The Impact of Preventive Maintenance Programs on the Condition of Roadway Networks

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ABSTRACT

The condition of our roads and highways greatly contributes to the overall vitality of the Canadian economy. By improving ride quality, extending pavement life and ensuring safety, effective pavement preventive maintenance programs will help to allow people and goods to move safely and insure that our road network remains in good condition.

Many pavement owner/agencies are now focusing on maintaining the overall value of their roadway assets and are striving to make better-informed decisions on how they allocate funding to minimize the deterioration of their assets. This new form of management referred to as Asset Management has clearly identified the benefits of strong pavement preventive maintenance programs compared to the commonly used "worst-first" repair approach.

Pavement maintenance and rehabilitation needs studies frequently indicate that current funding levels are not sufficient to maintain the road system at an optimal level of service. The Federation of Canadian Municipalities indicates that Canada is facing a massive infrastructure debt totaling an estimated $ 57 billion. These funding shortfalls are considerable and a significant increase in funding is not likely. A strong pavement preventive maintenance program offers an opportunity to help close the gap between pavement maintenance needs and optimal pavement condition to better serve the traveling public.

An effective pavement preventive maintenance program encompasses a full range of techniques with the goal of enhancing pavement performance in a cost-effective and efficient manner. A framework of mix-of-fix strategies, which includes a balance between pavement preventive maintenance work along with pavement rehabilitation and reconstruction, can assist a road agency to maintain an overall acceptable pavement condition while meeting the needs of the traveling public. This concept, as simple as it seems, has not been fully accepted by roadway agencies, who continue to react to problems after they occur rather than to prevent them from occurring in the first place.

This paper outlines the concept of a coordinated preventive maintenance and mix-of-fixes approach and how it may be integrated into a framework of pavement and asset management for municipal agencies. The paper provides details on common preventive maintenance techniques that can contribute to the effectiveness of a mix-of-fixes approach.

INTRODUCTION

Canada's roads keep our society mobile and contribute significantly to our economic growth. The economic (cost-effective) design, and more importantly preservation, of these valuable national assets cannot be overstated. Infrastructure deterioration is expected with renewal programmed though a series of planned maintenance and rehabilitation treatments. The pressure of an increasing rate of deterioration due to a significant increase in both volume and commercial vehicle loading is outpacing our ability to maintain our infrastructure.

There are over 3,000 Canadian municipalities that are responsible for the management of about 700,000 two-lane equivalent kilometres of roads ranging from multilane expressways to gravel roads, representing over 70 percent of all Canadian roads.

PAVEMENT DESIGN AND MANAGEMENT

The need to improve the design and performance of pavements is paramount to insuring the viability of our national infrastructure. Comprehensive monitoring of pavement performance through programs such as the Long Term Pavement Performance (LTPP) project has identified design, construction and maintenance improvements to extend the life of our infrastructure [1]. This has been accomplished through a better understanding of pavement design, rehabilitation and maintenance methods and applications. Advancements in pavement material technology, as well as pavement design methods, through research and development activities have made significant contributions to building longer lasting pavements with lower service costs.

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 and particularly the preventive maintenance component. A successful preventive maintenance program cannot function without the support of many features associated with pavement management systems. These features include pavement inventory and condition assessment, performance prediction, and the framework for the identification and prioritization of pavement preservation treatments.

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.

PREVENTIVE MAINTENANCE

Preventive maintenance, like the proverbial stitch-in-time saves nine, has instinctive appeal to those responsible for maintaining our municipal infrastructure. The potential benefits of preventive maintenance 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 utilized the concepts of preventive pavement maintenance [2]. In the early 1980s, the Regional Municipality of Ottawa-Carleton recognized the importance of timely pavement maintenance programs [3]. Recently, several US 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.

The most recent definition of preventive maintenance, attributed to the American Association of State Highway Transportation Officials (AASHTO) Standing Committee on Highways, states that preventive maintenance is “a 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) [4].

