Factors Affecting the Performance of Pavement Preservation Treatments

by

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ABSTRACT

Pavement preservation has become a very important tool box for agencies to maintain their roadway system. Federal Highway Administration (FHWA) funded the project titled "Factors Affecting the Performance of Pavement Preservation Treatments." The objective of this project was to determine how the uncertainty in the output of a model (such as the performance of a preservation treatment or the costs) can be apportioned to the different sources of uncertainty in the inputs (such as pavement condition, construction quality, quality of materials, traffic, and climate).

The project evaluated the use of existing databases to determine the sensitivity of the factors on the performance of pavement preservation treatments. Unfortunately, these databases were determined not to be robust enough to answer the questions posed. An alternate approach was used by surveying experts in the field of pavement preservation treatments. This latter approach proved more successful. The impacts on the effect on performance were evaluated using sensitivity analysis and a life cycle cost (LCC) approach.

The major factors that control the performance of many pavement preservation treatments that were considered in this study were: Pretreatment Pavement Condition, Materials Selection and Quality, Construction and Workmanship, Mix and Structural Design, Traffic Level, and Climate during and immediately after Construction.

This paper focuses on the results of the sensitivity analysis and life cycle cost analysis which show that the variation from good conditions can have a dramatic effect on the life of the pavement preservation treatments as well as the associated costs to the agencies.

INTRODUCTION

Pavement preservation represents a proactive approach to maintaining our existing highways. A pavement preservation program consists primarily of three components: preventive maintenance, minor rehabilitation (nonstructural), and some routine maintenance activities. It has been proven (primarily anecdotally) to be an effective approach to extend pavement's effective service life, improve pavement service condition, and provide a cost efficient approach in general climate and traffic conditions. Given the current economic environment, most State Departments of Transportation (DOTs) are now embracing the pavement preservation philosophy.

However, all pavement preservation techniques are not suitable for all conditions. With the limited resources available to DOTs, practitioners are often faced with making pavement preservation decisions with limited information or experience with a given treatment. Pavement preservation is now becoming the core business of future highway programs. By adopting effective preservation methods, that proactively correct minor road deficiencies, roadway lives can be extended at comparatively low cost. Although many States have introduced some pavement preventive maintenance applications (such as chip seals, slurry seals, crack seals, and thin hot mix asphalt (HMA) overlays) that have resulted in certain benefits, these practices continue to face many obstacles such as:

- Lack of proof that preventive maintenance treatments can perform and are cost effective.
- Knowledge of the factors that affect the performance of pavement preservation treatments.
- Need for guidance on identifying roadway candidates for pavement preservation treatment (i.e. when preservation treatments should be applied) and what preservation

treatments should be applied and the expected life extension of the treatment under varying conditions and climates.

Objectives
The objective of this project was to assess how the uncertainty in the output of a model (such as the performance of a preservation treatment or the costs) can be apportioned to the different sources of uncertainty in the model inputs (such as pavement condition, construction quality, quality of materials, traffic, and climate). The project was designed to answer the question, "What effect will deviations in the input factors have on performance of preservation treatments and ultimately the cost to the agency?" The factors that have little or no effect on the change in performance of a pavement preservation treatment may not need to be considered during treatment selection.

SUMMARY OF LITERATURE REVIEW
To build a foundation for the project, a literature review, expert survey, and assessment of available databases were conducted. Through the review of the literature, several factors were identified that affect the performance of preservation treatments including pre-existing condition of the pavement, traffic levels, climate, material selection, and construction process. This section provides a summary of the findings for each factor as well as the sensitivity of each factor to treatment performance.

