British Columbia's Success with Hot-In-Place Recycling – a 25 year History

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ABSTRACT

Traditionally, conventional hot-mix asphalt paving with virgin aggregate sources was the default resurfacing rehabilitation strategy used in British Columbia (BC). With recent trends of rising oil costs, diminishing aggregate sources and the concerns of Greenhouse Gas (GHG) emissions, Hot-In-Place (HIP) recycling has found a place in the options for pavement resurfacing.

Since 1986, the BC Ministry of Transportation and Infrastructure (BC MoT) has been using HIP recycling as one of its pavement resurfacing alternatives. The HIP industry has faced many challenges, ranging from technological to skepticism. Encouraged by the BC MoT, the HIP industry has taken on these challenges and addressed many of them over time. The Ministry's role has been one of providing opportunities for addressing the vision of recycling, reusing and renewing pavements even before concerns with global warming became widespread. The role of the industry has been one to overcome challenges and provide technical solutions that have resulted in an improved and reliable product.

This paper provides an account of the BC MoT HIP experiences, describing many of the technical challenges that the HIP industry has had to overcome over the last 25 years, and concluding with the Ministry's most recent HIP recycled performance experience.

RÉSUMÉ

Traditionnellement, le pavage avec l'enrobé bitumineux à chaud conventionnel avec sources d'agrégats vierges était la valeur par défaut de la stratégie de réhabilitation de la surface utilisée en Colombie-Britannique (BC). Avec les tendances récentes de la hausse des coûts du pétrole, la diminution des sources d'agrégats et les préoccupations des émissions de gaz à effet de serre (GES), le recyclage à chaud en place (RCP) a trouvé une place dans les options de resurfaçage de la chaussée.

Depuis 1986, le Ministère des Transports et Infrastructures de la BC (MoT BC) utilise le recyclage RCP comme l'une de ses alternatives de resurfaçage. L'industrie du RCP a fait face à de nombreux défis, allant du technologique au scepticisme. Encouragé par MoT BC, l'industrie du RCP a appris de ces défis et a traité plusieurs d'entre eux au fil du temps. Le rôle du ministère a été celui d'offrir des possibilités pour aborder la vision du recyclage, la réutilisation et le renouvellement des chaussées, avant même que les préoccupations avec le réchauffement climatique se soient généralisées. Le rôle de l'industrie a été celui de surmonter les défis et fournir des solutions techniques qui ont entraîné un produit fiable et amélioré.

Cet article rend compte de l'expérience des RCP de MoT BC, en décrivant plusieurs des défis techniques que l'industrie RCP a eu à surmonter au cours des 25 dernières années, et il conclut avec la plus récente expérience de performance du recyclage RCP du ministère.

1.0 INTRODUCTION

The Hot-In-Place (HIP) recycling process has many names and is carried out using many methods throughout the world. Not to be confused with Cold-In-Place Recycling, similar recycling processes include those known as hot profiling, heat scarification, thermo-recycling, hot-in-place surface recycling, hot-in-place remixing, and hot-in-place recycling repaving. This paper does not document all the various methods of HIP recycling, but suffice it to mention that there are numerous methods of heating and recycling asphalt in place. This paper focuses on the British Columbia (BC) HIP recycling method, which was uniquely developed in the Province over the last 25 years, consisting of a remixing method.

BC's HIP process today is a pavement resurfacing strategy that is intended to rehabilitate the pavement by treating the top 50 mm of asphalt and mitigating all surface distresses. The service life of the treatment has consistently increased as a result of systematic changes undertaken to the materials, the equipment and the HIP recycling process itself, which results in a new smooth and dense pavement.

The Ministry of Transportation and Infrastructure (BC MoT) has been instrumental in the advancement of this strategy by supporting and funding the initial development of the technology, identifying candidate sites for HIP treatment, and creating specific work programs as well as studying those sites. BC MoT recognized the potential of this technology at that time. Subsequently, BC has realized the additional socio-economic and environmental value of this strategy, by saving asphalt and aggregate already in place, committing to sustainable solutions, and continuing to work alongside of industry. BC has continued with the development of asphalt testing standards and specifications to meet desired HIP end product results. Not only is BC continuing to use this strategy and technology, but is also achieving comparable pavement life cycles at a lower cost as compared to Hot Mix Asphalt (HMA) because, in BC MoT's experience, the quality of the HIP end product approaches that of HMA.

2.0 BACKGROUND

2.1 Building BC's Highways

It is difficult to envision that as recently as 1950, British Columbia had few paved highways, as did most of Canada. Most of the highways that we know today were constructed and opened to traffic in the 20-year period from the late 1950's through to the early 1970's. During those 20 years, the economy was strong and oil prices were both consistent and economical. BC constructed most of its 56 provincial numbered corridors during this period. When the TransCanada Highway (TCH) opened in 1962 through the BC-Alberta Rockies, it was a celebration for both the Province and the Nation. The TCH was the longest paved 2-lane highway in its day at 7,900 centreline km [1].

Today, the BC MoT is responsible for the maintenance and rehabilitation of approximately 92,000 lane kilometres of provincial highways, as well as both paved and gravel roadways in the unincorporated areas of the Province. Of this total, approximately 25,000 lane kilometres form the provincial highway network, situated throughout the province including those highways designated as National Highways, such as, the Trans-Canada
Highway 1 (TCH), the Crowsnest Highway 3, the Yellowhead Highway 16, and the Cariboo Connector Highway 97, (with the exception of the Alaska Highway). These highways are among the provincial numbered highways that the MoT is responsible for, as shown in Figure 1.

