A FRAMEWORK TO QUANTIFY THE IMPACT OF COLD WEATHER ON NEIGHBOURHOOD ROAD DEVELOPMENT SCHEDULE

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Abstract: City authorities and roadways agencies in winter regions impose restrictions on neighbourhood roadway construction activities based on severity of weather. The limitations are imposed mainly to avoid inadequate compaction of hot mix asphalt, which results in poor performance of roads. Weather fluctuations during the late-fall season cause delays in work and extend project schedules. As a result, long-term project overhead and idle equipment costs lead to a significant increase in development costs. Meanwhile, there have been examples of successful paving in severe weather using innovative technologies and materials. Accordingly, construction managers must decide based on the cost-benefit analysis between these two options: (i) select an innovative technology to avoid schedule extension, or (ii) wait for the allowable weather. This paper presents a study of the weather limitations on asphalt paving operations, demonstrating application on a neighbourhood road construction project in Edmonton, Canada. It proposes a framework to quantify the impact of these limitations using historic weather data and develops a model of paving work in order to analyze the cost impact of changes in construction schedule to maintain compatibility with the existing paving standard. The outcome of this study can be used to develop an extended model for cost-benefit analysis of a neighbourhood development work.

1 INTRODUCTION

Jurisdictions impose paving restrictions to ensure asphalt performance based on different weather conditions, such as ground temperature, air temperature, precipitation, and wind speed. Many jurisdictions have calendar date restrictions, such as not permitting paving between October 15 and April 15. In terms of climate, Edmonton, Canada is different from most regions in North America and other colder European cities with its low annual average temperature and longer duration of snow cover.

In general, cold weather paving is defined as placement and compaction of hot mix asphalt (HMA) when either the base or air temperature is below 10°C (50°F) (Brakey, 1992). In many geographical areas during the colder season, achieving a desirable level of compaction for HMA with a thickness of less than 50 mm (2 in) is difficult, and satisfying all the requirements of compaction when the temperature is low reduces the available time for paving (Decker, 2006). Furthermore, research conducted on cold weather paving in other cities may not be capable of ensuring satisfactory performance of asphalt in Edmonton. Hence, jurisdictions in greater Edmonton have developed their own roadway design standards and construction specifications by limiting the weather conditions for asphalt casting, where HMA is allowed to be placed only when both the air temperature and wind speed conditions are within a certain limit. The specifications sometimes force construction managers to discontinue paving operation—usually during the early-spring or late-fall when the temperature falls below the minimum limit, resulting in rescheduling of paving work and increasing construction costs.

This paper considers the weather limitations on asphalt paving works in order to find out the reasons behind and the problems associated with asphalt paving standards in greater Edmonton. It proposes a framework to quantify the impact of these limitations using historic weather data and develops a cost model of paving work in order to analyze changes in construction cost and schedule while ensuring the asphalt performance in severe weather.

The following section provides a brief description of the weather limitations and the reasons underlying the asphalt paving standards. Subsequently, the problem and scope of this study are defined. The following sections describe the theoretical basis and methodology, followed by results and discussion.

2 WEATHER LIMITATION ON ASPHALT PAVING

The City of Edmonton imposes restrictions on paving work when rain or snow is imminent or when the surface is wet, ice- or snow-covered, or frozen within 150 mm of the surface to be paved. There are additional weather limitations; for example, for a pavement thickness of 50 mm, when the air temperature is not rising and is below 4°C and the wind speed is higher than 10 km/hr the paving work is restricted. For wind speeds higher than 10 km/hr, the specification imposes a restriction based on a linear correlation between wind speed and temperature. Other pavement thicknesses such as 75 mm must be placed only when the air temperature is rising and is above 2°C, and similarly the specification imposes a restriction based on a linear correlation between wind speed and temperature. The limiting equations for these two thicknesses as derived from the chart of Air Temperature and Wind Limitations on Paving mentioned in the Design Standards of the City of Edmonton are as follows:

[1.1] $T_{air} = 4$; when $0 > W > 10$ (for construction of 50 mm-thick asphalt pavement)
[1.2] $T_{air} = 3/5 * W - 2$; when $10 > W > 20$ (for construction of 50 mm-thick asphalt pavement)
[2.1] $T_{air} = 2$, when $0 > W > 10$ (for construction of 75 mm-thick asphalt pavement)
[2.2] $T_{air} = 2/5 * W - 2$, when $10 > W > 30$ (for construction of 75 mm-thick asphalt pavement)

Where W is wind speed in km/hr and T_{air} is the air temperature in degrees Celsius (°C) (City of Edmonton Transportation, 2012).