Pre-existing Pavement Condition
The condition of the pavement prior to application of a preservation treatment affects both the type of preservation treatment most applicable as well as the performance of the treatment once placed. Depending on the condition of the pavement, certain preservation treatments are better suited for application than others. The type and severity of distresses present in the pavement as well as the possible causes of the distresses need to be considered in the selection of the most appropriate treatment. Many studies have investigated the effect of the pre-existing pavement condition on the performance of asphalt pavement preservation treatments and have shown the negative effect on treatment life resulting from placing treatments on pavements in other than good condition (Luhr et al. 2010; Shuler and Schmidt, 2008; Hajj et al. 2010; Wilson and Guthrie, 2012; Li et al., 2012).

Based on 10 years of performance in Washington, Pierce et al. (2003) recommend dowel bar retrofit (DBR) is appropriate for portland cement concrete (PCC) pavements with less than 10% slab replacement and average faulting between 1/8 and 1/2 inch.

Construction Process
Construction practices, contractor experience, and workmanship are powerful contributors to the success of microsurfacing (Broughton and Lee, 2012; Gransberg, 2010). This also applies to other preservation treatments used for asphalt pavements.
Construction practices also greatly affect the performance of joint sealants with the two most significant factors that cause premature failure being the omission of sandblasting (cleaning of the joint) during placement and inadequate sealant recess (sealant overflow exposing the sealant to tire traffic) (Ioannides et al., 2004).

Several studies show the factors most affecting the performance of DBR are related to the construction process and include low concrete cover and low embedment length, lack of

grease which may restrain the doweled joint from opening and closing causing lockup, and dowel misalignment (Khazanovich et al., 2009; Pierce, 2009).

Materials

For flexible preservation treatments, the quality of the materials is particularly important. This includes the aggregate, binder and mix design. Several studies have shown the effects of material properties such as aggregate size, shape and gradation, aggregate cleanliness, and quality of asphalt on performance of chip seals and microsurfacing (Li, S. et al., 2012; Shuler et al., 2011; and Gransberg, 2010). The same is also true for thin HMA overlays.

For preservation treatments on concrete pavements, the quality of the materials in crack sealing and DBR is important. Studies have shown the importance of the quality of mortar for the performance of DBR (Battaglia and Paye, 2010; Pierce, 2009). Although there is no new material used in diamond grinding, softer aggregates in the PCC slab can cause a loss of texture as a result of polishing in diamond-ground pavements (Stubstad et al., 2005). Material selection in joint and crack resealing is an important factor affecting performance including durability to withstand abrasion and damage of traffic and climate, extensibility, elasticity, adhesiveness and cohesiveness of the sealant material (Caltrans, 2008).

Traffic Levels

The SHRP2 R26 project investigated preservation treatments for high-volume roadways and found that some low-volume preservation treatments such as crack seals and joint seals are also appropriate for high-volume roads by most highway agencies, while chip seals and slurry seals are considered appropriate for high-volume roads by some agencies. Fog seals and sand seals are not considered appropriate for use on high-volume roadways (Peshkin et al., 2011b).

When applying chip seals to higher volume roads (i.e., greater than 7,500 vehicles per day per lane), the use of polymer-modified asphalt emulsions is recommended as they provide better adhesion to the aggregates and reduces loss of chips (Shuler et al., 2011; Gransberg and James, 2005). When selecting the appropriate sealant for cracks and joints for concrete pavements, traffic volume and the percentage of heavy trucks need to be considered as more severe conditions require more durable sealants and may need more frequent replacement (Caltrans, 2008).

Climate

Climate can affect both the timing of construction for a preservation treatment as well as the performance of the treatments on asphalt pavements. Various preservation treatments require certain conditions during construction such as restrictive temperature and humidity for treatments using asphalt emulsions or moderately cool temperatures while crack sealing since temperature and humidity can affect the curing time required (Peshkin et al., 2011b). Treatments can also be susceptible to weather conditions such as rain or extreme temperatures following placement which can result in premature failures.

