A Rational Approach for Selecting the Optimum Asphalt Pavement Preventive and Rehabilitation Treatments – Two Practical Examples from Ontario

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ABSTRACT:

There is an array of options of pavement preservation treatments and pavement rehabilitation. It is challenging for pavement engineers to stay abreast of these developments, but it is totally bewildering for most municipalities. They are expected to make rational decisions to ensure the best use of scarce financial resourses in maintaining rapidly deteriorating road networks. All rehabilitation and preventive treatments are not equal and many have significant limitations with respect to their ability to solve specific road distresses. Thus, a straight cost comparison of rehabilitation and preventive treatment costs can be totally misleading. To add to the confusion facing municipalities is the influence of paving contractors who can be very persuasive about promoting their own technology.

This paper describes four simple steps that municipalities should follow, to put them in a better position to make informed decisions with respect to expenitures on pavement rehabilitation. It also describes the practical application of the selection process on a pavement preventive maintenance project in the Town of Whitby, and pavement rehabilitation design in one of the municipalities in Ontario.

1. INTRODUCTION

Fifteen or twenty years ago, the decisions facing road authorities with respect to road rehabilitation were simple, hot mix overlay or total reconstruction. That was prior to the boom in recycling and reclaiming techniques [1, 2]. Municipalities now have a huge array of options to choose from. These include: hot in-place recycling (HIR); cold in-place recycling (CIR) with emulsion; cold in-place recycling with expanded asphalt mix (CIREAM) and full depth reclamation (FDR) with expanded asphalt. There are also number of pavement preventive maintenance techniques currently available that include fog seals, surface rejuvanating, micro-milling and thin surfacings. Thin surfacings include surface treatment (chip seal), slurry seal, microsurfacing, Metro-Mat™, Nova Chip and thin asphalt concrete overlays. For agencies to make rational decisions about optimum pavement preventive maintenance and rehabilitation treatments, they need to understand the technologies and their limitations. All pavement preventive maintenance and rehabilitation treatments are not equal, so before attempting to select a preventive maintenance or rehabilitation treatment, it is important to understand the pavement structure and the nature and extent of the pavement distresses.

2. PAVEMENT MAINTENANCE TREATMENTS

Pavements deteriorate as a result of a combination of several factors. The primary mechanisms of asphalt concrete (flexible) pavement deterioration are environmental (such as aging and oxidation) and load related effects. Load related forces result in the development of structural distresses such as fatigue cracking and rutting; environmental forces (which include the effects of temperature, oxidation, and exposure to sun light) result in distresses such as thermal cracking, block cracking, and weathering and raveling. As the pavement cracks it loses its load-carrying capacity and becomes even more susceptible to the effects of moisture infiltration to subsurface layers, which can then weaken and further deteriorate.

Pavements which are left to deteriorate without timely maintenance treatments are likely to require major rehabilitation and reconstruction much sooner than those which are properly maintained. Many different techniques and treatments are available for the maintenance and preservation of existing pavements and can be divided into the following two major categories:

1. Routine Maintenance Treatments
    - Crack filling/sealing
    - Patching

2. Preventive Maintenance Treatments
    - Fog Seals
    - Surface Rejuvenating
    - Micro-Milling
    - Thin Surfacings
        - ➢ Chip Seal
        - ➢ Slurry Seal
        - ➢ Micro Surfacing
        - ➢ Metro Mat ™
        - ➢ Nova Chip
        - ➢ Thin Asphalt Concrete Overlays

Preventive maintenance is applying the right treatment to the right pavement at the right time. Thin surfacings are applied to existing pavements to preserve the pavement, retard the rate of future deterioration, and maintain and improve the functional condition of the pavement without increasing structural capacity [3]. These thin surface treatments also reduce the need for routine maintenance and can significantly extend the life of pavements. However, as they only preserve, not improve the structural capacity, they have to be applied while the pavements are still in good structural condition. In fact, the better the pavement condition when thin surfacings are applied, the longer the treatments will last and the more cost effective it is [4]. Thin surfacings are briefly described in the following paragraphs:

Chip Seal

Chip seals consist of a single application of conventional or polymer modified asphalt emulsion followed immediately by an aggregate cover. The goal is to have the aggregate particles embed themselves into the asphalt layer with about 30 percent of each particle exposed to provide texture. Applications with two layers are referred to as a double chip seal. Chip seals can be applied at any time in a pavement's life as an economical, durable and widely available treatment [5] and [6].