Neighbouring cities and counties within greater Edmonton have similar limitations. The City of St. Albert, for instance, discourages asphalt paving when the weather is foggy, rainy, windy, or when air temperature is 2°C or lower. The City of Spruce Grove emphasizes having sufficient daylight hours to complete compaction of asphalt pavement and a temperature of at least 2°C, as well as a dry road surface. The City of Leduc and Strathcona County follow air temperature and wind limitation curves for different pavement thicknesses, using limiting temperature equations which give a linear correlation between air temperature and wind speed, where minimum air temperatures for the two pavement thicknesses mentioned earlier, i.e., 50 mm and 75 mm, are 4°C and 2°C, respectively.

Different studies suggests production or pouring temperature of asphalt as well as standard range of compaction time relating to the air or base temperature. For example, Brakey (1992) has suggested minimum pouring temperatures for different pavement thicknesses as presented in Table 1.

Table 1: Recommended minimum pouring temperatures for various thicknesses (Brakey, 1992)

Base Temp (°C)	Pouring temperature (°C) according to pavement thickness			
	25 mm	35 mm	50 mm	> 75 mm
−7 to 0	-	-	-	141
1 to 4	-	152	146	138
5 to 10	154	149	141	135
11 to 16	149	146	138	132
17 to 21	143	141	135	129

The US Army Corps of Engineers, in association with AASHTO, NAPA, et al. (2000), have suggested available compaction times for different pavement thicknesses in the 'Hot-Mix Asphalt Paving Handbook', considering the time required for cooling to 80°C, which is the minimum required temperature for final compaction of asphalt according to some standards. This information is summarized in Table 2. However, the jurisdictions in Edmonton and the surrounding areas are not specific in relating the temperature to different aspects of asphalt works.

Table: 2 Recommended maximum compaction time for various thicknesses (US Army Corps of Engineers, 2000)

Asphalt temperature during production (°C)	Base Temp (°C)	Available compaction time (minutes) according to pavement thickness			
		25 mm	35 mm	50 mm	75 mm
105	-12 to 15	2 - 4	4 - 6	5 -8	9 - 14
120	-12 to 15	3 - 5	5 - 8	8 - 12	15 - 22
135	-12 to -1	5 - 8	7 - 9	11 - 12	21 - 24
	- 1 to 4			12 - 14	24 - 26
	4 to 10			14 - 16	26 - 27
	10 to 15			16 -17	27 - 29
150	-12 to -1	6 - 8	9 - 12	14 - 15	26 - 29
	-1 to 4			15 - 16	29 - 32
	4 to 10			16 - 17	32 - 34
	10 to 15			17 - 19	34 - 36

2.1 Problems associated with asphalt casting in severe weather

These weather limitations have been developed based on the long-term performance of HMA if casted in severe weather. For instance, since asphalt pavement does not have contraction joints, when the pavement temperature drops quickly to a low temperature, tensile stresses develop along the entire pavement surface, resulting in tensile cracks in the pavement. Low-temperature cracking may not cause a significant problem initially, but cracks tend to become more numerous and wider as time passes and cause a significant performance problem after several years (Walker, 2012). Thermal contraction and volume change occurs along the border layers after the asphalt pouring is completed and the temperature differential between the asphalt layers and the atmosphere is high. However, asphalt pavement loses bearing capacity during spring when higher temperatures soften the asphalt. These factors reduce both the functional and the structural levels of service of pavements (Dore, 2002).