Agencies have found that applying a series of low-cost preventive treatments can effectively extend the service lives of their pavements. This translates to a better investment, better ride quality and increased customer satisfaction and support [5]. All types of maintenance treatments (including preventive maintenance, emergency maintenance 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. The line separating preventive maintenance treatments from other treatments is blurred. For example, Michigan Department of Transportation considers any hot mix overlay that is not intended to improve pavement strength (that is, non-structural overlay) to be a preventive maintenance treatment [6]. To provide guidance and to facilitate the generation of candidate treatments, the agencies usually develop decision trees or matrixes. However, preventive maintenance has a unique feature: it is proactive and systematically looks for opportunities to eliminate small problems before they become large.

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.

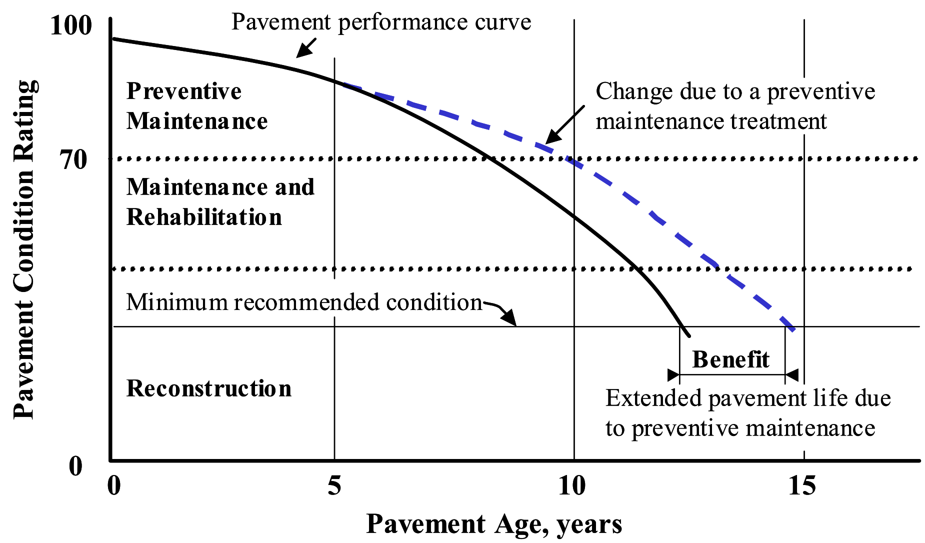

Figure 1. Benefits of Preventive Maintenance in Terms of Extended Pavement Life

The beneficial effects of preventive maintenance treatments depend on the characteristics of the pavement structure, type and extent of distresses, and other factors. 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), identify pavement preventive maintenance needs in timely manner (the right time) and to select the most beneficial treatment (the right treatment).

PLANNING AND BUDGETING

One of the least understood factors in establishing the cost-effectiveness of pavement preservation treatments is the life span of the treatment used for cost effectiveness analysis. The proper factor to use is not the life span of the treatment, but the *effect of the treatment on the life span of the pavement* (as compared to the effect without the treatment or with an alternative treatment).

Every municipality prepares a budget to preserve pavements, and every municipality has some sort of planning that precedes budgeting [5]. The quality of planning and budgeting process has a major impact on the condition of the pavement network and on the cost of maintaining it. The link between planning and budgeting is important. Planning should provide the basis for the budget and substantiate the budget. The budget should be based on well-documented pavement preservation needs.

Decision-making for pavement maintenance and rehabilitation should be integrated into a yearly management cycle of planning, budgeting, engineering, and implementation activities summarized in Figure 2. There are eight basic steps in the yearly management cycle: Theses steps are: establishment or review of service levels, pavement inventory, identification of needs, prioritization, budgeting, project design, project implementation, and performance monitoring.

The decision-making process starts with establishing and reviewing level of service policy concerning pavement condition (Step 1). This activity requires the involvement of a municipal council. Step 2 is to establish a pavement inventory. Every municipality needs to know which assets it owns, and in which condition, in order to manage the assets effectively.

Step 3 is the identification of needs. Each pavement section is reviewed as to the appropriate pavement preservation treatments that should be carried out in future. The process yields a list of candidate pavement preservation projects. Step 4, prioritization, is one of the most important steps in the management cycle. It determines which of the candidate projects will or will not be completed.

Step 5, budgeting, secures the budget and controls spending. Also, as part of budgeting, projects are programmed and packaged to minimize inconvenience to the traveling public and to improve construction efficiency (e.g., by combining construction projects).

