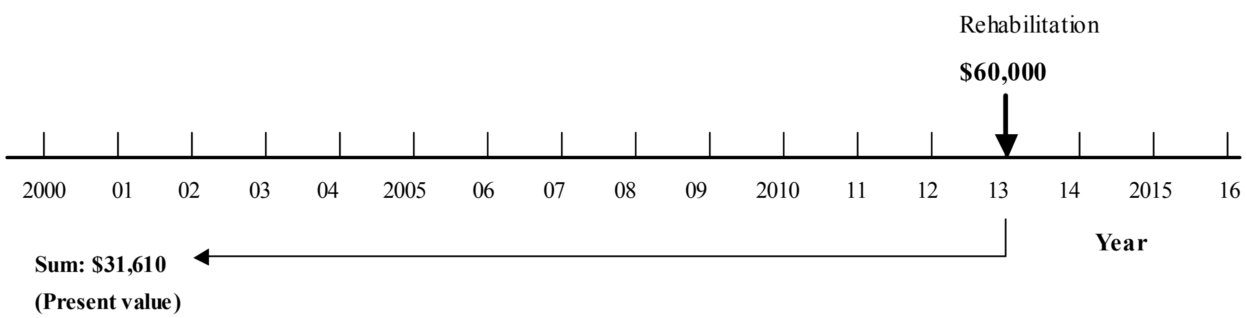
EXAMPLE 1: EVALUATION OF COST-EFFECTIVENESS OF PREVENTIVE MAINTENANCE TREATMENT

Consider:
It is proposed to rout and seal a four-year old asphalt concrete pavement next year (in 2003), and repeat the treatment (reseal) in four years (in 2007). These two consecutive preventive maintenance treatments are expected to postpone pavement resurfacing by three years.

It is assumed that that the section is one kilometre long, the cost of sealing is $1,100, the cost of resealing is $1,500 and the cost of rehabilitation (resurfacing) is $60,000.

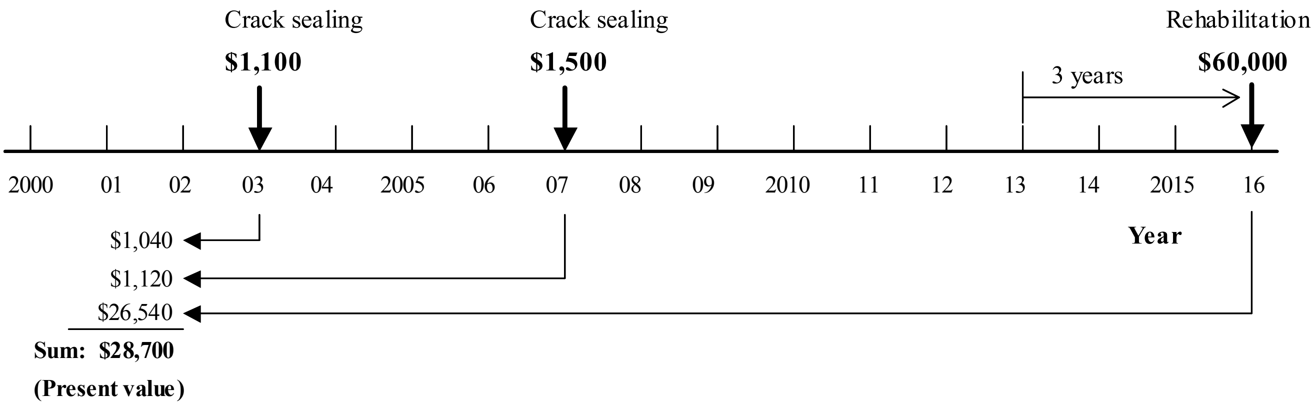
Question:
Will the proposed preventive maintenance treatment be cost-effective?

Without Preventive Maintenance
The following diagram assumes that without preventive maintenance, a rehabilitation treatment will be required in the year 2013. The present value of the rehabilitation treatment, considering a six percent discount rate, is $31,610.