Asphalt experts identify compaction as one of the key factors in controlling the performance of asphalt pavement. The optimum level of compaction of asphalt ensures strength, durability, resistance to deformation, resistance to moisture damage, impermeability, and skid resistance. Achieving good density of the newly placed asphalt ensures all these desirable mix properties. Also, getting the air voids at an acceptable level improves the performance of the pavement, which can be achieved through proper compaction. Lindel et al. showed that a 1% increase in air voids (above the base air void level of 7%) tends to produce about a 10% loss in pavement life (Linden et al., 1989), while non-uniform compaction causes early pavement failure. Retaining the temperature of the asphalt mat until it is compacted is important due to its kinematic viscosity property. According to the temperature viscosity characteristics of various asphalt grades, it has been observed that at high temperatures (near 150°C) asphalts are liquids with similar consistency to water, whereas at an ambient temperature near 20°C asphalts are semi-solid and at low temperatures (e.g., −15°C) they are brittle (Terrel, 1988). Cut-off temperature is the term used to define the temperature at which the asphalt mix becomes so stiff that further compaction becomes inactive. The compaction times between placement and cut-off temperatures for asphalt are approximately the same for almost every grade of asphalt. However, this temperature loss from newly paved asphalt is not only related to air temperature and wind speed; it is also dependent on the thickness and temperature of the new asphalt mat, base temperature, and solar radiation flux (Brakey, 1992). Figure 1 shows the major sources causing the cooling process of newly paved asphalt.

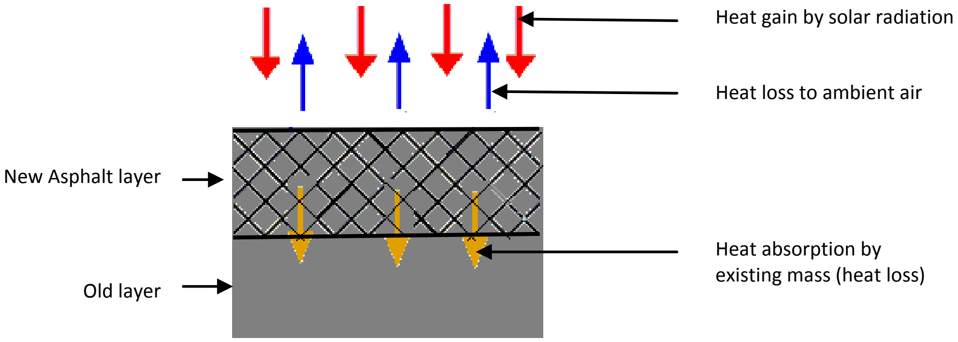


Figure 1: Heat transfer process in newly paved asphalt layer

Rapid heat loss of asphalt during cold weather is a major concern within the paving construction industry. Many studies have been conducted to improve asphalt performance during winter construction focusing on the steps in the pavement construction process, e.g., production, transportation, placement, compaction, and quality assurance. A study conducted in Iowa and Wisconsin, USA has suggested increasing the temperature of liquid asphalt if the air temperature drops in order to compensate for the cooling effect of the outside temperature. However, it also suggested that overheating the liquid asphalt can compromise the integrity of pavement by causing the coating on the aggregate to be thinner. Hence, adjusting the temperature of the asphalt mixture is a critical issue and it must be done in a manner that will not impact the quality of the pavement materials (Benchmark Inc., 2009).

2.2 Scope of study

The weather limitations for Edmonton and surrounding jurisdictions are not specific in terms of required asphalt production temperature or recommended available compaction time. This narrows the window of opportunity in searching for alternative methods or suitable temperatures for asphalt construction. However, this study analyzes the durations of different air temperatures within Edmonton that lie within the range specified in Table 2, and attempts to determine the cost savings associating with relaxing the weather limitations. The study also explores alternative paving methods based on efforts in various cold-climate regions in order to increase the paving season of greater Edmonton, as well as analyzing the expected performance of these alternative in terms of cost efficiency.

3 METHODOLOGY

To develop the methodological framework used to analyze the impact of lower temperatures on road construction schedule, it is useful to begin with a hypothetical situation in which the weather limitation has been relaxed to a certain extent and to determine the corresponding cost savings if the time is used for construction. This study makes a separate effort to find an alternative construction method which is workable in lower temperatures, to determine the additional cost involved with this method, and to compare it with the cost of the current practice. The detailed methodological flowchart is provided in Figure 2:

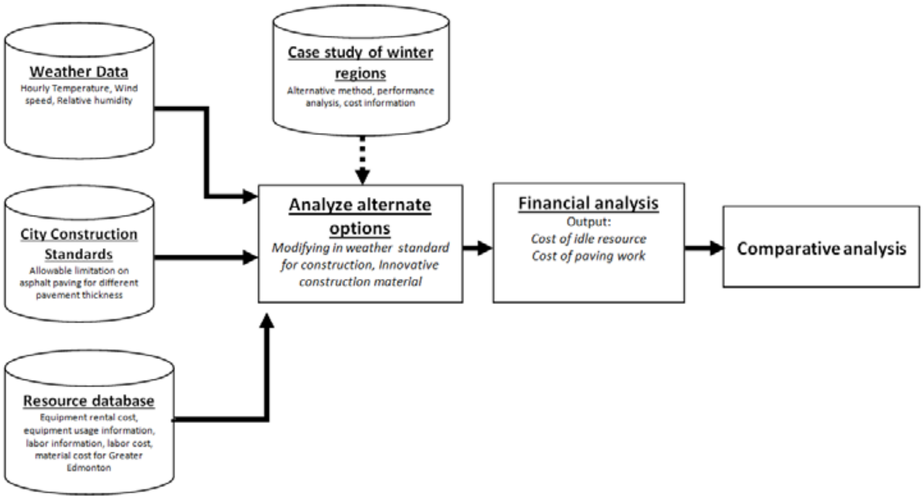


Figure 2: Methodological flowchart

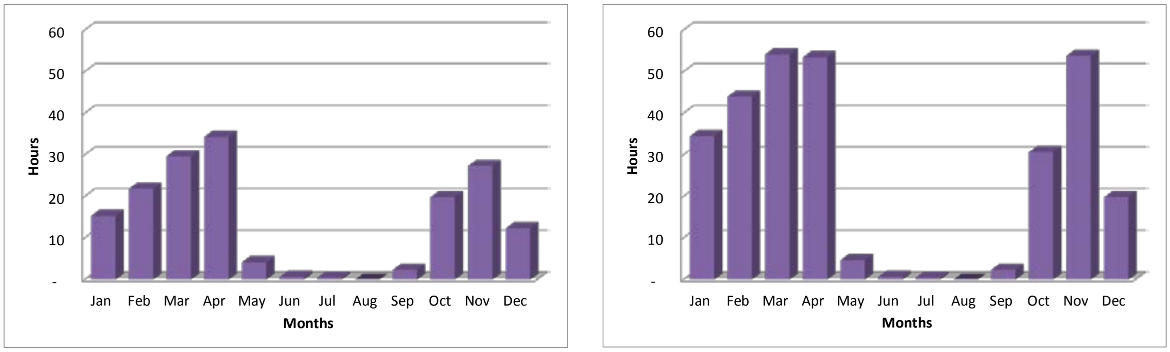
4 ANALYSIS AND RESULTS

4.1 Sensitivity analysis of weather data

For this study, a sensitivity analysis is performed on air temperature and wind speed data from Edmonton, Alberta. Seven years of air temperature and wind speed data from the Government of Canada's Climate webpage (http://climate.weather.gc.ca) is analyzed to determine how many additional construction hours can be achieved in one year if the temperature limitation is relaxed by 1°C or more.

The following assumptions are made in this analysis:
1. Additional construction hours are considered only when daylight is available.
2. No construction can be performed while there is any form of precipitation (rain, snow, hail, etc.).
3. May to November is considered to be the timeframe during which additional construction hours can be achieved. For the remaining months, the ground is assumed to be covered with thick snow which does not allow any paving work.
4. Any number of consecutive hours (one hour or greater) during daytime is considered as construction hours.
5. Wind speed limitation is considered according to the city of Edmonton's weather limitation specification.

For 50 mm asphalt thickness, the minimum allowable air temperature for paving is 4°C; lowering the allowable temperature for asphalt pouring from to 0°C or -4°C increases the available construction hours as shown in Figure 3:



a) Additional hours for lowering the standard to 0°C b) Additional hours for lowering the standard to -4°C

Figure 3: Additional construction hours for lowering the air temperature standard during asphalt pouring

Achievable construction time from lowering the allowable air temperature limit during asphalt pouring are summarized in Figure 4, considering the available hours from May to November. Figure 4 shows that, for

50 mm thick asphalt, 55 hours of construction time is achievable if the temperature limitation is relaxed from 4°C to 0°C, while 84 hours of additional construction time is achievable if the temperature limitation is relaxed from 4°C to −4°C.