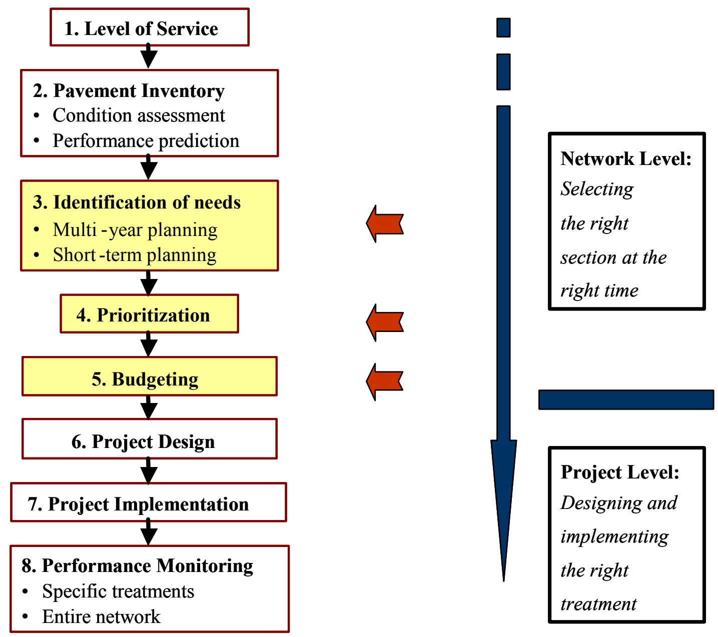

Figure 2: Decision-Making Framework for Pavement Preservation

The first five steps of the management cycle represent network level management activities as shown on the right side of Figure 2. The objective of these activities is to ensure that the right pavement sections receive treatments at the right time. The rest of the steps (5 to 8) can be viewed as project level activities. The objective of these activities is to ensure that the selected pavement sections receive the right treatment.

Step 6, project design, provides technical direction for the most cost-effective treatment, including type of materials, layer thicknesses, and construction procedures. Step 7, project implementation, or construction stage, must be supported by quality control and quality assurance procedures. Step 8, performance monitoring, is at the end of the management cycle and provides feedback on how the process is working.

To be credible, the management cycle must be consistent, transparent and logical. The cities of Corner Brook, Gander and Saint John's, Newfoundland, use a common outside agency to provide them with recommended 5-year pavement preservation plans. In the early 90's, the Ontario Good Roads Association developed a short-term planning and budgeting method for road maintenance and distributed it to all Ontario municipalities [5].

In a recent Canadian survey conducted on behalf of the National Guide for Sustainable Municipal Infrastructure (NGSMI), municipal representatives were asked a series of questions to obtain a better understanding of how municipal agencies select pavement preservation projects [7]. A number of interesting trends were confirmed. About 50 percent of municipalities had a PMS (Figure 3) and that the existence of a PMS is not confined to large municipalities only. This is encouraging considering that the presence of a functional pavement management system is one of the prerequisites for judicious selection of the time and type of pavement preservation treatments.

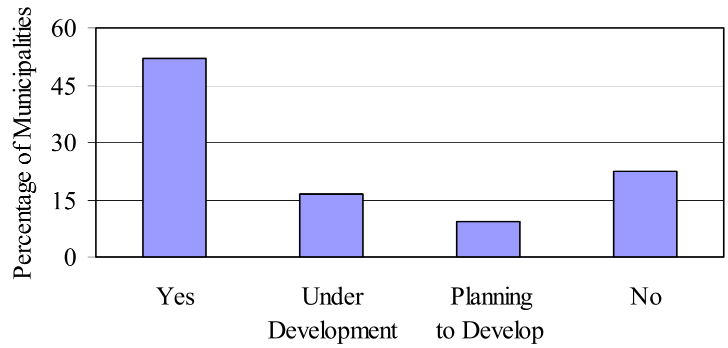

Figure 3: Existence of a Pavement Management System

The large majority of municipalities reported using a pavement condition rating system. In fact, 47 out of 55 municipalities reported that they rate the condition of their pavements (Figure 4). Only 6 municipalities reported not rating pavement condition. This is encouraging because without condition rating no systematic treatment selection process is possible.