Chip seals can waterproof the pavement surface, provide sealing of low severity cracks, and restore surface friction. The chip seal membrane also slows down the asphalt cement oxidation process within the original asphalt surface layer. Chip seals are not effective on pavements exhibiting medium to high severity fatigue, linear or block cracking, rutting, roughness and shoving [6]. The serviceable life of a chip seal treatment is considered to be about 3 to 6 years with a typical average of 4 years under low to moderate traffic. The typical cost of a chip seal treatment in Ontario ranges from about \$1.40 to \$1.75/m^2 (if polymer modified emulsion is used). Numerous qualified and experienced contractors are available throughout Ontario.

Slurry Seal

A conventional slurry seal is a mixture of well graded fine aggregate, slow setting asphalt emulsion, water and mineral filler (most often Portland cement). It is considered to be a thermal process. The conventional process takes from two to eight hours to cure depending on the heat and humidity.

Slurry seals will not perform well if the underlying pavement exhibits medium to high severity fatigue, linear or block cracking, rutting, roughness or shoving [7]. It should be applied only where the existing surface is stable with only low severity cracking.

Slurry seals, as the name implies, seal the existing pavement surface, slow surface raveling, seal small cracks and improve surface friction. They are effective where the primary problem is excessive oxidation and hardening of the asphalt concrete or where there are aggregate 'pop-outs' in asphalt wearing courses incorporating soft limestone. Slurry seals do not have a strong skeleton and are typically applied as one aggregate layer thick. They are not suitable to correct surface irregularities and rutting.

The life of a slurry seal is from about 3 to 5 years. The typical cost of slurry seals range from about $1.35 to $1.50/m^2 for a single lift and about $1.75 to $2.00/m^2 for a double lift. Experienced slurry seal contractors are available throughout Ontario and the product is highly reliable.

Microsurfacing

Microsurfacing is a mixture of polymer modified emulsion, well graded crushed mineral premium aggregate (typically 9.5 mm minus), mineral filler (normally Portland cement), water and chemical additives that control the break time, i.e. the time for the emulsion to achieve a set [8]. The aggregates are tough in terms of hardness and resistance to polishing. Microsurfacing is a chemically controlled process. The materials are mixed in a truck mounted traveling plant and then deposited into a spreader box. No compaction is needed and traffic may be allowed on the mat within an hour after placement. This pavement treatment typically involves two coats including a scratch or leveling coat followed by a surface coat. A typical rate of application is 10 lane kilometers per day.

Microsurfaing is applied on streets or highways carrying medium to high volume traffic, on high speed roads and airfield pavements. The pavements should be in good structural condition and not exhibiting any significant structural surface distresses (not to be used on pavements with moderate to high severity alligator cracking). Microsurfacing has a strong skeleton and can be applied in relatively thick layers; it is very effective in correcting surface irregularities including minor transverse profile corrections, and low to medium severity surface wheel track rutting problems [9].

Microsurfacing provides a high quality skid resistant surface for an existing asphalt concrete pavement, seals the pavement surface, restores surface profile, eliminates hydroplaning, and provides a surface that is more resistant to rutting and shoving. Microsurfaing is applied at ambient temperatures and has low energy requirements. Due to its quick application rate, it causes minimum disruption to traffic. The life expectancy of microsurfaing is 7 or more years. The typical cost ranges from $3.75 to $4.00/m^2. A number of qualified microsurfaing contractors are available in Ontario.

Thin Hot-Mix Asphalt Overlays

Dense graded HMA mixes are typically used in thin overlays in Ontario to improve the functional condition of a pavement including smoothness, skid resistance and roadway profile correction. Gap graded mixes (such as Stone Mastic Asphalt) and open graded friction course mixes can also be used. Thin overlays add little or no structural improvement to the pavement [10]. Prior milling may be required if more severe surface distresses are present or where curb reveal needs to be maintained. Thin overlay thicknesses typically range from 20 to 40 mm. The mixes are sometimes modified with polymers for better field performance. Thin overlays will correct some small surface irregularities and low severity rutting; however, more severe irregularities should be repaired before the thin overlay application.

Thin asphalt overlays should be applied prior to the onset of fatigue-related pavement cracking. Candidate pavements may exhibit surface distresses such as moderate to severe raveling, and moderate longitudinal and transverse cracks with some secondary cracking. Isolated structural distresses, such as alligator cracking must be patched prior to overlay. Thin overlays are particularly suitable for high volume roads in urban areas.

Thin overlays provide a skid resistant surface for existing asphalt concrete pavements, restore surface profile, eliminate hydroplaning and improve smoothness. The life of a thin overlay ranges from about 5 to 10 years with the average of about 8 years.

Depending on the thickness of the overlay, type of hot mix used and weather milling and/or tack coating are required, the cost of this treatment ranges from \$5.50 to \$8.00/m^2. Qualified contractors are readily available throughout Ontario; essentially the same contractors as for conventional hot-mix asphalt paving.