Certain treatments such as slurry seals and crack seals have reduced performance in freeze climates compared to non-freeze climates while others, such as chip seals, perform very well in wet non-freeze zones and well in all climatic zones (Peshkin et al., 2011b). Performance of crack sealants is partly dependent on installation as the cooling rate of the sealant affects the adhesion of the sealant to HMA (Collins et al., 2006). Crack sealants are also susceptible to poor performance at low temperatures (Oliver, 2004; Yang et al., 2010).

The effect of climate is less critical on treatments for concrete pavements such as diamond grinding and DBR. However, precipitation can significantly affect the faulting performance on non-doweled diamond-ground pavements (Rao et al., 1999) and freeze-thaw cycles can reduce the effectiveness of diamond-grinding as a result of PCC material durability issues (Stubstad et al., 2005). Flooding can also adversely affect joint sealant (Ioannides et al., 2004) and lower modulus sealants are required in colder climates (Caltrans, 2008).

SURVEY OF EXPERTS
To augment the findings from the literature review, online surveys were conducted with 36 experts (national and international) in the area of pavement preservation. To the authors' knowledge, this is the first time that this approach has been used to identify the important factors affecting the performance of pavement preservation. The objectives of the online survey were to obtain their insights into the important factors affecting the performance of preservation treatments, the availability of information on the sensitivity of these factors on performance, and the availability of models which could be used to predict the performance of these treatments. The experts identified the most important factors as:
- Condition of existing pavement prior to treatment
- Quality of construction
- Quality of materials
- Proper design of preservation treatment materials
- Traffic volume
- Climate

The experts agreed that the sensitivity analysis should focus on treatment types with the most robust available data. Therefore, based on the literature review and expert surveys, the sensitivity analysis focused on thin HMA overlay, chip seals, slurry seals, and crack sealing for asphalt pavements, and diamond grinding, DBR, and crack/joint sealing for concrete pavements.

PAVEMENT PRESERVATION DATABASES
One aspect of investigation for this research effort was to review available databases that could be used to examine the sensitivity of factors affecting the performance of pavement preservation treatments. The desire to use field data to establish objective measures to evaluate the significance of factors affecting performance of preservation treatments on a factual basis was considered to be very important.

This portion of the research review was influenced by the following recent NCHRP project efforts:
- NCHRP Project 1-48 found that insufficient data on pavement preservation treatments was available to develop national models of the effect of pavement preservation treatments within the context of the Mechanistic-Empirical Pavement Design Guide (MEPDG) design process (Peshkin, 2011a).
- The research need identified by American Association of State Highway Transportation Officials (AASHTO) members that lead to implementation of the 2012 NCHRP Project 14-31, "Developing a Pavement-Maintenance Database", should be considered sufficient proof that adequate database resources do not exist to address national issues of maintenance effectiveness and use of pavement maintenance data in PMS (TRB, 2012).

While the Long-Term Pavement Performance (LTPP) database contains the most promising data set to address issues related to pavement condition at the time of treatment, treatment

construction techniques, and workmanship, the amount of data that must be considered confounds statistical approaches. The cost of performing such analysis, as observed from fourteen previous analysis efforts on LTPP pavement preservation data summarized by Carvalho et al. (2011), exceed $5 million alone. In addition, the LTPP database does not contain some of the required detailed information necessary to conduct the analyses for this project.

As a result of the required effort and funding that would be required to perform the analysis using LTPP data and the fact that some of the required detailed information is not contained in the LTPP database, it was determined that the LTPP database is not a viable option for conducting the sensitivity analysis.

SUMMARY OF SENSITIVITY ANALYSIS
This section presents the results of the database mining, expert knowledge mining, and the sensitivity analysis conducted using the data gathered from the survey of experts. The survey provided data regarding the estimated treatment life, the reduction in treatment life for each factor based on changing levels of quality, and the risk of early treatment failure for each factor for various levels of quality. A treatment with high risk has a higher probability of earlier failure than its normal treatment life. The data analysis performed included the following:
- Identify the expected life of the various treatments.
- Develop performance curves based on the input from experts.
- Use risk of failure as a method to capture the opinions from the experts to identify the effect of the different factors in the strategy selection process.