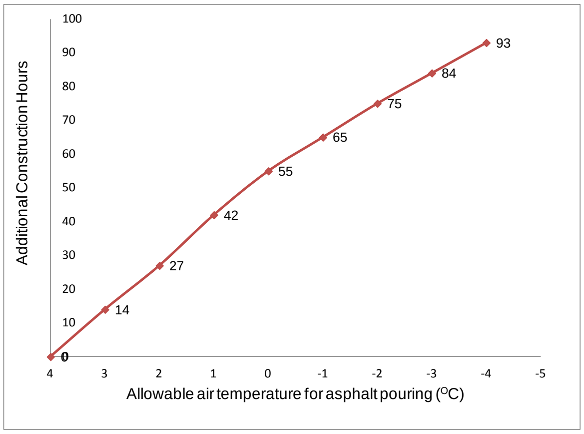


Figure 4: Additional construction hours (May to November) for lowering the air temperature standard

The sensitivity analysis may indicate an insignificant increase in construction time. However, for a standard size of crew (Crew B-25B) according to the RSMeans data consisting of one (1) foreman, seven (7) general workers, and three (3) equipment operators, as well as one each of an asphalt paver, a tandem roller, and a pneumatic wheeled roller, the daily cost (based on 8 hours of working) including overhead and profit is 8,553.72 CAD (RSMeans Online, 2015). The idle time cost during work interruption is charged at the same standard according to the daily working rate; the costs incurred are summarized in Table 3. It is observed that the large number of contractors and developers involved in road paving in greater Edmonton's construction market incurs significant loss due to unavailability of suitable alternatives for paving during lower temperature conditions. Hence, further study is required in terms of additives or innovative construction methods during asphalt paving in order to extend the construction season as well as maintain the targeted level of roadway performance.

Table 3: Cost for idle time based on lowering asphalt pouring temperature to 0°C and to -4°C:

Temperature limitation	**Idle time (hours)**	**Cost (CAD)**
0°C	55	58,806.00
−4°C	88	89,812.80

4.2 Warm Mix Asphalt as an alternative

Contractors in different cold countries apply different techniques to ensure sufficient asphalt performance while pouring asphalt in low temperatures. For example, heating the base layer by spreading hot sand or laying asphalt in two layers are two novel techniques for overcoming cold weather-related obstacles (Dutch Highway Authority, 2010). However, due to scarcity of aggregate and shortage of construction time these practices are not applicable in Edmonton. Various jurisdictions in North America have performed extensive analyses on Warm Mix Asphalt (WMA) as an alternative to HMA for cold weather paving. These analyses have encompassed environmental and economic performance of WMA as well as its life cycle cost analysis. Case studies in Germany have shown paving using WMA to have been successfully completed when ambient temperatures are between -3°C and 4°C (FHWA, 2008). A study by Louisiana State University researchers has shown that, compared to HMA, WMA reduces emissions, fossil fuel depletion, smog, and other detrimental environmental effects, reducing overall environmental impact by 15%, although the cost is marginally higher. In a study for the Ontario Ministry of Transportation, Politano (2012) has shown that WMA reduces fuel consumption and emissions at the asphalt plant. It also reduces asphalt at the paving site and improves long term pavement performance. The cost of the WMA binder course is approximately 24% less than conventional HMA, while the cost of the WMA surface course is found to be approximately 9% higher than conventional HMA. Transportation Ontario intends to expand the use of WMA for its projects and expects that increased use will reduce the cost of WMA (Politano, 2012). Diefenderfer et al., in their report to the Virginia Transportation Research Council, showed that HMA and WMA perform similarly through the first two years of service. Their report suggested that if 10% of the HMA used for maintenance contracts during the period February to October

2010 were to have been replaced by WMA, it could save approximately $1.15 million for the specified duration. The City of Edmonton conducted a study to compare the laboratory and field performances between WMA and HMA, where the WMA contained chemical additives as well as water-based foaming additive. The case site appeared to perform well after two winters and most of the test samples qualified for the different lab tests (Donovan, 2012).

As a general observation it is noted that WMA has a higher initial cost; however, reduced fuel consumption at the plant, faster paving, and longer haul distance makes it more appropriate for low temperature paving.

4.2.1 Sensitivity analysis of cost of Warm Mix Asphalt

Using WMA to replace HMA during cold weather paving increases cost, since the market price for WMA with any type of additives increases the material cost in a range from $1 to $6 per ton (Wakefield 2011). This study performs a sensitivity analysis to study the cost increase per metre of paving work, considering Edmonton's local road's paving width, i.e., 9 m for 50 mm pavement thickness, and using the standard costs specified by the Alberta Road Builders & Heavy Construction Association (ARHCA, 2014). The findings are summarized in Figure 5.