Other methods of thin surfacings include Metro-Mat ™ and Nova Chip. More information on thin surfacings is provided in [11].

3. MAJOR PAVEMENT REHABILITATION TREATMENTS

As the pavement condition deteriorates, there comes a point when maintenance treatments are no longer effective and rehabilitation is required. Major pavement rehabilitation treatments can be divided into the following categories:

- Structural Overlays
- Recycling
  - Hot In-Place Recycling (HIR)
  - Cold In-Place Recycling (CIR)
    - Cold In-Place Recycling with Emulsion
    - Cold In-Place Recycling with Expanded Asphalt Mix (CIREAM)
  - Full Depth Reclamation (FDR) with expended asphalt
- Total Pavement Reconstruction

Structural Overlays

This represents the traditional and simplest pavement rehabilitation technology. It involves placing a new hot mix asphalt overlay directly on an old deteriorated pavement. Typical overlay thicknesses are in the range of 40 to 100 mm. A properly designed and constructed overlay will add structural strength, correct surface defects and provide a smooth riding surface. With prior hot mix padding, substandard cross-fall and superelevation can be corrected. The major limitation with a conventional overlay is that it only masks and does not eliminate most of the underlying pavement defects. In particular, transverse and longitudinal cracking will reflect through the overlay, sometimes within as little as three years. To enhance the long-term performance of a hot mix overlay, some pre-treatments can be undertaken to the existing pavement. Options could include: cold milling, localized patching and partial- depth or full depth crack repairs to mitigate reflective cracking.

Hot In-Place Recycling (HIR)

With HIR, 100 percent recycling of the existing asphalt pavement is completed on site. HIR reconstitutes the upper portion of an existing asphalt pavement. In HIR the typical processing depths are 25 to 50 mm and the old asphalt is heated to at least 110° C and softened so that it can be scarified or hot rotary mixed. A recycling agent is usually added to rejuvenate the old asphalt cement binder. Fine aggregate can also be added to improve the hot mix properties, particularly air voids. HIR is generally performed with a dedicated recycling train and some processes allow the placement of an integral hot mix overlay above the recycled layer.

HIR has proved to be a very effective means of rehabilitating urban streets, where there are severe constraints on grade raises due to curbs and private and commercial entrances. One disadvantage with the process is that it only restores the upper portion of the old asphalt and so many of the more severe pavement distresses can remain below. Further, pavement with extensive crack sealing or patching can create problems with maintaining the quality of the rejuvenated mix. However, with the use of perpetual (long-life) pavements with occurrence of only top-down cracking (TDC), HIR can be more effective in renewing pavement surface with TDC cracking. A coring program is needed to assess the suitability of the existing asphalt for HIR. The performance of properly designed and executed HIR projects has been good and it has even been used successfully for the rehabilitation of municipal and military airport runways [12].

Cold In-Place Recycling (CIR)

This process involves milling the existing asphalt partial depth or sometimes almost full depth, sizing the RAP, adding a bituminous binder (i.e. asphalt emulsion, sometimes with rejuvenators and/or recycling agents), re-spreading and compacting. Typical processing depths are 50 to 125 mm. CIR is usually performed using a recycling train. The blended material is deposited in a windrow where it is then picked up and placed using conventional paving equipment. Since this is a cold process, it requires favourable weather conditions for the emulsion to break and allow the compacted layer to gain adequate strength. The completed cold recycled layer can sustain traffic. However, for long term performance it should be protected with a conventional hot mix overlay or thin surfacing. The wearing course shall not be placed until the CIR mix has been allowed to cure for a minimum of 14 days.

Another method of CIR is cold in-place recycling using expanded asphalt mix (CIREAM), in which expanded (foamed) asphalt is used to bind the mix, instead of emulsified asphalt. One of the advantages of CIREAM over the conventional CIR with emulsified asphalt is its short curing period. In Ontario, for instance, a 2-day curing period is required for CIREAM as compared to 14-day period required for CIR with emulsified asphalt prior to placement of the new HMA overlay (provided moisture and compaction requirements are met). The curing requirements may be different in other parts of Canada depending on environmental conditions and the additives used in the mix.

One of the significant advantages of CIR, when compared to a straight hot mix overlay, is that it removes the majority of the asphalt distresses, such as wheel ruts, potholes and cracking. It also allows the old pavement to be re-profiled with restoration of crossfall. Since CIR does not treat the entire asphalt layer, there is a concern that over time, previous severe transverse cracks could reflect through the new pavement. The potential for this is generally low, since cold mix asphalt has been shown to be much more resistant to crack propagation than hot-mix asphalt [13]. Recent experience has shown that provided the mix is properly designed, cold mix attains a relatively high stability and is sufficiently rut-resistant to be used on busy arterials (high volume roads).