Database Mining
As stated previously, the study team concluded that based on review of the literature, review of database contents, and findings from the millions of dollars already spent investigating this and other closely related topics, current databases do not contain adequate information to provide answers to the relative importance of the micro-sensitivities on resulting performance of pavement preservation treatments. Pavement databases can be used to determine macro trends, but are not yet sophisticated enough to reliably distinguish between the types of micro-effects required for this study.

Expert Knowledge Mining
The objective of this section is to summarize the results of a survey of experts dealing with the factors affecting the performance of pavement preservation treatments. As a result of the difficulty in finding useful information from database mining, using detailed supportive data was gathered using a survey of experts. A total of 33 experts responded to the survey providing information based on the expertise and experience related to factors affecting the performance of pavement preservation treatments or contributing to the risk of early failure. The experts consisted primarily of agency or former agency personnel and industry along with a few academics.

Expected Life of Treatments
Table 1 summarizes the results for the estimated treatment lives under good conditions based on the experts' responses. As expected, there was considerable variation in the responses, but it provided a good starting point.

Table 1. Summary of estimated treatment lives under good conditions

Treatment Life, Years	Average	Standard Deviation	Lowest	Highest
Thin HMA Overlays (< 1.5")	9	3	4	18
Chip Seals	7	1.9	4	10
Slurry Surfacings	6	1.8	4	12
Crack Sealing	5	2.4	2	12
Diamond Grinding	12	4.3	4	20
Dowel Bar Retrofit	15	3.8	5	20
Joint and Crack Sealing	7	4.1	2	15

Percent Reduction in Life

The expected treatment life presented in table 1 represents the performance of the pavement preservation treatment under good conditions. The performance of the treatment is reduced as the quality of the condition of the factors deviate from ideal conditions. The higher the percent reduction in treatment life, the more sensitive the treatment performance is to the factor. Table 2 summarizes the percent reduction of treatment life for the various treatments and factors based on averaging the experts' responses. The levels of quality for each factor were specified as:

- Pavement condition
    - Good: i.e., Pavement Condition Index (PCI) is 80 or more; Pavement Condition Rating (PCR) is from 4 to 5
    - Fair: i.e., PCI is from 50 to 80; PCR is from 2.5 to 4
    - Poor: i.e., PCI is less than 50; PCR is less than 2.5
- Materials selection and quality
    - Good: Materials meet specifications
    - Marginal: Material quality varies in and out of specifications
    - Poor: Material quality is consistently out of specifications
- Construction and workmanship
    - Good: All work within specifications
    - Marginal: The construction process is both in and out of specifications
    - Poor: Most of the construction does not meet specifications
- Mix and structural design
    - Good: Follows standards
    - Marginal: Either mix or structural design information not considered
    - Poor: No mix or structural design information provided
- Traffic
    - Low volume: Less than 5,000 vehicles per day per lane
    - Medium volume: Between 5,000 and 20,000 vehicles per day per lane
    - High volume: More than 20,000 vehicles per day per lane
- Climate during and immediately after construction
    - Good: No problems with weather during or immediately after construction
    - Marginal: Some rain or high or low temperature issues
    - Poor: Rain and weather issues throughout construction

Table 2. Summary for percent reduction of treatment life due to different factors

Treatment Life Reduction Percentage, %		Thin HMA Overlay	Chip Seal	Slurry Surfacings	DBR	Joint and Crack Sealing
Pretreatment Pavement Condition	Fair	36%	31%	35%	26%	N/A
	Poor	64%	62%	62%	N/A	N/A
Materials Selection and Quality	Marginal	36%	40%	38%	30%	40%
	Poor	57%	64%	62%	53%	60%
Construction and Workmanship	Marginal	45%	46%	44%	42%	44%
	Poor	61%	68%	65%	67%	67%
Mix and Structural Design	Marginal	35%	31%	40%	N/A	N/A
	Poor	57%	51%	62%	N/A	N/A
Traffic Level	Medium	22%	26%	23%	11%	11%
	High	45%	48%	44%	32%	27%
Climate During and Immediately After Construction	Marginal	33%	44%	44%	21%	29%
	Poor	50%	66%	65%	38%	53%