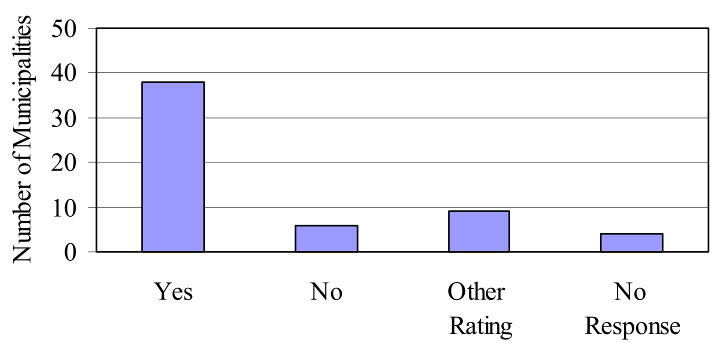

Figure 4: Use of Pavement Condition Rating

A summarized in Figure 5, 18 municipalities (one third) responded that they initiate pavement rehabilitation only when a perceived hazard exists. This type of maintenance initiation is not conductive to pavement preservation.

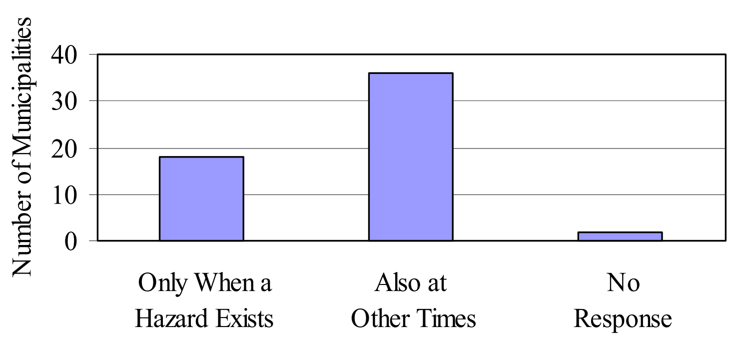

Figure 5. Initiation of Pavement Maintenance

Figure 6 shows the response received to the question "How do you select projects for pavement maintenance and rehabilitation?" Four options were provided: Using PMS; Decision Trees; Engineering Judgement; Worst Condition First. Some respondents selected more then one option. However, 18 municipalities, that is one third of the municipalities surveyed, again responded that they use the worst condition first criterion.

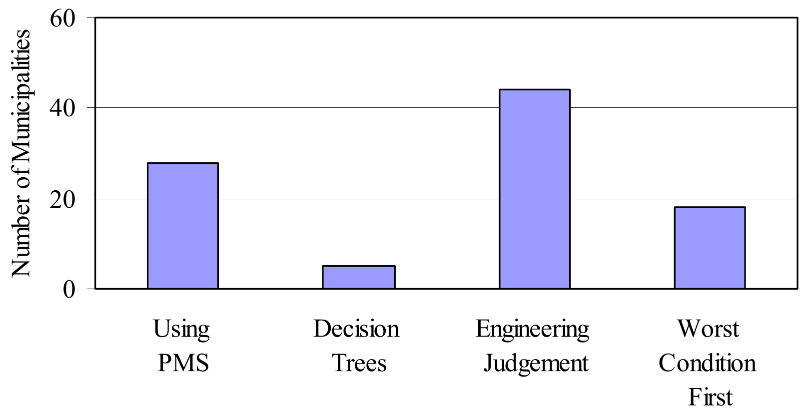

Figure 6. Methods used for the Selection of Pavement Preservation Treatments

The general concern of all municipalities was a lack of funding for adequate pavement maintenance (i.e., "doing more with less"). The larger municipalities also indicated that there is a lack of information on the timing of preventative treatments (i.e., the best time to initiate), how to choose acceptable alternatives and what important items should be in the specifications. Smaller municipalities responded that they simply do not have budgets for "experimenting" with new technology. Also mentioned was a lack of a standardized condition rating method between pavement management systems.

TYPICAL PAVEMENT PRESERVATION TECHNIQUES

Crack Treatment

The strength of pavement structure materials and subgrades are affected by the moisture content of the materials. Typically, fine grained materials are softened by increasing moisture contents which results in a lower strength which in turn results in a lower structural capacity for the pavement. An effective method to preserve the strength of the pavement is to prevent water from getting into the pavement structure/subgrade. For in service pavements, this is typically accomplished by ensuring that the pavement has good drainage in the form of ditches or subdrains and that the pavement surface is sealed to prevent water penetrating into the pavement structure. An effective method to seal the surface of the pavement is to treat any cracks in a timely and effective manner. Crack treatments include crack sealing and crack filling. Typically, cracks less than 20 mm in width are routed and sealed with cracks greater than 20 mm in width filled with either emulsion and aggregate or fine graded hot mix asphalt.