Full Depth Reclamation (FDR)

In full depth reclamation (FDR), the asphalt surfacing is pulverized and blended into the underlying granular base. Additives can be used to produce a stabilized base course. Typical additives include asphalt emulsions, Portland cement, lime, fly ash and calcium chloride. These pavement rehabilitation treatments typically increase the structural capacity of the existing pavement and eliminate existing pavement distresses. The emphasis in this paper is on the FDR with expanded (foamed) asphalt stabilization. FDR is usually followed by placement of a wearing surface course. This treatment is especially useful where a pavement has inadequate structural capacity and where the pavement is severely distressed. It also eliminates the risk of reflective cracking.

In addition, where a stabilizing additive will not be used, it is usually desirable to pulverize to a depth at least twice the thickness of asphalt. This ensures that the blended mix will have performance characteristics similar to a granular base. Maximum processing depths are about 300 mm. It is usually necessary to verify that cobbles (such as coarse, pit-run subbase) will not be encountered within the depth to be in-place processed. In addition, it is important to verify that the existing granular base extends to the full in-place processing depth. Otherwise, the final pulverized product will become contaminated with sandy subbase or subgrade soils.

Total Pavement Reconstruction

Clearly, this is the most expensive form of road rehabilitation and can only be justified where no other recycling options are viable. It involves complete removal of existing granulars and asphalt surfacing. Following subgrade preparation, a new pavement section is constructed. Recycling options for some of the materials removed should be explored. For example, if the asphalt layers are removed by milling, the RAP can be used in recycled hot-mix, or blended with granular base, typically up to 50 percent or can be used 100 percent on shoulder rounding to minimize erosion. Old granular base can be re-used as subbase and old subbase used for minor road platform widening.

The most frequent application of pavement reconstruction is to address localized poor performing areas. These can be areas of persistent frost heaves, poor transition treatments at rock cuts or sections of pavement above topsoil or organic layers. These problems cannot be addressed by overlays or in-place recycling and must be dealt with effectively to avoid on-going and costly maintenance. The problem areas can only be identified by a detailed review of the pavement history, maintenance records and a thorough investigation by knowledgeable and experienced practitioners. Total reconstruction may also be needed where an existing road is to be upgraded to a higher level of service and where vertical and horizontal alignment adjustments are required to improve road geometrics and operational safety.

4. SELECTING THE OPTIMUM TREATMENT

On every road rehabilitation project, the main question that must be asked is, "What is wrong with my pavements, how do I fix it?" All pavements deteriorate in different ways and exhibit a different range of distress features. In the past, rehabilitation treatments were sometimes designed solely on the basis of establishing the existing pavement structure, either in terms of spring rebound or granular base equivalency. This was then compared to the appropriate value needed for a new pavement with similar traffic and the structural deficiency calculated. The deficiency was generally converted to a thickness of asphalt overlay. This simplified approach can be modified to deal with recycling treatments, however, is totally inadequate if it does not consider the type, extent and severity of pavement distresses. The visual pavement distresses tell the story of how the pavement has deteriorated. The following five key measures are typically used to characterize or define the condition of the pavement:

Structural Evaluation:

1. Pavement Surface Distresses
2. Load-Deflection (structural adequacy assessed through Falling Weight Deflectometer (FWD) testing or other suitable NDT method)

Functional Evaluation:

3. Surface Roughness (longitudinal profile, International Roughness Index (IRI) or ride quality)
4. Skid Resistance (surface friction)
5. Rut Depth

Prior to selecting a pavement rehabilitation strategy, it is critically important to establish what are the predominant pavement distresses and their underlying causes. Without a thorough understanding of what needs to be fixed with the pavement, it will be impossible to identify the most appropriate remedial measures. Establishing only the pavement structural capacity (without carrying out pavement distresses evaluation) will not provide the required information to design a serviceable rehabilitation treatment.

5. STRUCTURAL CAPACITY AND RIDE QUALITY

Pavements "fail" when the level of driving comfort reaches an unacceptably low level. The level that triggers remedial action is different for different classes of road and for different road authorities. The distresses giving rise to the poor ride may not necessarily be representative of a structural deficiency. Many pavement distresses are not “load” related. A prime example of this is the widespread problem of transverse cracking. This distress mode is caused by the asphalt cement binder being too stiff to withstand the internal stresses at very low ambient temperatures. Over time, these cracks deteriorate with the action of traffic and water seepage. The cracks become wider and develop cupping on the underside and are a major contributor to rough ride quality on Canadian roads. The rehabilitation strategy for this distress mode is not related to a structural inadequacy. So correcting a perceived structural deficiency by adding more structure in the form of an asphalt overlay, will provide only short term relief for this distress mode. In a similar manner, where the main distress mode is wheel track rutting, increasing pavement structure will not necessarily address the problem. In many instances, wheel track rutting is caused by the use of an unsuitable asphalt mix for the actual loads and traffic volumes.