The sensitivity analysis was not conducted for the crack seal treatment as crack sealing can be used in preventative maintenance, routine maintenance, and corrective maintenance. Therefore, its treatment life varies depending on its purpose and usage. Diamond grinding should normally be applied to pavements in good condition. Materials selection and quality are not factors for this treatment. It does not involve mix and structural design. Because many of these factors do not apply for diamond grinding, its sensitivity to these factors was not surveyed.

Table 3 presents the rankings of the sensitivity levels of the factors where 1 represents most sensitive and 6 the least sensitive.

Table 3. Rankings of sensitivity levels of factors on treatment life

Factor	Thin HMA Overlay	Chip Seal	Slurry Surfacings	DBR	Joint and Crack Sealing
Pretreatment Pavement Condition	1	4	3	5	N/A
Materials Selection and Quality	3	3	5	2	2
Construction and Workmanship	2	1	1	1	1
Mix and Structural Design	4	5	4	N/A	N/A
Traffic Level	6	6	6	4	4
Climate During and Immediately After Construction	5	2	2	3	3

Risk of Early Treatment Failure

The experts also assigned risk levels for early failure of treatments according to changes in the quality of the factors. A treatment with high risk has a higher probability of earlier failure than its normal treatment life. Below is summary of the highest risk of failure for the various treatments:

Thin HMA Overlay: Existing pavement in poor condition; using poor construction practices and workmanship.

- Chip Seal, Slurry Surfacings and Crack Sealing: Existing pavements in poor condition using either poor construction practices, poor materials or placing it in poor climate.
- Diamond Grinding: Existing pavement in poor condition; using poor construction practices and workmanship.
- DBR: Using poor construction practices and workmanship; using poor materials selection and quality.
- Joint and Crack Sealing (PCC): Existing pavement in poor condition; using poor construction practices and workmanship.