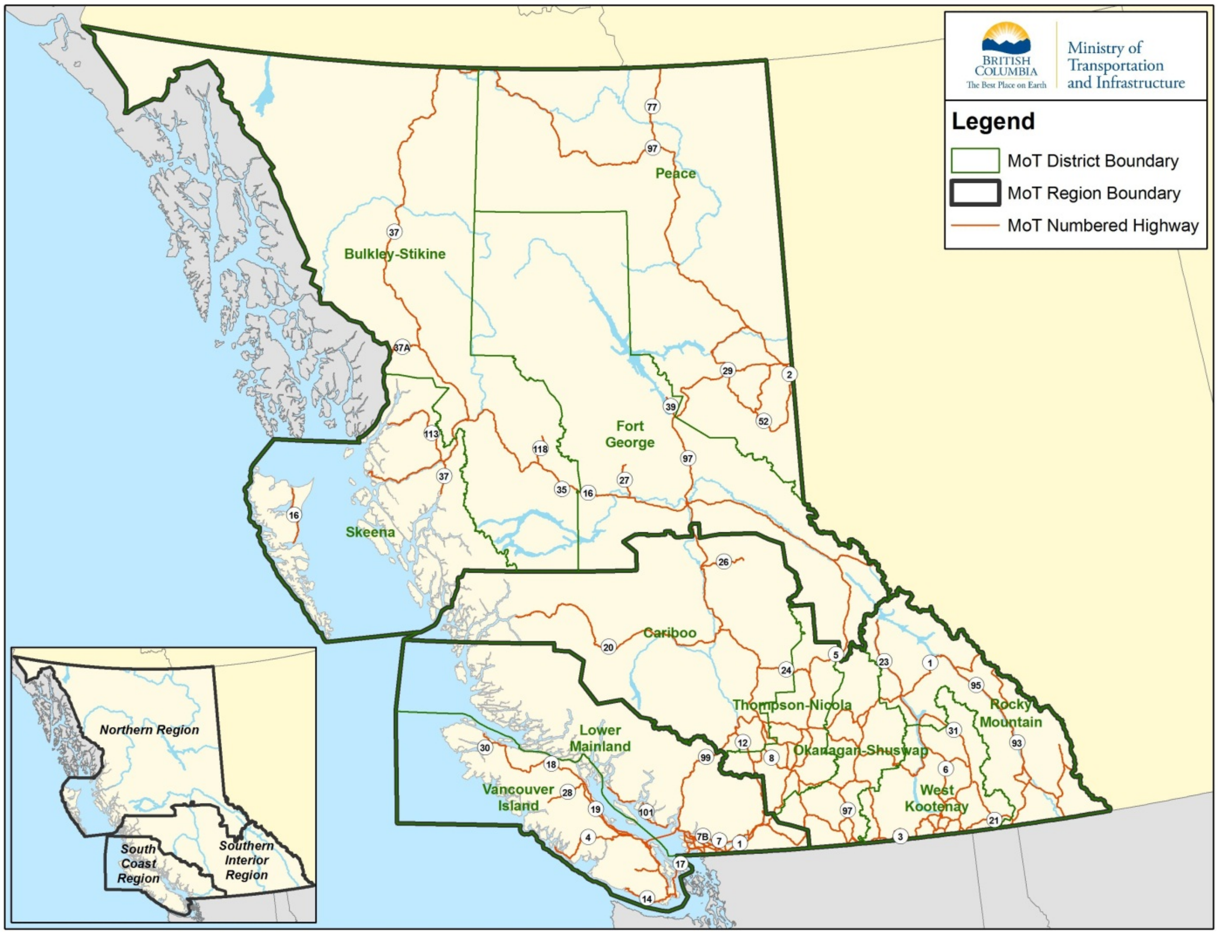


Figure 1. Provincial Map Depicting Current Numbered Routes in BC

2.2 Rehabilitation of BC's Highways

During most of the 20 year construction period from the late 1950's to the early 1970's, asphalt technology was developed for new designs. As the newly constructed network began to age, pavement cracking, rutting and other distresses became an increasing reality. Pavement distresses began to be measured in the 1970's. Over the next 20 years, by the late 1970's, 1980's and into the early 1990's, the first highway locations requiring rehabilitation appeared and rapidly increased in numbers.

Deterioration of pavement condition was becoming a common theme throughout the world and in BC it was becoming a significant concern. Measuring and tracking pavement conditions became an important part of the preservation and cost effective management of a road authority's assets. By 1986, the International Roughness Index (IRI) was adopted as the most commonly used indicator of pavement condition.

2.3 The World Economy

In 1973, the first oil crisis caused significant economic challenges throughout the world which would continue through to 1979's second oil crisis. Figure 2 shows the nominal "oil prices from 1861–2007, showing a sharp increase in 1973, and again during the 1979 oil crisis. The orange line in 2008 dollars has been adjusted for inflation [2]. By 1974, the price of oil had quadrupled. This, along with other economic crises at the time was the beginning of a long lasting turn in the economy, even though oil prices began to drop generally from 1980 to the 1990's.