Inadequate structure can manifest itself by premature surface distortions and alligator cracking. However, these distress modes are also evident in pavements that have reached their normal terminal serviceablility level. Thus, unless the pavement history is known, it is difficult to interpret the significance of a condition survey.

6. STEP 1 – REVIEW DATA

Pavements are unique structures. They start deteriorating from the first day they are opened to traffic. The implications of specific distress modes can only be established when the age of the pavement and construction type are known.

A typical check list should include the following information:

- Original pavement construction, either from contract documents or “as-built” records
- Quality control and quality assurance testing and inspection records
- Records of previous rehabilitation and maintenance

- Materials types and sources
- Previous condition survey data from pavement management system records

In addition to the above, the rehabilitation design will require detailed information on traffic. This should include, as a minimum, the average annual daily traffic (AADT), the percentage commercial traffic and the annual growth rate. On major arterials and freeways, more detailed traffic data will be advisable, such as axle load distributions and any seasonal or directional traffic variations.

STEP 2 – CONDITION SURVEYS

A detailed condition survey provides an inventory of pavement distress frequency and severity and yields vital data in identifying the weaknesses in the pavement. This level of condition survey is considerably more detailed than that needed for, say input to a pavement management system. In the case of a condition survey undertaken prior to a rehabilitation design, it must attempt not only to establish the extent and severity of the distresses but also to suggest the likely contributing causes. Thus, the survey needs to be undertaken by personnel experienced with pavement performance, geotechnical and materials engineering, and subsurface drainage. Any records of the previous performance of the existing pavement may be very useful in the design of the required pavement rehabilitation treatment.

In addition to a visual condition survey of the traveled lanes and shoulders, the condition survey should also review drainage provisions and identify all areas where pavement performance is being affected by inadequate drainage. The condition of culverts should also be recorded so that culvert replacement can be undertaken as part of the rehabilitation works, where deemed necessary. Pavement crossfall should also be measured. The need to re-establish crown and crossfall can influence the choice of remedial measures and can also significantly affect hot mix quantities for padding.

Route borings establish the details of the pavement structure. They reveal the subgrade type, granular and asphalt thickness. The borings should penetrate the traveled lanes as well as shoulders and should record moisture condition and any standing water encountered. Borehole offset distances from the pavement centerline should be identified so that conditions within paved lanes can be distinguished from boreholes through partially or fully paved shoulders.

Sufficient samples should be taken to provide uncontaminated specimens for subsequent laboratory testing. Establishing the quality and consistency of the granular base and subbase materials and the frost susceptibility of the subgrade soils will be the key objectives of the laboratory testing program.

Load/deflection testing provides valuable information for establishing overall structural strength. It is particularly useful for delineating weak areas and areas requiring special treatments. It can be undertaken using a Falling Weight Deflectometer (FWD), Benkelman Beam or a Dynaflect; a dynamic cone penetrometer (DCP) is also used on some projects. The FWD load/deflection testing is particularly useful when investigating concrete or composite pavement sections to determine the load transfer efficiency across joints. The FWD testing data allows a back-calculation analysis of pavement resilient moduli which is very useful as input to a mechanistic pavement analysis.

STEP 3 – REVIEW OF REHABILITATION OPTIONS

Selecting the optimum rehabilitation strategy for a highway is a complex process. A number of sometimes competing criteria needs to be considered. These criteria relate to technical merits and performance expectations, as well as financial issues. Occasionally, even political or policy issues become factors in the selection of remedial measures. However, it is important to remember that one rehabilitation treatment will not suit all situations. The wide variety of options to select from, should be used by road authorities to their advantage by matching treatments to specific problems and seeking competitive bids. Since no two rehabilitation treatments will be identical, there needs to be a means of comparing treatments, so that a road authority can be assured that they are getting the best value for money invested.

The main issues that need to be considered when selecting a rehabilitation treatment are discussed below:

Construction cost

For most capital projects, best value can usually be determined by lowest price. This approach is reasonable when acceptable quality can be easily defined. Pavements are somewhat unique when compared to other civil infrastructure. The loss in serviceability may be slow or rapid and the serviceable life of the pavement is difficult to define precisely. Therefore in the case of pavements, construction cost is not a good indicator of value, since no two alternative design strategies will be similar in terms of performance or level of service. Irrespective of the limitations in judging value based purely on construction cost, it is still a fact of life that road authorities have limited budgets at their disposal and generally must use construction cost as a major factor in selecting rehabilitation treatments.