Crack sealing is typically performed for pavements in relatively good condition. The selection of which types and severity of cracks to be sealed should be established through the use of a decision matrix based on the experience of the agency. The National Municipal Guide for Sustainable Municipal Infrastructure has published guidelines for sealing and filling cracks in asphalt concrete pavements [8].

Patch Repairs

Patch repairs are typically used to address localized pavement distress. Patching is typically completed by marking the pavement in neat square or rectangular patterns beyond the area of visible surface distress, sawcutting the limits and removing the distressed asphalt (or by localized cold milling), cleaning and treating the underlying granular base followed by the placement of new hot mix asphalt. If the distress is a result of a structural deficiency, it may be necessary to remove and replace some or all of the granular base/subbase and subgrade to mitigate the distress from reoccurring. Many agencies rout and seal the interface between the patch repair and the surrounding pavement to prevent moisture infiltration.

Thin Hot Mix Overlay

To be considered a thin surfacing, the thickness of a hot mix overlay must be less than 40 mm. Overlays that are less than 40 mm thick are typically singled out by agencies as typically thin overlays that may require special construction provisions. Overlays thinner than 40 mm do not contribute substantially to the structural strength of the pavement and tend to provide a similar function as do other thin pavement surfacing techniques. Overlays that are less than 25 mm thick are typically called ultra-thin (hot mix) overlays.

The two main types of hot mix used for thin overlays are polymer-modified dense-graded and open-graded mixes. Dense-graded mixes typically use sandy mixes with the largest aggregate particle passing the 13.2 mm sieve, and seal the pavement surface from the intrusion of water. Open graded mixes contain a large percentage of one-size coarse aggregate resulting in a mix with interconnected voids and high permeability. Open graded mixes provide good pavement friction, reduce the potential for hydroplaning, and reduce pavement-tire noise.

Thin overlays are typically used for structurally sound pavements to provide a new protective surface, improve ride quality and pavement friction, and to provide a quiet pavement surface. They can also be used as a preventive maintenance treatment to slow surface raveling, seal small cracks, and seal the pavement.

Thin pavement overlays should be constructed on a uniform platform that bonds well with the overlay. The improvements to the existing surface may include precision milling to improve ride quality and cross-section, an application of a leveling course or a scratch course, patching, full-depth repairs, and an application of a tack coat. The existence of distresses such as segregation, raveling and block cracking, or conditions that do not permit raising of the pavement surface, may dictate a partial removal of the asphalt concrete by milling or precision milling prior to overlay.

The majority of agencies use a tack coat prior to placing a thin overlay. The tack coat strengthens the bond between asphalt concrete layers. The bond increases the strength of the pavement structure (by limiting slippage between layers) and the durability of the overlay (by reducing the possibility of delamination). Tack coat is also required to seal the underlying pavement layers when an open-graded overlay is used. Some agencies use a tack coat on previously milled surfaces only, arguing that these surfaces lack asphalt binder; other agencies use a tack coat only when the surface is not milled, arguing that a milled surface already provides a good aggregate interlock. Considering the relatively low cost of a tack coat (usually less than $ 0.5 per square meter), its routinely used.

Hot In-Place Recycling

Hot-in-place recycling (HIR) is included as a pavement preservation treatment because sometimes it is used to “rejuvenate” the surface of a hot mix pavement or to provide a uniform surface after patching or the installation of utility trenches.

The recycled asphalt concrete is typically mixed with a recycling agent, and can be further supplemented with pre-heated aggregate and/or (beneficiating) hot mix. The resulting recycled layer can be used as a wearing surface or can be protected by a slurry seal, micro-surfacing, surface treatment or a hot-mix overlay. If an integral overlay is used, the overlay serves as the wearing surface.