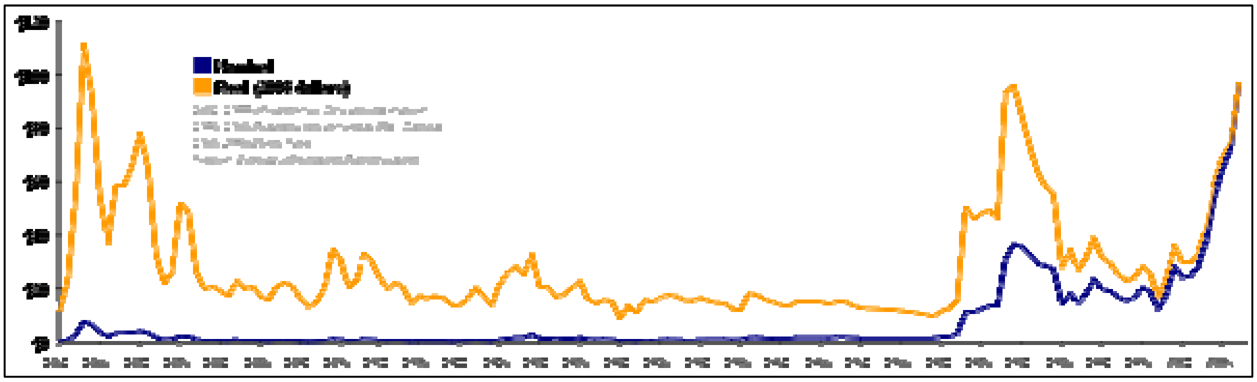


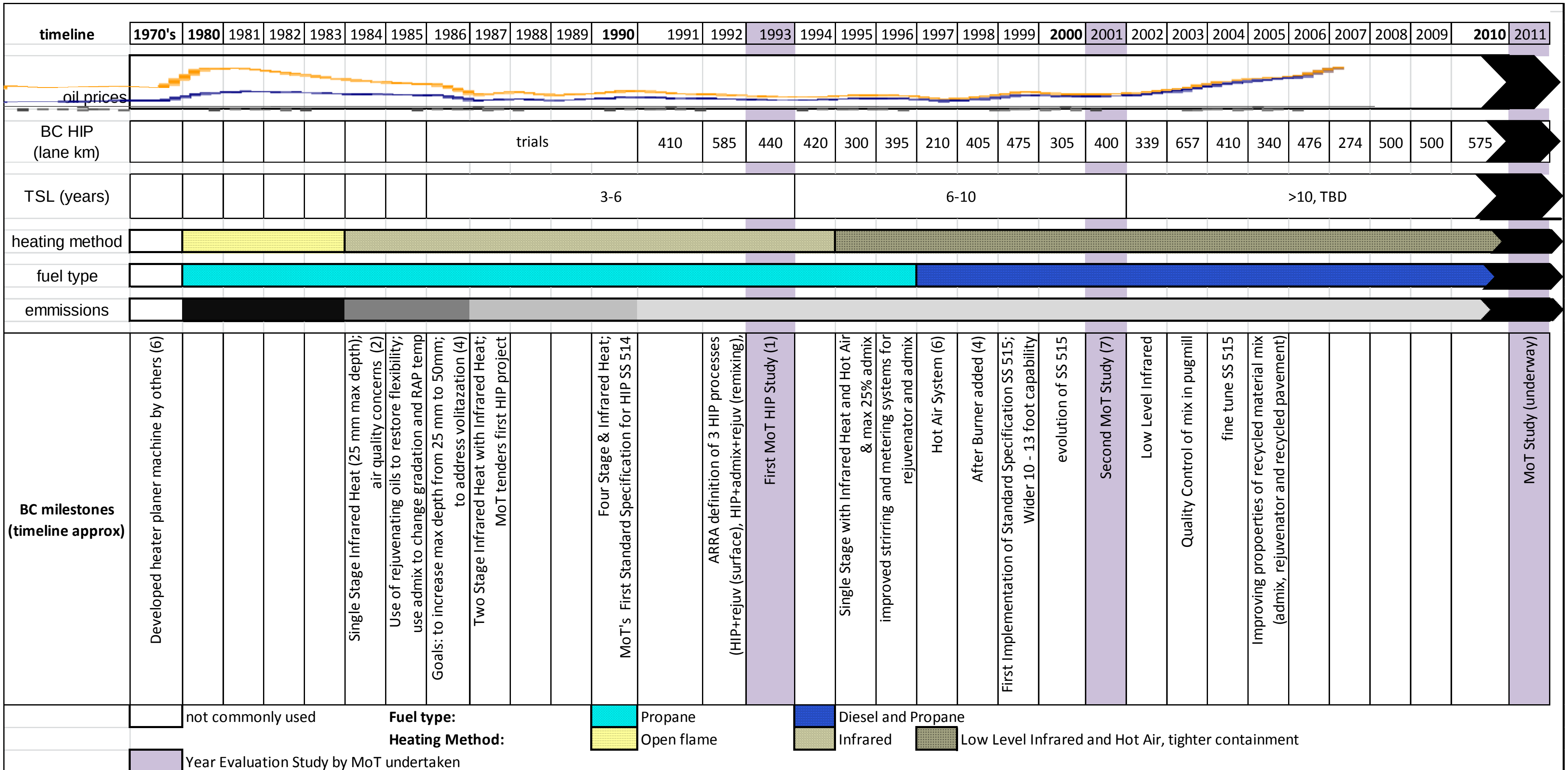
Figure 2. Oil Prices, 1861 to 2007

3.0 HOT IN PLACE (HIP) RECYCLING

3.1 Overview

In BC, the first few candidates for pavement rehabilitation were typically overlaid or milled and inlayed with virgin HMA. BC MoT, faced with a rapidly maturing highway network, first considered the concept of recycling road asphalt in place in the early 1980's. The concept was simple; heat the pavement in place in order to 1) soften the asphalt cement to facilitate milling and minimize aggregate breakage, 2) protect the quality of the aggregate and enable re-use, and 3) to facilitate better mixing of the milled product with rejuvenators and admix. At the start, challenges were prevalent requiring many trials and experimentation to try to get the process to work just right. Technical challenges that had to be overcome included severe smoke issues and air quality concerns, as well as concerns with the recycled product and the process itself.

The late 1970's to the mid 1980's was a key period for the development and implementation of HIP. According to Eco Pave, by 1984 the Johnson Recycling [3] machine had made its first appearance, but clearly visible black emissions made the process unacceptable. Yet, the concept of recycling made a lot of sense, and MoT continued with trials in the early 1980's. Spurred on by the entrepreneurial nature and enthusiasm of the BC road building industry that was willing to make modifications to the paving equipment to improve the quality of emissions, the BC MoT tendered its first HIP project in 1987. Figure 3 shows a summary of the HIP development timeline.



References used to produce this figure:

(1) Haughton, D. and Terra for MoT, Perfomrance & Economics of HIP Recycling in BC (1993)

(2) Oliver, M, BC MoT, interview Victoria, BC (2011)

(3) Pilkington, Ian, BC MoT, interview Victoria, BC (2011)

(4) Terrel R, Hicks, RG, Viability of HIPR as a Pavement Preservation Strategy (2008)

(5) Baker, C, Dubets, C, Freeman, D, Grainger, M and Miller T, An Environmental Reivew of HIPR in BC (1998)

(6) Terrel, R., Epps, J, Joharifard, M, and Wiley P, Progress in HIPR Tecnology I CAP (1997)

(7) EBA for MoT, An Update on the Perfomrance and Economics of HIP Recycling in BC (2001)

Figure 3. The History of BC's Success with HIP Recycling.