Life cycle cost

Life cycle costing is a process that allows all costs associated with providing a product or service over a chosen life cycle period. It considers both the initial construction costs as well as the on-going or periodic maintenance costs. It can also include user delay costs that are a significant issue for the managers of major highway systems. In a life cycle analysis all costs over the analysis period (typically 30 to 50 years) are corrected to present worth costs. This approach would appear to be the solution to the limitations of considering initial construction costs only. However, it too has some limitations, such as the difficulty of predicting future maintenance costs, the selection of discount rates and salvage values and the issue of whether to include user delay costs. Nevertheless it is a widely accepted means of comparing rehabilitation alternatives.

Initial service life

Highway serviceability records indicate that properly designed and constructed flexible pavements have an initial service life of at least 15 to 18 years before a major rehabilitation is needed. By comparison, some rehabilitation strategies, e.g. very thin overlays, may only extend the serviceable life for as little as seven years. Short term treatments may be necessitated by the need to address a road safety concern. However, generally, the longer the initial predicted service life, the more acceptable the option, particularly in the case of major highways, where user delay costs and disruption to the traveling public need to be minimized.

Risk minimization

Road agencies develop a comfort level over the years with specific rehabilitation techniques. These are techniques that have been used successfully in the past. Similarly, techniques that are new or that have not performed satisfactorily will have an associated increased risk level. Smaller municipalities generally wish to avoid newer technologies since they require additional engineering design and monitoring effort, which may not be available to them.

Best technical solution

No two rehabilitation alternatives deal with pavement distresses in an identical manner. However, it is usually possible to make an engineering assessment as to the best technical rehabilitation option. This is the one that from a purely engineering design point of view, best addresses the range of pavement distresses and structural deficiencies. In the decision making process, the best technical solution should be a relevant factor.

Environmental considerations

Environmental and excess material management are becoming increasingly important in assessing road rehabilitation strategies. This is particularly important for provincial agencies, where policies exist for maximizing the re-use of all materials generated during highway rehabilitation, within the right of way. This can be a powerful factor in favour of treatments that maximize recycling.

Serviceability level

Pavement rehabilitation treatments have different levels of maintenance associated with them. While the future projected maintenance costs are factored into life cycle cost analysis, the ability of an agency to deal with regular maintenance operations, may be a factor.

Capabilities of local contractors

To ensure a competitive bidding process, road agencies have a preference for construction materials and technologies that are readily available locally. This also helps to ensure that the selected contractor will have the equipment and trained staff to perform the work effectively.

Size of project

Some technologies may only be viable on certain sized projects. The mobilization costs of recycling trains to more remote areas may make some treatments feasible only on larger projects.

STEP 4 – SELECT OPTIMUM TREATMENT

The data gathered from the investigation described above needs to be analysed in detail. Depending on the complexity of the project and data collected, a pavement engineer could be retained to carry out the analysis and develop pavement rehabilitation recommendations. Corrective treatments are selected for all poor performing areas. Some of these localized problem areas may be addressed by the overall rehabilitation treatment but others will require total reconstruction. The remainder of the pavement section would then be divided into subsections of relatively uniform layer composition. Typical sections would be analysed for structural adequacy and compared to that needed for long-term performance under the design traffic loading and environmental conditions. This analysis can be done using AASHTO design method or mechanistic pavement analysis or using granular base equivalencies for lower traffic volume roads.

Depending on the magnitude of the structural deficiency, the extent of rehabilitation treatment is determined. If there is no structural deficiency, the rehabilitation treatments need only address the restoration of ride quality and extending pavement life. In the case of severe structural deficiencies, it is likely that improvement of the underlying granular support layers will be needed in addition to treating the asphalt layers.

To help facilitate the selection of a rehabilitation strategy, a step-wise process should be used. The process should objectively consider the important criteria affecting the selection. One simple approach is to identify four or five selection criteria that are important to an owner. Then by applying each of these criteria in turn to two or three acceptable rehabilitation strategies, a probability of acceptance value can be determined for each one. Once the probability of acceptance of each criteria has been determined, then the individual criteria are combined to arrive at an overall probability of acceptance for that rehabilitation option, using weighting factors. This process is illustrated below.

Criteria

Rehabilitation selection/evaluation criteria are owner specific and possibly even project specific. The previous section described a number of typical evaluation criteria. The appropriate ones would be selected to suit the specific needs of an individual agency.