HIR is suitable for structurally sound pavements with surface defects, such as raveling and segregation, cracking, and rutting, that affect mainly the top pavement layer. An additional requirement is that the asphalt concrete surface layer should be suitable for recycling. The layer should have a relatively uniform composition (aggregate gradation, asphalt content, and thickness), and materials of good quality (aggregate and asphalt binder). Material properties of pavements considered for HIR should be thoroughly evaluated.

Micro-surfacing

Micro-surfacing is an unheated mixture of polymer-modified asphalt emulsion, high-quality frictional aggregate, mineral filler, water, and other additives, mixed and spread over the pavement surface as a slurry. Micro-surfacing is used to correct superficial distresses such as slight block cracking, raveling and segregation, flushing, and loss of pavement friction. Because micro-surfacing contains high-quality crushed aggregate, it is also used to fill-in ruts and surface deformation to the depth of up to 40 mm. Micro-surfacing has excellent frictional properties and is used on high speed roads including expressways. As a preventive maintenance treatment, it can be used to seal the surface of the pavement protecting the pavement from water infiltration and greatly reducing the rate at which the existing bituminous surface oxidizes. Oxidization of the bituminous surface material leads to raveling and cracking.

The surface on which micro-surfacing is applied should have uniform pavement condition. Areas that exhibit significantly more severe defects (for example raveling, cracking, or rutting) than the reminder of the section should be repaired. The repairs can by made using an additional course of micro-surfacing (Figure 3-8) or by other means depending on the type, extent, and severity of the defects. On high traffic volume facilities, and/or when the surface of the pavement has minor distortions and/or has ruts exceeding about 6 mm, two courses of micro-surfacing are recommended. The first (scratch) course is intended to improve the profile of the pavement and the second course provides the wearing surface. Ruts exceeding 13 mm should be filled with micro-surfacing material using a rut-filling spreader box.

<u>Slurry Seal</u>

Slurry seal is a mixture of asphalt emulsion, graded fine aggregate, mineral filler, water, and other additives, mixed and uniformly spread over the pavement surface as a slurry. Slurry seal systems are formulated with the objective of creating a bitumen rich mortar. They are similar to micro-surfacing, but the mineral skeleton is typically not very strong and has limited interlocking of the aggregate particles. Consequently, slurry seals are applied in thin lifts to avoid permanent deformation by traffic.

Slurry seals are used to correct superficial distresses such as raveling and coarse aggregate loss, seal slight cracks, and improve pavement friction. They are also used as a preventive maintenance treatment to seal pavement surfaces from intrusion of water and slow surface oxidation and raveling. Slurry seals are best placed on structurally sound pavements that are in good condition with little or no cracking. Slurry seals should not be placed on pavements exhibiting moderate or severe cracks, or progressive rutting.

The surface on which a slurry seal is applied should have uniform characteristics. If defects such as moderate or severe raveling, cracking, or rutting occur intermittently or frequently, the section is not a good candidate for slurry sealing. Working cracks, such as transverse cracks should be sealed, preferably after the slurry seal.

<u>Surface Treatment</u>

Surface treatment is the application of asphalt binder, immediately followed by an application of cover aggregate, to any type of pavement surface. Typically, surface treatments are applied on top of a granular base producing surface-treated pavement, one of the most common pavement types in Canada. Surface treatments can be also applied to asphalt concrete pavements as a preventive or corrective maintenance treatment.

Surface treatments applied on top of asphalt concrete pavements can be used as preventive or corrective treatments. As preventive treatments, surface treatment is primarily used to seal the surface with non-load associated cracks and raveling. As a corrective measure, surface treatments are used to restore skid resistance and to maintain wearing surface on thin asphalt concrete pavements.

The surface on which surface treatment is applied should have uniform capacity to absorb emulsion. If the pavement has, for example, raveling near the centerline or the evidence of end-load segregation, the raveled and segregated areas should be pre-treated (e.g., by spray patching). If left untreated, these areas will absorb emulsion and will fail to have enough binder to seal the surface and retain cover aggregate – precisely in the areas where the pavement needs the protection most. On the other hand, an increase in the emulsion application rate to match raveled and segregated areas may result in flushing elsewhere. Active cracks, such as transverse cracks, should be sealed, preferably after the surface treatment application.

Restorative Seals

Restorative seals consist of an application of a bituminous material, typically diluted asphalt emulsion, to the surface of asphalt concrete pavement (Figure 3-17). Restorative seals are also called rejuvenators or fog seals. Some agencies or suppliers recommend light sanding of restorative seals (about one kg of sand per square meter).