During this period, BC MoT proceeded with caution, continuing to identify possible locations in the provincial network that appeared to be ideal candidates for HIP. With the capabilities of heating and milling restricted to 25 mm, the selection of candidate projects was limited to asphalts that were still in fair condition, and had mostly minor severity cracking.

By 1987, RW Blacktop had produced the first BC designed/built two stage infrared HIP processing equipment that allowed a maximum of 25 percent admix to be introduced to the recycled asphalt. Admix consisted of virgin asphalt added to the 100 percent recycled asphalt during the HIP process. The admix criteria are specified based on the recycled asphalt properties and are discussed below. The BC MoT continued to monitor the results of these asphalts, gradually seeing an improvement in performance life.

Early results showed the treatments were useful for deferring an overlay or mill and fill for a short amount of time. The first project constructed in September 1987 was followed by a 50 mm HMA overlay in 1990. The second HIP project constructed in 1988 was also overlaid with 50 mm HMA by 1992. The benefits were quantifiable at the project level and especially meaningful at the network level where so many other re-paving candidate locations appeared simultaneously. While, during this stage, HIP often was followed by an overlay or graded aggregate seal [5], some were not overlaid at all and used the HIP as the riding surface.

The service life was then assessed from a point of view of additives incorporated into to the recycled asphalt. Different levels of rejuvenating agents (Cyclogen L being the most common product used) were considered as was the addition of virgin asphalt mix, at a rate of 10 percent. Initially, the rejuvenating agent was added to compensate for the additional aging that may have occurred due to the heating process of HIP. Results from tests undertaken in 1993 confirmed that the “temperature susceptibility of several pavements [treated by HIP recycling] had been affected by the process” based on Penetration Viscosity Numbers (PVN) determined before and after HIP treatment.

Some locations were more successful than others, lasting from 3 to 6 years [4]. By 1993, it was recognized that if surface temperatures could be lowered, resulting in less oxidation, the product may be further improved over the process being used at that time.

Most HIP equipment modifications took place between 1987 and 1995, by RW Blacktop, Artec and Pyrotech. In 1987, RW Blacktop introduced the two-stage infrared heat machine and in 1990, Artec introduced the four-stage infrared heat machine with both improving heat transfer to allow recycling milling depths to 50mm. Then Pyrotech also introduced a two-stage infrared with emissions incinerator and finally in 1995, Artec produced the single-stage hot air/infrared machine that resulted in less oxidation of the recycled material though treatment depths were in the range of 40mm. The returned hot air was incinerated along with the smoke and emissions.

The BC MoT was serious about HIP and by 1991, the BC MoT had undertaken HIP on 485 lane-km of highway.

Since then, nearly 8,000 lane-km more of HIP has been undertaken. HIP is considered a pavement rehabilitation strategy in its own right. In general terms, the improved process used today is referred to as a multi-stage process as it consists of a heater/miller first stage that heats and mills the first layer of asphalt typically to a depth of 12.5 or 25mm per stage. Similarly, the subsequent stage consists of an identical heater/miller that sequentially heats and mills the asphalt typically to a total depth of 50 to 60mm. This is followed by the remixer unit, which consists of equipment in series to bring together the admixture, rejuvenator and recycled asphalt prior to laying down the recycled mix with the final stage which is a conventional paver, followed by typical compaction and finishing rollers. The production rate is about 4 km per day using this non-stop process.

Between 1993 and 2001, most of the important issues affecting HIP recycling had been addressed. The in-place density, smoothness rating, segregation, and surface texture were at acceptable levels according to BC MoT. Centreline and shoulder longitudinal joints had also been improved. The material properties had been addressed, the minimum processing depth increased, and the temperature of screed and overheating of recycled material was no longer an issue. In addition, the mixing of the admixture and rejuvenator with the recycled pavement was also improving as was the production rate.

By 2001, the performance of HIP recycling as a pavement resurfacing option was yielding reliable and consistent results. The BC MoT concluded that results varied by region, where climate, traffic types and traffic volumes were significantly different. The HIP study undertaken in 2001 [5] reported that according to MoT's experience, adding admix (up to 20 percent) increased the performance to 6 or 7 years while adding rejuvenator increased it to 7 or 8 years. Adding rejuvenator in a Wet Freeze zone achieved an 8 year Treatment Service Life (TSL), while the same in a Wet No-Freeze zone, increased the TSL to 5 or 6 years on average. Adding both rejuvenator and admix to a project located in a Wet No-Freeze zone yielded a service life of 9 or 10 years on average.

Many projects that had just been rehabilitated at the time of the 2001 study were not included in the figures above; however, a follow up study was undertaken as background to this paper with over 30 projects reviewed. IRI data had been collected for approximately every two years. A study of the IRI changes over time confirms the performance life figures quoted above and in fact, exceeds them in some cases. It is worthwhile to note that for the first time the MoT has considered the repeated application of the HIP process at the same location. In the case of four project locations in the study sample, the MoT is proposing the "re-HIP" of the road section. The performance of the re-HIP recycled section will be of significant importance and will be reported on in a few years' time as these projects are just in the process of being implemented.

3.2 Traffic Characteristics

It is common knowledge that traffic volumes, and in particular truck traffic, have a detrimental effect on pavement life. However, what may not be commonly known are the changes that trucks have experienced from the 1960's to 1990's. Over this time period, two parameters have increased significantly; truck size and truck length. In 1962, when the Trans-Canada Highway opened, the maximum Gross Vehicle Weight (GVW) was 36 tons (33,000 kg). By 1993 this maximum legal GVW had increased to 69 tons (68,000 kg). This represents an increase of 33 tons (29,000 kg), nearly doubling the allowable vehicle weight. Similarly, truck dimensions and hence loading characteristics on pavements, have also changed during this time. Truck length increased from a maximum length of 50 feet (15 metres) in 1962 to a maximum length of 82 feet (25 metres) for a B-train double heavy truck by 1993. This represents an increase of 32 feet (9.75 metres) or 64 percent in length over that same 30 year period [2].