Probability of Acceptance

When a pavement rehabilitation design is assessed on the basis of a series of desirable attributes, it is fairly easy to decide what outcome is completely acceptable and what outcome would be totally unacceptable. To illustrate this point, we can consider a criterion such as initial pavement life. Since few flexible pavements last beyond about 20 years, we could assume that a rehabilitation treatment that had a projected life of 20 years or more would be completely acceptable. At the other extreme, a pavement life of as little as 5 years would probably be totally unacceptable. Between, the range of 5 to 20 years, there is an increasing level of acceptance. These levels of probability of acceptance can be assigned numerical values, where 1 represents totally acceptable and zero represents unacceptable. On this basis a graphical relationship can be established between the range of values for a chosen criterion and level of acceptability by a particular agency.

Weighting Factor

The selection process allows any number of evaluation criteria to be considered. Each evaluation criterion is then assigned a weighting factor that represents its relative importance in the overall selection process.

The most important criterion would have the highest weighting factor and the least important, the lowest. Two or more criteria can have similar weighting factors, provided the sum of all factors equals one.

Comparing the Options

The viable rehabilitation options are compared by summing the weighted probability of acceptance of each criterion. The option with the highest resulting probability of acceptance is the option that best meets the owner's requirements.

The essence of this technique is to allow agencies the flexibility of establishing their own selection criteria in an objective way and to compare widely different rehabilitation strategies in a way that addresses their specific needs. More information on the selection of optimum treatments is provided in [14].

7. PRACTICAL EXAMPLES

EXAMPLE 1

The optimum method of preventive treatment was considered for asphalt pavement on Thickson Road in Whitby, Ontario. This section of Thickson Road through a busy intersection carries about 30,000 vehicles per day with high percentage of trucks. Curbs and gutters are present on both sides of the road. The original surface course asphalt incorporated relatively soft limestone aggregates prone to polishing.

Although no Falling Weight Deflectometer or other structural condition testing was carried out, the pavement was considered to be in good structural condition. The observed visual distresses included low severity rutting and a few low severity longitudinal and transverse cracks. The pavement surface was polished (Figures 1 and 2) and frictional characteristics were of concern.

Figure 1 – Pavement surface on Thickson Road in Whitby before microsurfacing application. The shine is due to the presence of polished stone in the surface course mix.

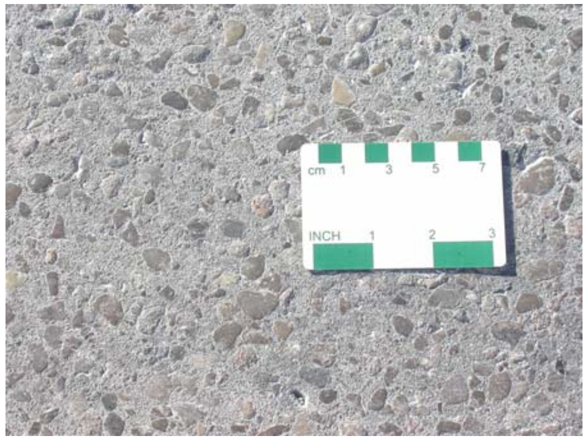

Figure 2 – Close up of pavement surface texture on before microsurfacing application.

The following preventive treatments were considered for this section:

1. Slurry seal;
2. Thin overlay; and
3. Microsurfacing.

The following evaluation criteria were considered:

1. Initial construction costs;
2. Level of service; and
3. Proven experience.

The initial construction cost of slurry seal of about $2.00/m^2 was the lowest one followed by the cost of microsurfacing of about $4.00/m^2. The cost of thin overlay would be the highest one and it would also have to include the cost of milling; the total cost of the thin overlay treatment would be about $9.00/m^2.
The slurry seal treatment would improve the frictional characteristics and seal the pavement. However, as it has a relatively weak stone skeleton, it was not considered suitable for filling rutting on high volume roads.

The thin overlay treatment would address all observed pavement distresses (polished surface, low severity cracking and low severity rutting). However, due to the presence of curb and gutter, it would require milling of the existing asphalt to a depth of 40 mm and would cause some disruption to traffic on this busy road.

The microsurfacing would address all of the observed pavement distresses. As it has a strong stone skeleton, it considered suitable for filling low to medium severity rutting on high volume roads. It can also drastically improve frictional characteristics of the pavement.
There are constructors in the area who have extensive, proven experience in the application of all three preventive treatments.

Based on the cost and level of service analysis, double microsurfacing was selected as the optimum treatment of this section of Thickson Road. During the rehabilitation, low to medium severity rutting was filled with the first lift of microsurfacing (Figure 3) and then the surface lift was applied (Figure 4). The close-up view in Figure 4 compares the surface of the original HL 1 surface containing polished limestone aggregate and the texture of the microsurfacing surface applied on this section. The Skid Number as measured with the ASTM brake force trailer almost doubled from about 28 before to about 52 after the microsurfacing application. After 11 years of service, while in a number of areas the microsurfacing has worn off, it has remained intact and functional on the majority of the section (Figure 5).