Restorative seals are used to reduce oxidation and hardening of asphalt binder and to seal minor cracks. Restorative seals can also slow the progression of raveling and coarse aggregate loss. The pavement should be in good condition and should be broomed before the emulsion is applied.

Texturization

Texturization techniques include diamond grinding, micro-milling, precision milling and other techniques that remove unevenness from the pavement surface, or improve its texture, and leave an abraded surface that is used as a driving surface (Figure 3-18). Diamond grinding, micro-milling and precision milling texturization techniques are described in the Glossary.

Texturization techniques can smooth out stepping at transverse cracks, wheel track rutting and improve pavement friction. The pavement should have sufficient structural capacity so that the reduction in thickness is not of concern.

MUNICIPAL EXPERIENCE WITH MAINTENANCE AND REHABILITATION TECHNIQUES

Many larger Canadian cities and regional municipalities indicated that they have tried and are using several relatively new pavement maintenance and rehabilitation techniques such as micro-surfacing, Novachip, emulsion stabilization, hot in-place recycling, and cold in-place recycling. As an example, micro-surfacing is being used to address pavement surface defects including frictional resistance problems. Although the micro-surfacing does not prevent reflection cracking, it is effective in improving the pavement surface frictional resistance.

Cold in-place recycling techniques, including full depth reclamation (pulverizing) and foamed asphalt stabilization, appear to be gaining wider acceptance as reflection cracking is often mitigated.

Rut mitigation at intersections has been identified as a common problem across Canada. Municipalities with high volumes of commercial traffic (the Cities of Toronto, Ottawa, and Windsor) have been evaluating stone mastic asphalt (SMA) mixes. Several municipalities including the Cities of Brampton, Calgary, Markham, Mississauga, Ottawa, Vancouver, and Windsor and have completed demonstration projects using whitetopping and ultra thin whitetopping to address rutting problems and have reported good initial performance.

The survey has found that Canadian municipalities have shown a willingness to explore new technologies and are often at the forefront of utilizing new technologies. As an example, the first trial section of SMA in North America was paved on Miller Avenue in Markham, Ontario [9]. Since then, SMA usage has steadily been on the rise across North America, especially in the U.S., and it continues to be used in large quantities in Europe as well as Japan. In Ontario, the Ministry of Transportation recommends SMA pavements for roadways with traffic loadings in excess of 3 million equivalent single axle loads per year.

A recent survey [10] of representatives of 22 Canadian municipalities known for their innovative approaches to pavement preservation, and a survey of over 40 other Canadian municipalities indicates a large variation in the use of pavement preservation treatments between municipalities. About 30 percent of municipalities do not use any pavement preservation techniques whereas about 20 percent of municipalities routinely use three or more treatments.

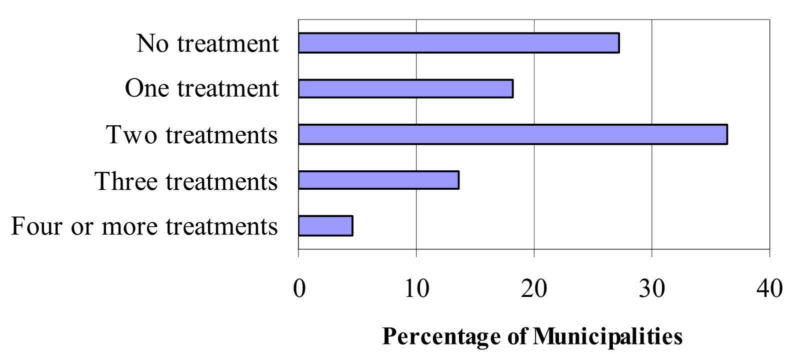

Figure 7. Frequency of use of Preservation Treatments by Canadian Municipalities

As shown in Figure 8, even though a relatively high percentage of municipalities used several preservation treatments in the past, a relatively small percentage of municipalities routinely use them. For example, about 55 percent of municipalities used micro-surfacing in the past, whereas only about 15 percent of municipalities routinely use it.