While traffic growth is generally accommodated in the asphalt design, it is nearly impossible to predict changes in the future configuration and maximum GVW for the trucks that will drive the highway network 20 years from today. Hence, not only are overall traffic volumes increasing, and truck traffic growing as a proportion of annual average daily traffic, but the trucks are also getting larger and heavier themselves, thereby affecting pavement life. There is no indication that this trend will not continue into the future.

3.3 Pavement Management and Network Level Studies

By 1993, the BC MoT began to consider the network level condition establishing a province wide provincial highway data collection program that included International Roughness Index (IRI) and distresses. This provided BC MoT with important information for managing its network of nearly 25,000 lane km of primary and secondary numbered routes, in addition to nearly 50,000 lane km of paved local roads.

MoT also adopted a pavement management system and by 1996, formed the MoT's Highway Rehabilitation Section to manage the rehabilitation of its assets, including pavements. Pavement management and preservation was now rooted in the ministry business model. Collecting roughness and distress information at the network level provided MoT with the ability to monitor and predict the network pavement condition, and also identify priority locations for rehabilitation. Continuous enhancement to this data collection process, including obtaining strength information at the network level, may provide an improved methodology to determine the locations suitable for various treatments. Additional testing at the project level follows the network level evaluations to determine the most appropriate treatment at a given location.

Generally, MoT's practice when selecting projects is to balance risk while considering a cost effective and proactive response as follows:

- Rehabilitation of assets that are a safety concern is always undertaken first.
- Whenever possible, assets that can be rehabilitated at least cost and greatest benefit are scheduled before those in worse condition so that overall costs can be minimized;

The result is the condition of a paved network somewhat predicated on available resources and decisions made. Therefore, having the ability to forecast condition provides a good understanding of the level of resources that should be required in order to predicate the outcome condition and manage the pavements pro-actively.

The process to determine the suitability of HIP for a candidate location was the same process that was applied to the selection of other resurfacing or rehabilitation alternatives, including project level testing. In addition, similarly to paving projects, the MoT has developed standard specifications for HIP projects and has been able to achieve a standard of excellence similar to newly paved roads. These are described in the following sections. In addition, it was recognized that if the depth could be increased from 25 to 50mm, then the list of candidate locations would increase. While the concepts of less heat and more depth are diametrically opposite, the industry has risen to the challenge with increased depth now viable.

3.4 Selection Criteria for HIP Suitability

3.4.1 General Criteria

Selection for HIP suitability is typically not completed based on any single criteria or in isolation, but rather through consideration of several criteria and an assessment of the risks associated with those criteria. In this sense, there is both a subjective (criteria based) and objective (risk based) component to the selection of HIP.

As a starting point, it is generally assumed that the resultant HIP mixture with admixture will be more oxidized (stiffer asphalt binder) and tighter (finer gradation) than a conventional virgin MoT mixture such as the Class 1 Medium Mix with 80-100 penetration graded asphalt cement (used in the Southern regions) or a 120-150 or 150-200 penetration graded asphalt cement (utilized in the Northern regions). Also, the treatment depth for HIP will be limited to about 60mm.

Structural strength, roughness and surface defects are the three most common physical criteria used to represent the parameters for selection of HIP suitability:

3.4.2 Structural Criteria

Pavement strength is one of the most important selection criteria for HIP suitability. Similar to other pavement rehabilitation methods, such as conventional mill and inlay strategies, the pavement to be rehabilitated must not have strength deficits that exceed the additional strength gain of the proposed treatment. HIP is expected to provide only nominal structural improvement to an existing pavement. From an American Association of State Highway and Transportation Officials (AASHTO) structural design perspective, a 50 mm HIP with 20 percent admixture (total 60 mm treatment) would provide about Sn= 20 mm of total strength, however, because you are initially removing existing pavement which contributes some strength, the net structural benefit is in the range of Sn = 5 to 10 mm or the equivalent of 12.5 to 25mm of additional asphalt pavement strengthening. Therefore, roadways requiring additional asphalt strengthening greater than 25mm are less suitable for HIP unless an overlay on the HIP is proposed. Large strength deficits in pavement cannot be mitigated by HIP and the performance of a HIP treatment would be significantly compromised if applied to a roadway with low strength. As such, strength testing by FWD or other methods is a standard investigative tool for determining HIP suitability.

3.4.3 Roughness Criteria

Relatively smooth initial conditions are preferable. Pavement surfaces that are too rough (IRI > 2) likely have other underlying issues (e.g. structural) and would not make suitable HIP candidates. Additionally, BC has an End Product Specification (EPS) criterion for which smoothness tolerances need to be met. A relatively thin treatment (60mm), such as HIP, provides limited opportunity to improve smoothness. It should be noted that the smoothness criterion is routinely exceeded on HIP projects, which may be partly owing to the HIP process that has a continuous supply of hot mix product to the paver.

3.4.4 Surface Defects

Cracking, raveling and rutting are the surface defects often associated with a particular treatment. While cracking and rutting depths are a concern with HIP recycling due to its typical treatment depth of 50-60mm, raveling on the other hand is a surface defect that a HIP project would be able to correct easily.

Moderate and high severity cracked pavements should be avoided, however the nature of the cracking is also important to consider. As a surface rehabilitation treatment, HIP is not considered an effective mitigation of existing cracks that have propagated from the bottom up. The relatively thin treatment depth and stiffer nature of a HIP pavement also makes thermal cracking problematic as HIP would not be expected to offer much mitigation to prevent the return of thermal induced cracking. Thicker pavements (>150mm) with existing bottom up cracks would also not be well mitigated by a HIP treatment, particularly if the treatment thickness represents only 1/3 or less of the total asphalt pavement thickness.

Raveling of the surface aggregates would not preclude HIP from being selected. On the contrary, a raveled pavement may be an ideal candidate for HIP as the poor texture of a raveled pavement would be replaced by a tight surface texture provided that the other asphalt pavement attributes (e.g. binder penetration, gradation of aggregate, etc.) were favorable for re-use in the HIP mixture. The other attributes of the existing asphalt mix would need to be verified through laboratory testing.