In general, the lowest risk of failure occurs when good quality is maintained. Figure 1 depicts an example of the early failure risk levels for thin HMA overlay under various levels of quality.
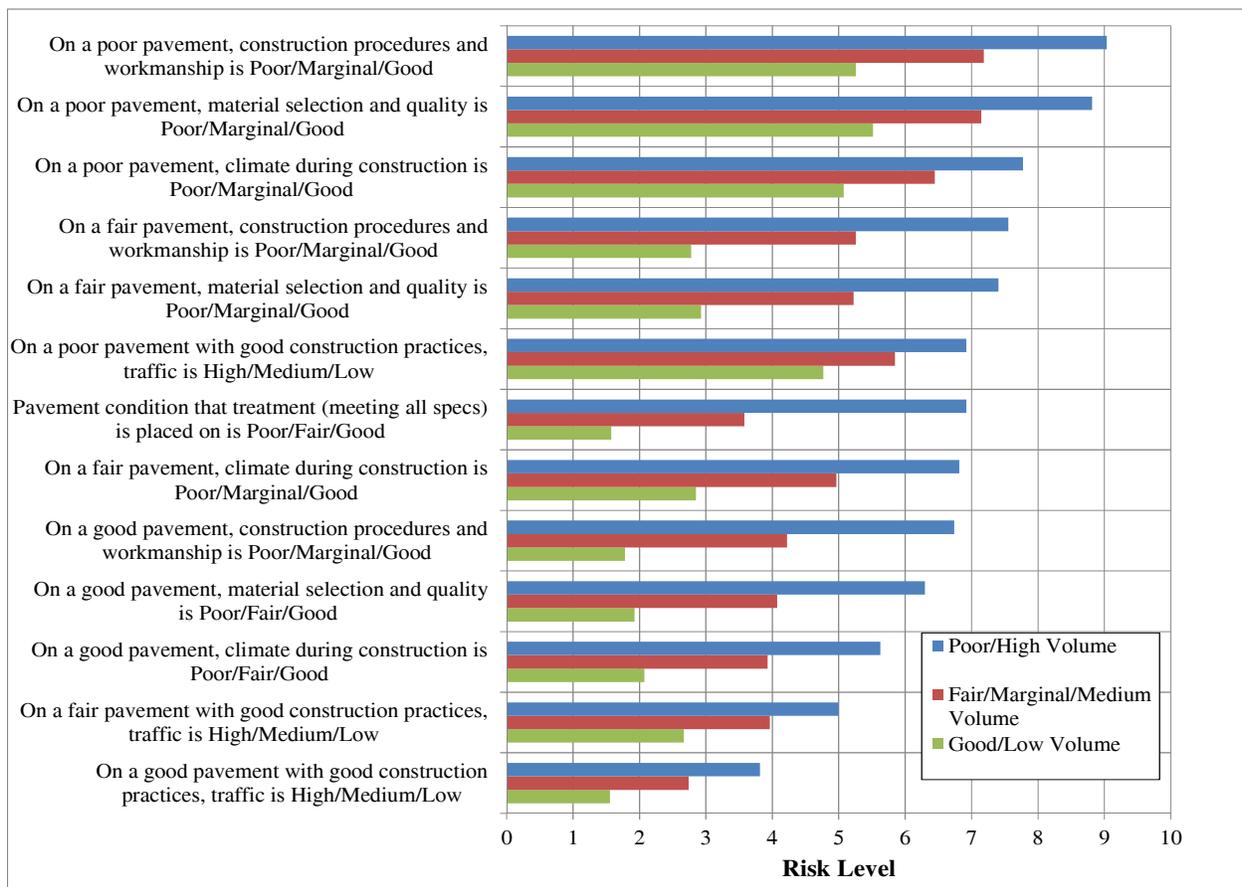

Figure 1. Early failure risk levels for thin HMA overlay under various levels of quality

Economic Analysis
FHWA's pavement design life cycle cost analysis (LCCA) software, RealCost 2.5 (Version 2.5), was used to perform the economic analysis (FHWA, 2004). RealCost 2.5 allows for the comparison of up to six alternatives, with each alternative consisting of up to 24 activities. For each LCCA, the inputs were held constant other than the type, number and cost of treatments (activities). The inputs held constant include traffic, project length, and discount rate. A deterministic approach was used for the analysis.

The scenarios used for the economic analysis were developed based on results from the sensitivity analysis by using the average treatment life under good conditions as the expected treatment life and by applying the percent reduction for variations from the good condition to determine the treatment life for other conditions. The scenarios compared the LCC of the various conditions for each factor. For example, the LCC for a thin HMA overlay placed on a pavement in good condition was compared to the LCC for a thin HMA overlay placed on both a pavement in fair and poor condition. This was repeated for all factors and treatments for which the treatment life and reduction in life due to a change in levels of quality of factors were known. Table 4 presents the life of each treatment for good conditions and the life as a result of the reduction in condition of each factor.