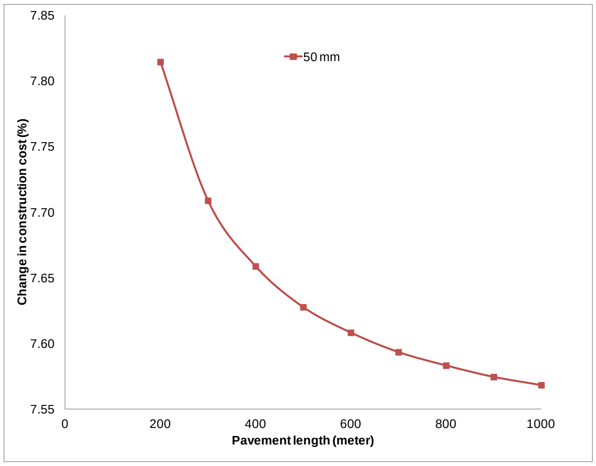


Figure 5: Change in construction cost (percentage) associated with using WMA

4.2.2 Comparison of idle resource cost with additional cost for WMA

Using the daily output of the standard crew from RSMeans data and then considering a reduced output for truck hauling and other wastages, a comparison is made between idle resource cost and additional cost of paving with WMA for pavement thicknesses of 50 mm. From this comparison, further analysis is carried out to determine the cost savings in Canadian Dollars (CAD) of using WMA at a lower temperature than the existing standard. A summary of the findings is provided in Figure 6.

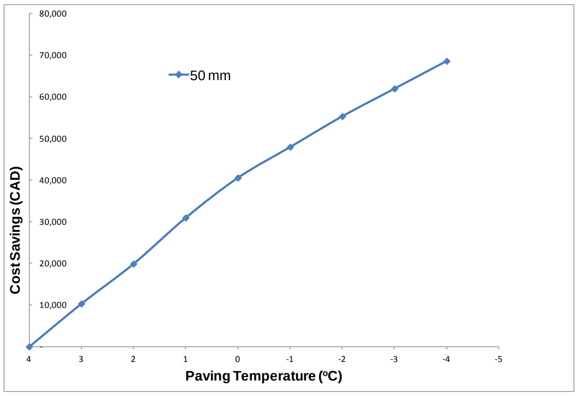


Figure 6: Cost savings for paving with WMA at lower temperatures

4.3 Discussion of Results

An analysis of weather data for greater Edmonton shows that construction expenditures can be significantly reduced if weather limitations are relaxed. However, asphalt performance needs to be ensured in terms of available compaction time and segregation of binding material if the air temperature limitation is lowered.

The cost analysis is made based on the market price of chemical additives for WMA available in Canada, showing a higher cost of WMA compared to HMA. However, for greater volume of paving work the proportional change in total construction cost decreases. In addition, the cost of idle construction workforce and paving equipment is relatively high in Edmonton's construction market. The additional cost of WMA for paving work compared to this idle resource cost is low, as observed in the resulting cost savings chart. It should be noted that these analyses have been conducted for a generalized condition; differences in results may be observed for larger volumes of work with larger crews.

5 CONCLUSION

This study determines the cost savings associating with relaxing the weather limitations by exploring an alternative paving methods to increase the paving season of greater Edmonton. Experience from different jurisdictions shows that Warm Mix Asphalt (WMA) has a better performance in lower temperature compared to Hot Mix Asphalt (HMA), and can potentially replace HMA for paving in cold weather. This study proposes an alternative method to minimize the impact of low temperature on paving schedule based on the existing standards in greater Edmonton. It provides useful insights analyzing the work interruption costs as well as the additional costs required for the alternative method, in order to assist construction managers with decisions on whether or not to continue WMA paving during severe weather. It can also assist policy makers with determining appropriate specifications and limitations for WMA paving based on performance assessment. Extended use of WMA can reduce the equipment modification costs required in the asphalt plant to accommodate WMA in the production line. Its environmental benefits need to be studied further to determine whether the jurisdictions can offer subsidies to contractors to promote the use of WMA. Further studies are needed to measure comprehensively the potential financial benefits of changes to paving practice in cold regions.

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