Pavement surfaces exhibiting low to moderate rutting are usually still considered candidates for HIP. Similar to the selection criteria for conventional mill and inlay, the potential depth of the rutting in the asphalt will be the determining factor. If the influence of the rutting is presumed to be deeper than the proposed treatment depth (e.g. 50mm milling) then HIP would likely not be suitable as some of the rutted pavement mixture may still remain after the treatment. In cases where there is a history of rutting or the potential for rutting exists (such as climbing lanes or deceleration zones), it may be beneficial to select HIP, as the stiffer nature of the mixture may provide some additional rut resistance.

The above noted items represent the first set of criteria to be assessed when determining HIP suitability. These specific criteria are physical properties that would be assessed through either network and/or project level pavement investigations. Each criterion provides some objective understanding of the pavement to help determine suitability; however, the importance of any of the given criteria also depends on the owner's priorities and risk tolerance for future mitigation. For instance, the need to mitigate raveling or rutting may outweigh the risk of thermal crack potential, therefore an owner may elect to proceed with HIP understanding that thermal cracking could occur and be addressed by other mitigation such as crack sealing, or HIP may be part of a phased rehabilitation strategy and the performance expectations changed.

The next set of criteria for HIP suitability selection involves testing the material properties of the pavement to be rehabilitated. In this context, HIP is different than a conventional mill and inlay as HIP requires the existing asphalt pavement to have certain material qualities present in order to be effective in the recycled mixture. Conventional mill and inlay does not require the re-use of the milling materials.

The asphalt pavement to be rehabilitated needs to have several key physical properties within acceptable tolerances before it would be considered suitable for HIP. Existing pavements with asphalt cement content either too high or too low, overly hardened asphalt binder, or with high amounts of fines (material passing the 0.075 mm sieve) are not considered suitable candidates for HIP, however, minor variances in these properties can be corrected through the addition of admixture.

Once the existing pavement properties are understood, admixtures can be formulated to bring those key properties within acceptable tolerances. The existing technology allows the addition of a maximum of about 30 percent admixture (virgin mix). The properties of the existing pavement therefore have a significant impact on the quality and the performance of the final recycled mix and the admixture has limited opportunity to correct the shortcomings of poor quality pavement.

It is also understood that the HIP process itself age hardens the existing asphalt cement through the heating process, as well as generates additional fines through the milling process. As such, samples taken from pavement to be rehabilitated have additional process-induced impairment that will occur and this needs to be estimated so that the admixture can be designed to meet the targeted requirements of the final product. Therefore, the first step to understanding the properties of the existing pavements is to retrieve representative samples from the project roadway.

3.4.5 Sampling

The frequency of sampling is dependent upon a number of things including the length of the project roadway and an understanding of the pavement history. However, representative samples are typically obtained at a frequency of one sample (core) per centreline-kilometre of the project roadway. Uniformity of the pavement is a key factor in determining the number of samples required. Statistical relevance is also a motivating reason to adjust the number of samples required.

The number of samples acquired will also change depending on the size of the cores obtained, as sufficient material needs to be obtained at each sample site in order to complete requisite testing. Preference is given to 150 mm (6") diameter cores, as they will typically yield enough material (based on a 50mm depth) to satisfy mix quantity requirements for various required laboratory tests.

Once core samples have been retrieved, they should be visually inspected to determine the thickness of various pavement layers present and to determine the presence of possible paving geotextiles and other reinforcing membranes such as glass grids. The cores should also be evaluated to determine the presence of stripping, free asphalt or other discrepancies that could be readily identified visually. After the visual inspections, the cores should be trimmed to the target rehabilitation treatment depths. The trimmed core representing the thickness of proposed treatment should then be tested to determine the bulk specific gravity of the in place mixture.

3.4.6 Laboratory Testing

Samples are tested in the lab for the following properties;

- Asphalt cement content;
- Gradation of aggregate;
- Penetration of the recovered asphalt cement;
- Maximum theoretical relative density of the mix (MTRD or Gmm); and
- Percentage of the aggregates with two or more fractured faces.

The in-place air voids at each core location should be calculated from the MTRD and the bulk specific gravity of the core. The various test results should then be evaluated to determine the consistency of the asphalt mix within the project limits and the suitability for HIP.

As noted, asphalt mixes with too much or too little asphalt binder, stiff binders (low penetration values) or with high amounts of aggregate material passing the 0.075 mm sieve (# 200 sieve) are not considered suitable candidates for HIP, particularly if they are at the extreme levels that would have no opportunity for correction by the admixture.

Typical discrepancies of the key properties and the potential corrective action of the admixture as related to asphalt content, gradation, penetration, volumetric properties and percentage fracture are discussed below.

3.4.7 Asphalt Binder Content

Minor adjustments in the asphalt content could be made by adjusting the asphalt content in the admixture. However, if the asphalt content in the existing mix is either relatively high or low, it may not be possible to completely correct the problem owing to the limit on the maximum addition rate (30 percent) of admixture. Typically, existing pavement with asphalt content of less than 4.5 percent and more than 6 percent by weight of the asphalt mix cannot be corrected by admixture alone and are therefore not considered suitable for rehabilitation using HIP.

3.4.8 Gradation

Target gradations can typically be achieved by adjusting the gradation of the admixture. The HIP process generates approximately 1.5 percent fines (material passing the 0.075 mm sieve), which needs to be accounted for during the blending and development of the admixture gradation. Existing asphalt pavements with more than 7 percent fines will result in recycled mixes with slightly higher fines content.

If the existing asphalt mix has a fine gradation and/or higher fines content, then admixtures with relatively coarser gradation such as Open Graded Friction Course (OGFC) gradation can be used as admix to correct the gradation and improve the air voids in the mix. Similarly, if the existing asphalt mix has a coarse gradation, fine graded admixtures such as BC MoT’s fine graded asphalt mix is used. More often, effort is made to use the regular mixes such as a Class 1 Medium Mix as an admix to simplify construction. Sometimes Class 1 Medium Mixes are modified to have a custom gradation to correct the discrepancies in the existing in-place asphalt mix.