Figure 3 – Rut filling with microsurfacing lower lift on Thickson Road in Whitby, Ontario in 1993.

Figure 4 – Application of the second lift of microsurfacing.

Figure 5 – Condition of microsurfacing after 11 years of service.

EXAMPLE 2

The optimum method of rehabilitation was considered for the pavement structure on one of municipal roads carrying medium volume of traffic in the Province of Ontario. The geotechnical investigation was a part of the pavement design procedure. It included pavement visual condition survey, borehole and coring investigation, FWD testing, Ground Penetrating Radar (GPR) pavement structure survey, laboratory testing of selected samples, cost analysis and pavement optimum rehabilitation method selection.

The pavement visual condition was considered to be fair with the Pavement Condition Rating (PCR) of 65 and Ride Comfort Rating (RCR) of 6.9. The main observed distresses were intermittent low to medium severity alligator cracking (Figures 6 and 7), frequent low to medium severity longitudinal and transverse cracking, localized medium severity rutting, some polished aggregates and low severity raveling.

Figure 6 – Low to medium severity alligator cracking observed on the road.

Figure 7 – Localized medium severity alligator cracking.

The FWD testing indicated that the pavement was in fair structural condition for the design traffic loading. The mean deflection was 0.28 mm with a standard deviation of 0.06 mm and the pavement surface modulus is 545 MPa with a standard deviation of 116 MPa. The corrected spring static deflection is 0.96 mm. In accordance with the Asphalt Institute "Asphalt Overlays for Highway and Street Rehabilitation" MS-17, the maximum allowable spring static deflection for this pavement to carry a traffic loading of 2.0 million ESAL's over a period of 20 years is 0.72 mm.

The existing pavement structure consisted of an average of 100 mm of hot-mix asphalt, a thick layer of 450 mm of crushed gravel placed over 400 mm of sand subbase. The subgrade material was identified as sandy silt and silty clay.

The following pavement rehabilitation treatments were considered for this section:

1. Structural overlay;
2. Foamed asphalt stabilization – full depth;
3. Cold in-place recycling; and
4. Reconstruction.

An analysis of the four considered options provides the following estimates:

	Option 1		Option 2		Option 3		Option 4	
	Estimate	Acceptability	Estimate	Acceptability	Estimate	Acceptability	Estimate	Acceptability
Initial construction cost	$16	0.98	$20	0.90	$17	0.92	$31	0.80
Level of service	12	0.80	18	0.95	16	0.90	25	0.98
Proven experience	20	1.00	10	0.95	15	0.97	25	1.00
Life cycle cost	+40%	0.65	+10%	0.90	+20%	0.80	Lowest	1.00
Extent of recycling	20%	0.40	70%	0.90	60%	0.85	10%	0.20

The criteria considered and the weighting factors are as follows:

Criterion	**Weighting Factor**
Initial construction cost	0.40
Level of service	0.30
Proven experience	0.15
Life cycle cost	0.10
Extent of recycling	0.05
Total	**1.00**

The optimum rehabilitation strategy was identified simply be summing the product of the acceptability of each criterion and the relevant weighting factor. The option with the highest overall acceptability was selected as the best solution.

Criterion	**Option 1**	**Option 2**	**Option 3**	**Option 3**
Initial construction cost	0.392	0.360	0.368	0.320
Level of service	0.255	0.285	0.270	0.294
Proven experience	0.150	0.143	0.145	0.150
Life cycle cost	0.066	0.090	0.080	0.100
Extent of recycling	0.020	0.045	0.043	0.010
Total	**0.002**	**0.923**	**0.906**	**0.874**
Ranking	**3**	**1**	**2**	**4**

The full depth foamed asphalt stabilization option was selected for this road. Localized base repairs were also required in areas exhibiting medium severity alligator cracking. The existing asphalt should be pulverized and stabilized with foamed asphalt to a depth of 130 mm and then 50 mm of HMA surface course should be placed.

8. CONCLUSIONS

The wide range of pavement rehabilitation options currently available are a great benefit to road agencies. The diverse technologies present opportunities to provide very cost-effective preventive treatments and rehabilitation. However, the technologies must be used appropriately and wisely. With the wide choice available it becomes more important that road agencies identify the precise needs of each road to be upgraded. By undertaking a detailed investigation of a road condition and performance history, owners can select the rehabilitation treatments that best address the distresses within the pavement and meet their expectations with respect to in-service performance. Without a rational approach to needs identification and rehabilitation selection, inappropriate rehabilitation strategies will be applied with disappointing and often costly outcomes.

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