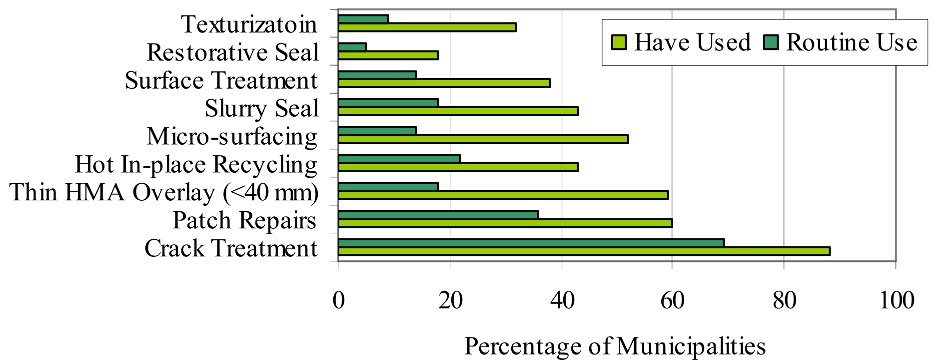

Figure 8. Types of Preservation Treatments used by Municipalities

IMPACT OF A COORDINATED PROGRAM

The focus of roadway activity in the early to mid 20th Century was on the construction of new roads. In the latter part of the 20th Century continuing into the 21st Century, this focus has shifted to the maintenance and rehabilitation of pavement infrastructure. In a 2001 distinguished lecture presented by Dr. R. Haas [11], a number of early Canadian contributions to pavement preservation were noted. The initial process of pavement management began in the mid 1960's based on the integration of engineering technologies and economic analysis. An outline for a pavement management system was published for the Canadian Good Roads Association's Pavement Committee in 1968 [12] followed by a management system for highway pavements in 1970 [13].

Coordination of pavement preservation activities with a maintenance and rehabilitation program will result in an improvement in the overall condition of a road network. The results of a National Cooperative Highway Research Program (NCHRP) study completed in the United States in 1996 [14] is shown in Figure 7.

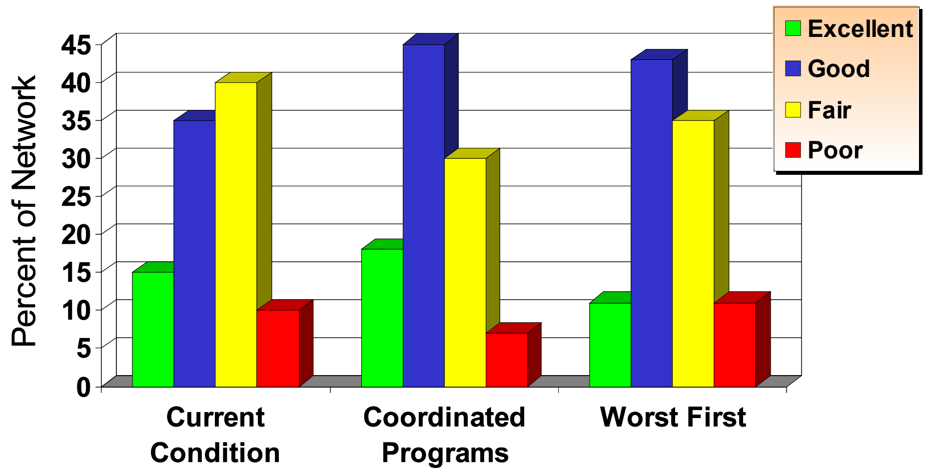

Figure 7. Impact of a Coordinated Maintenance and Rehabilitation Program on Network Condition [14]

This coordinated program or "mix of fixes" as it is referred to in Michigan, has been shown to have a significant impact on pavement condition. Galehouse [15] has indicated that typical rehabilitation and reconstruction project cost about 14 times as much as preventive maintenance projects per lane kilometre and that by implementing a preventive maintenance program, the State of Michigan has experienced a cost savings of more than $ 700 million since 1992. The Ontario Ministry of Transportation has concluded that crack sealing and cost effectively extend the service life of an asphalt pavement by at least 2 years [16]. The anticipated benefits of a properly design and implemented preventive maintenance program can lead to one or more of the following:

- Higher user satisfaction;
- Better informed pavement management decisions;
- Improved strategies and techniques;
- Improved pavement condition;
- Cost savings; and
- Increased safety.

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