3.4.9 Penetration

Asphalt cement in the in-situ pavement oxidizes and hardens with aging as it gets exposed to sunlight, water and air. The hardened binder can be softened to some extent by the addition of a “rejuvenating agent” or the use of softer asphalt cement in the admixture, and both of these approaches are typically employed on a regular basis. However, existing pavements having asphalt cement with penetration values of less than 25 dmm, are typically considered unsuitable for HIP, as the asphalt in the existing mix is considered too hard to be softened even by the maximum recommended dosages of rejuvenation agents or softer asphalt cement in the admixtures.

Blending charts and monographs are used to predict the outcome penetration values following HIP.

3.4.10 Volumetric Properties

Volumetric properties such as air voids in the recycled mix can also be altered slightly by adjusting the gradation of the admixture. If the in-situ air voids determined from the sample cores is less than 1 percent, the existing mix is considered unsuitable for HIP as the resulting pavement will be susceptible to rutting and bleeding. For existing pavements with air voids less than 1 percent, adjustments in the admixture gradation are unlikely to be effective to mitigate the low air voids.

3.4.11 Percentage of Fractured Aggregate

Finally, if the percentage of the fractured aggregates in the existing pavement is lower than the target values of 85 percent, it can usually be corrected by increasing the amount of fractured aggregates in the admixture.

3.4.12 Past Experience

All in all, based on what has been observed from the numerous projects recently completed, the aggregate gradation and the penetration of the asphalt cement are the most important mix properties that dictate the feasibility of the existing pavement for HIP. Achieving the other mix properties such as air voids and compaction is typically not a problem. Smoothness of the recycled pavement depends on the construction practices adopted during the construction and is also a function of the smoothness of the original pavement.

Typically, attempt is made to bring the properties of the recycled mix as similar as possible to the mixes that would normally be used for that roadway (i.e. a 16 mm Class 1 Medium Mix for majority of BC Highways). Different gradations (Class 1 Medium Mix, modified Class 1 Medium Mix, MoT's Fine Graded Mix, Graded Aggregate Seal Coats, Modified Graded Aggregate Seal Coat gradations etc.) have been used for the admixtures. Similarly, various grades of asphalt cements (80-100, 120-150, 150-200 and 200-300 penetration graded asphalt cements) have been recently used during the HIP projects.

Typically, Cyclogen L®, at an addition rate of 0.3 percent by weight of the mix, is used as a rejuvenating agent. Variability in the asphalt mix within the project limits also has a significant impact on the success of the HIP treatment. If the asphalt cement in the existing mix is too hard, then the recycled pavement will likely have premature raveling. Existing cracks reflect through the recycled pavement surface (similar to mill and inlay or other thin treatments) and crack sealing of the reflective cracks should be anticipated and included as part of the future rehabilitation strategies.

3.5 MoT Standard Specifications for HIP

The BC MoT issues Standard Specifications (SS) for highway construction. Paving specifications have been available for a long time, but could not be used for HIP. Shortly after RW Blacktop of Kamloops developed the first BC designed/built two staged heating process for selected HIP projects in the summer of 1987, MoT developed Special Provisions for its HIP contracts that would specify the equipment requirements based on what was then available. Eventually, these evolved together with the capabilities of the industry. Once the HIP process was acceptable to the MoT, Standard Specification SS 514 for HIP was developed that was very method-specific, reflecting the industry capability at that time.

The SS 514 consisted of specifications for materials, equipment, construction, measurement and payment. The materials included rejuvenating agent requirements and asphalt admixture details. Rejuvenating agents were used to rejuvenate the HIP milled asphalt. Early on, the use of rejuvenating agents was more effective than low viscosity asphalt cements. The small percentage of rejuvenating agent made more sense to conserve, enhance and reuse the existing asphalt cement in the milled asphalt material. The process and results developed along with improvements to the equipment and rejuvenating agent. By varying amounts of Class 1 Medium Mix and Coarse Mix with varying Asphalt Cement (AC) amounts, these admixtures were added to the HIP process to optimize the HIP. Admixture amounts and AC binder levels were also defined for the HIP paving work.

The description of the equipment was specific to that used for processing and for proportioning of the rejuvenating agent into the mix. The capability of processing to a depth of 50mm yielding an average mass of 120 kg/m^2 along the width to be heated and the working minimum temperature are all specified. The rejuvenating agent requirements included all associated ASTM International (ASTM) tests and specifications. Construction specifications were those related to the work area and recycling area, as well as compaction and finishing details. Measurement specifications referred to the area to be recycled, litres of rejuvenating agent used and tonnes of admixture. Finally, these measured quantities formed the basis of the payment specification.

As the MoT was moving their paving specification to End Product Specifications (EPS), starting in 2003, SS 515, an EPS for HIP replaced SS 514. These new specifications differentiated from method and prescriptive requirements and consisted of two parts. First, SS 515 required the Contractor to undertake the quality control with the MoT responsible for undertaking quality assurance. Quality control requirements and guidelines were provided, and generally defined in terms of testing reports, minimum acceptable construction practices, standard sampling and testing procedures and frequency for admix and recycled pavement. Second, SS 515 introduced payment adjustments for density and smoothness to encourage the Contractor to achieve certain performance measurements or alternatively receive deductions for poor work performance. Then, acceptance and rejection criteria were also defined. Finally, payments at unit prices plus payment adjustments were applied according to SS 515.

As part of the overall process, the MoT works with industry stakeholders, meeting after every construction season. Together they review what specification processes are effective and which could be improved. This partnership has proven to be fundamental for the ongoing development of the HIP industry in BC.