Table 4. Treatment life comparison for various conditions of factors, years

Factor	Condition	Thin HMA Overlay	Chip Seal	Slurry Surfacings	DBR	Joint and Crack Sealing
Treatment Life (all good)	Good	9	7	6	15	7
Pretreatment Pavement Condition	Fair	5.8	4.8	3.9	11.1	N/A
	Poor	3.2	2.7	2.3	N/A	N/A
Material Selection and Quality	Marginal	5.8	4.2	3.7	10.5	4.2
	Poor	3.9	2.5	2.3	7.1	2.8
Construction and Workmanship	Marginal	5.0	3.8	3.4	8.7	3.9
	Poor	3.5	2.2	2.1	5.0	2.3
Mix and Structural Design	Marginal	5.9	4.8	3.6	N/A	N/A
	Poor	3.9	3.4	2.3	N/A	N/A
Traffic Level	Medium	7.0	5.2	4.6	13.4	6.2
	High	5.0	3.6	3.4	10.2	5.1
Climate During and Immediately After Construction	Marginal	6.0	3.9	3.4	11.9	5.0
	Poor	4.5	2.4	2.1	9.3	3.3

The LCCA for the asphalt treatments was based on a 20 year analysis period. The LCCA for the PCC treatments was based on a 30 year analysis period. With the exception of the DBR analysis, the LCCA considered the number of treatments needed for each treatment-factor combination to reach the end of analysis period. It was assumed that once the initial treatment reached the end of its life, another treatment of the same type was placed again with the same life. Treatments were placed repetitively until the end of the analysis period was reached. Since it is not realistic to perform several DBR treatments, it was assumed that once the initial DBR treatment reached the end of its life, thin HMA overlays were placed repetitively having a life of 9 years, until the end of the analysis period. The cost of treatments was based on typical numbers from a Metropolitan Planning Organization (MPO) in the San Francisco Bay area. The specific costs are not reported, as costs vary by region, and the purpose of this analysis was to illustrate the relative effects on cost of placing treatments under various conditions. The results are reported as percentages, so that the results can be used throughout the country. User costs were not considered in the analysis as the focus of this study was on agency costs.

Results Summary
Table 5 shows the percent increase in cost for placing treatments in other than good conditions. These percentages can be used by agencies to translate the increase in cost in dollars to local pricing conditions. These are the maximum costs that would be incurred for the worst case scenario. Lower costs would be expected since an agency would not normally be placing a treatment on a poor pavement every time.

Overall, the economic analysis illustrated the importance of placing preservation treatments under good conditions or using good practices. By failing to place preservation treatments under good conditions or using good practices, agencies could risk spending almost 200% more over 20 years for some treatments and factors. This is assuming the worst case situation where the treatments are not placed in the proper manner. However, it does illustrate the costs associated with not doing preservation correctly.

Table 5. LCC comparison for various conditions of factors, percent increase from good conditions

Factor	Condition	Thin HMA Overlay	Chip Seal	Slurry Surfacings	DBR	Joint and Crack Sealing
Pretreatment Pavement Condition	Fair	45%	39%	46%	16%	N/A
	Poor	151%	138%	142%	N/A	N/A
Material Selection and Quality	Marginal	45%	58%	55%	19%	53%
	Poor	107%	156%	142%	36%	124%
Construction and Workmanship	Marginal	66%	73%	67%	26%	65%
	Poor	130%	190%	165%	47%	171%
Mix and Structural Design	Marginal	43%	39%	59%	N/A	N/A
	Poor	107%	92%	142%	N/A	N/A
Traffic Level	Medium	23%	30%	27%	7%	12%
	High	66%	82%	67%	21%	29%
Climate During and Immediately After Construction	Marginal	41%	67%	67%	12%	29%
	Poor	83%	167%	165%	25%	94%

SUMMARY
Pavement preservation is an important part of an agency's approach to maintaining their roadway system. This project determined how the uncertainty in the output of a model (such as the performance of a preservation treatment or the costs) can be apportioned to the different sources of uncertainty in the model inputs (such as pavement condition, construction quality, quality of materials, traffic, and climate). This report answered the question, "What effect will deviations in the input factors have on the performance of preservation treatments and ultimately the costs to the agency?" The results clearly showed that the variation from good conditions can have a dramatic effect on the life of the pavement preservation treatments as well as the associated costs to the agencies. These results are based primarily on the survey of experts.

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