With Preventive Maintenance

The following diagram shows that with the two preventive maintenance treatments, the rehabilitation treatment will be postponed to the year 2016. The corresponding present value of this strategy, considering a six percent discount rate, is $28,700.



COMPARISON OF ALTERNATIVES

Compared to the alternative without preventive maintenance, preventive maintenance results in $2,910 saving ($31,610 – 28,700). The question can be asked, "What type of savings can be expected if the postponement of the rehabilitation treatment is only two years?" To answer this question, LCCA was repeated and the results plotted in Figure A1. According to Figure A1, the preventive maintenance alternative will be effective even if the postponement of the rehabilitation alternative is only two years. While road-user costs have not been included in the examples, it should be recognized that they can play a significant role in LCCA and can have a substantial impact on the ultimate decision.

Figure A1: Savings as Function of Time Rehabilitation Is Postponed

EXAMPLE 2: EVALUATION OF TRADE-OFF BETWEEN INITIAL CONSTRUCTION COST AND SUBSEQUENT PRESERVATION COSTS

Example 2 considers two flexible pavements, a conventional pavement and a premium pavement as shown in Figure A2.

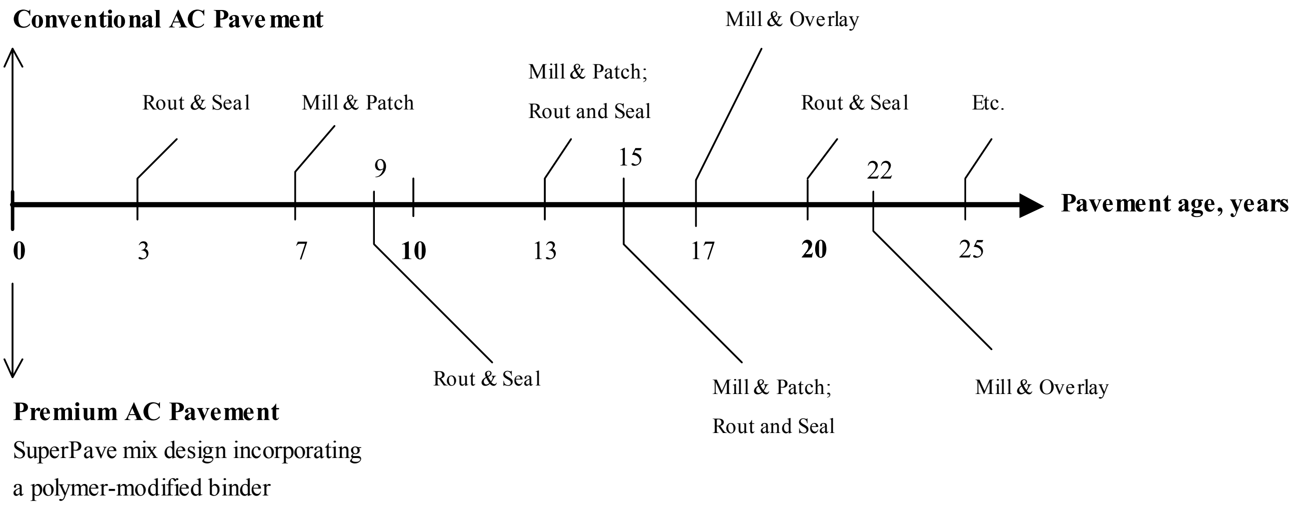


Figure A2: Influence of Initial Construction on Subsequent Maintenance and Rehabilitation Treatments

Conventional pavement is expected to require more extensive and more frequent preventive and corrective maintenance treatments than premium pavement. For example, the first anticipated maintenance treatment for the conventional pavement is routing and sealing of cracks in Year 3, whereas the first anticipated maintenance treatment for the premium pavement is in Year 9. Similarly, it is expected that the conventional pavement will require a rehabilitation treatment in Year 17, whereas the premium pavement will require a rehabilitation treatment in Year 22.