3.6 Costing Information

The MoT is currently undertaking a review of the most recent HIP projects. This review included the costing of 23 HIP projects undertaken between 2010 and 2011. The lengths of these projects ranged from 19.5 to 109 lane-kilometres and were located throughout the province. They also ranged in complexity. In some cases, HIP was undertaken in the bottom lift after milling in order to reach deeper crack remediation. In other cases, where strength and drainage were sufficient, HIP recycling was performed. This treatment has become the default whereas in the past HIP was more typically used as lower lift treatment, HIP has now been increasingly used as the riding surface. Early on HIP was commonly followed by an overlay, this is now changed whereby HIP is now considered the rehabilitation treatment of the riding surface without overlay.

The projects were often complex including utilities removal or relocation, curb and gutter upgrades, median and road-side barrier improvements, etc. When these costs for non-HIP activities were extracted from the total contract cost, then the HIP only costing could be estimated. It was found to be approximately 50 percent of a mill and fill cost per square metre, on average.

3.7 Environment

The environmental benefits relating to HIP are quantifiable in terms of Greenhouse Gas (GHG) emissions. They are the result of re-use of in-situ asphalt and gravels. The production of additional asphalt and additional gravel, the transporting of materials to the asphalt plant, and subsequently transporting the asphalt cement to the site are activities that are mostly eliminated. In addition, because the millings are fully recycled in place, stockpiling of millings is not an issue.

With respect to the generation of greenhouse gas emissions, the HIP process, with the exception of the admixture portion, avoids a majority of the processes associated with paving, including the production of the aggregates and additives, the energy to produce the hot mix asphalt, and finally the transporting of the mix. While the BC process uses up to 20 percent admixture and generates some of these associated emissions, more than 80 percent of the recycled mix is utilized as in-situ materials.

Most conventional paving projects have emissions from paving plants and crushing operations, as well as emissions from transport trucks that must be accounted. As a result, in MoT's experience, compared to other more conventional paving projects, HIP generates about 30 to 40 percent less GHG emissions. This assumes that all processes and all materials produced are taken into consideration, and is dependent on haul distance. This results directly from the reduction of non-renewable aggregate resources and asphalt cement quantities used in the rehabilitation process by recycling 100 percent of what is in place.

It may appear that the GHG emissions generated by the HIP equipment are significant given that the entire process occurs on the roadway. However, as noted earlier, the HIP process has evolved significantly over the last 25 years and the quality control process has mitigated the emissions levels to acceptable levels, reducing overheating significantly. The heating of asphalt binder or crack filler or even a patch is random and much localized in nature and tends to generate unwanted smoke.

In addition to this, the HIP recycling process also has GHG emissions savings due to effects on traffic. Faster HIP production rates result in about 75 percent less lane closure time. Production rates for HIP are up to 4 km/day whereas those for mill and fill are up to 1 km/day. As a result, additional GHG savings would be materialized from users, depending on the level of traffic volumes on the highway being rehabilitated.

Finally, additional GHG savings occur as a result of the reduction in the necessity to move and store millings created during the mill and fill process.

4.0 CONCLUSIONS

Although the Hot-In-Place (HIP) process has many names and is carried out using many methods throughout the world, BC's HIP process today is a unique pavement rehabilitation strategy that is intended to increase the pavement's service life by treating the top 50mm of asphalt and mitigating cracking.

Given that most of BC's 56 provincial numbered highways were built over a relatively short 20-year period, the management of pavements has left a bow-wave effect, where many locations warranting resurfacing were coming due at the same time. The inclusion of HIP as a pavement treatment has given the BC MoT a cost effective method of spreading out rehabilitation needs to better match available resources.

Since 1986, the MoT has been using HIP recycling as one of its pavement resurfacing alternatives. In the last 25 years, the HIP industry has faced many challenges, ranging from technological to skepticism. Encouraged by the BC MoT, the HIP industry has taken on these challenges and addressed many of them over time. The BC MoT's role has been one of providing opportunities for addressing the vision of recycling, reusing and renewing pavements even before concerns with global warming became widespread. The role of the industry has been one to overcome challenges and provide technical solutions that have resulted in an improved and reliable product.

The service life extension has been increased since the early trial days from 3 to 6 years to most recently, up to ten years, and perhaps even longer. In BC's experience, then the project locations were carefully selected and the treatment used the latest technology that controlled the quality of the recycled product, the asphalt condition reset was comparable to that of new HMA. The selected locations must undergo project level testing to ensure 1) material in place is conducive to recycling, and 2) the resultant recycled mix is engineered to contain optimal performance qualities.

This cost effective solution has been applied to more than 30 million square metres of BC's provincial highways and paved side roads to date. With recent trends of rising oil costs, diminishing aggregate sources and the concerns of GHG emissions, HIP recycling has found a place in the options for pavement resurfacing.

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REFERENCES

[1] Morrall JF, McGuire TM. "Highway Improvements to Minimize Environmental Impacts within the Canadian Rocky Mountain National Parks", Canadian Journal of Civil Engineering, 27(3) 523-532 (2002).

[2] Wikipedia. "Energy Crisis", www.wikipedia.com (2008)

[3] Eco Pave Systems. "Ecopaver 400 presentation dec09sm.ppt", www.ecopavesystems.com (2011).

[4] Haughton D, Terra Engineering. "Performance and Economics of Hot-In-Place Recycling in British Columbia", BC MoT, Geotechnical and Materials Engineering Branch, Victoria, British Columbia (1993).

[5] EBA Consulting Engineers. "An Update on the Performance and Economics of Hot In-Place Recycling in BC", BC MoT, Victoria, British Columbia (2001).

[6] Terrel RL, Hicks G. "Viability of Hot In Place Recycling as a Pavement Preservation Strategy", Report Number CP2C-2008-106, California Pavement Preservation Center, CALTRANS (2008).

[7] Baker C, Dubetz C, Freeman D, Grainger M, Millen T. "An Environmental Review of Hot In Place Recycling in British Columbia", Royal Roads University, Victoria, British Columbia (1998).

[8] Terrel RL, Epps JA, Joharifard M, Wiley P. "Progress in Hot In Place Recycling Technology", Proceedings of the Eighth International Conference on Asphalt Pavements (ICAP), Seattle, Washington (1997).

[9] GHG Emission Calculations for sample projects (2007), BC MoT, Climate Action Branch (2008).