To ascertain the cost-effectiveness of premium pavement over conventional pavement, all relevant initial construction costs and subsequent maintenance and rehabilitations costs should be accounted for using LCCA symbolized in Equation A1. The results of LCCA will depend local construction costs, discount rate, the length of analysis period and other factors such as the inclusion of user costs. This example also illustrates the influence of the initial pavement structure on the subsequent need for preventive maintenance and rehabilitation.

Even though both LCCA examples presented herein were for asphalt concrete pavements, similar procedures apply for other pavement types such as PCC pavements and composite pavements.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO), 1993. *Guide for Design of Pavement Structures 1993*. Washington, DC.

American Concrete Pavement Association, *Concrete Pavement Restoration, Resurfacing and Reconstruction*, 1998-2000. Skokie, IL 60077-1059, www.pavement.com.

American Society for Testing and Materials, 2000. D6433, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*, West Conshohocken, PA.

Anderson, K.O., 1987. *Pavement Surface Condition Rating Systems*, Transportation Association of Canada, 1765 St. Laurent Blvd., Ottawa, ON.

Blum, W.E. and W.A. Phang, 1980. *Preventive Pavement Maintenance Concepts*, Report PAV-80-02, Ontario Ministry of Transportation, 1201 Wilson Avenue, Downsview, ON.

British Columbia Ministry of Transportation and Highways, 1994. *Pavement Surface Condition Rating Manual*, Geotechnical and Materials Engineering Branch, Victoria, BC.

Chong, G.J., W.A. Phang and G.A. Wrong, 1989. *Flexible Pavement Condition Rating: Guidelines for Municipalities*, Report SP-022, Ontario Ministry of Transportation, Downsview, ON.

Chong, G.J., W.A. Phang and G.A. Wrong, 1989 to 1995. Reports SP-021, SP-024 and SP-026, Manuals for Rating of Surface-Treated, Flexible, and Rigid Pavements, respectively, Ontario Ministry of Transportation, Downsview, ON.

Foundation for Pavement Preservation, 2001. *Pavement Preventive Maintenance* Guidelines, March, http://fp2.org.

Geoffroy, D.N., 1996. *Cost-Effective Preventive Pavement Maintenance*, Synthesis of Highway Practice 223, National Cooperative Highway Research Program, Washington, DC.

Hajek, J.J., et al., 2002a. *Preventive Maintenance of Municipal Roads, Best Practices Scan MR1*, ERES Consultants, Toronto, ON, March.

Hajek, J.J., et al., 2002b. *Reference Manual of Pavement Preservation Treatments*, ERES Consultants, Toronto, ON, March.

Hicks, R.G., S.B. Seeds and D. G. Peshkin, 2000. *Selecting a Preventive Maintenance Treatment for Flexible Pavements*, Foundation for Pavement Preservation, http://fp2.org.

Michigan Department of Transportation, 2000. *Capital Preventive Maintenance Program Guidelines*, February 15.

Northwest Territories, Government of, 1993. *Highway Maintenance Standard*.

Ontario Ministry of Transportation, 1990. *Ontario Pavement Design and Rehabilitation Manual*.

Quebec, 1999. *Guide d'entretien et de réhabilitation des chaussées en béton de ciment* [Quebec guidelines for rehabilitation of PCC pavements].

Saskatchewan Highways and Transportation, 2001. *Surfacing Manual*.

Sheflin, M.J.E., 1985. *Decision Levels and Issues – A Municipality Perspective*, Proceedings of the North American Pavement Management Conference, Volume 1, Toronto, ON.

Transportation Association of Canada, 1997. *Pavement Design and Management Guide*.

Transportation Association of Canada, Highway Asset Management Systems, 1999. A Primer, www.tac-atc.ca/products

U.S. Federal Highway Administration, 2000. Insights into Pavement Preservation, www.fhwa.dot.gov/infrastructure/asstmgt/resource.htm

Walls, J., III, and M.R. Smith, 1998. *Life Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin*, Report FHWA-SA-98-079, Federal Highway Administration, Washington, DC.