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DEVELOPMENT OF PAVEMENT PERFORMANCE PREDICTION MODELS FOR PRESERVATION TREATMENTS: VOLUME 2

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A report of the findings of
ICT PROJECT R27-150
Revised Condition Rating Survey Models to Reflect All Distresses

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16. Abstract
The implementation of a pavement preservation program was initiated in Fiscal Year (FY) 2005 at the Illinois Department of Transportation (IDOT) by appropriating funding for four specific pavement preservation treatments. The types of treatments included micro-surfacing, slurry seals, cape seal, and bituminous surface treatments (also known as chip seals). The scope and funding level for the state's nine highway districts has expanded over the years. As a result, several years of performance data was collected from the projects constructed since the inception of the program. In this study, the performance of preservation treatments used by districts as part of the pavement preservation program were evaluated. After treatments were applied, pavement condition prediction models were developed for nine preservation treatments. Two methodologies were followed in developing the models. The first is solely based on the collected data when historical pavement condition data were sufficient. Due to the lack of data for many of the treatments, an alternative method was used to develop models. A multi-criteria decision-making method known as the analytic network process (ANP) was used to integrate expert opinion collected through questionnaires into the model development. The proposed model form is consistent with the existing condition rating survey CRS prediction models with a single slope, with the addition of project-specific factors to adjust the deterioration rate. The model variables included the existing pavement condition prior to the treatment, traffic, and truck percentage, along with the base deterioration rate. According to the modeling results, chip seals, slurry seals, and Half-SMART treatments were among the shortest-lived treatments, with an average service life of 3–4 years. For micro-surfacing treatments, single-pass and double-pass, could extend the service life to approximately 6 and 7 years, respectively. The average service life extension for cape seal treatment was more than 7 years, whereas cold in-place recycling treatment, with surface overlay and surface treatment, can extend pavement service life by approximately 8–10 years. It was also found that the performance of the ultra-thin bonded wearing course UTBWC treatment can be comparable to that of the micro-surfacing treatments, by extending the pavement service life by 6 years on average with a wider range of variability.

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pavement preservation, condition rating, micro-surfacing, chip seals, slurry seals, Half-SMART

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Members of the Technical Review panel were the following:

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EXECUTIVE SUMMARY

Local and state transportation agencies utilize preservation programs to manage their pavement network using cost-effective measures. The ultimate goal is to extend the service life of pavements and maintain or improve the overall condition of the road network. The longevity of pavement preservation treatments and the service life added to the existing pavement, are the key ingredients to the success of pavement preservation programs. The effectiveness of a pavement preservation treatment depends primarily on selecting the right treatment at the right time and for the right pavement.

The implementation of a pavement preservation program was initiated in fiscal year (FY) 2005 at the Illinois Department of Transportation (IDOT) by requiring districts to spend a specific amount of their annual funding for projects using one of four specific pavement preservation treatments. The types of treatments included micro-surfacing, slurry seals, cape seal, and bituminous surface treatments (also known as chip seals). The scope and funding level for the nine districts has expanded over the years. As a result, several years of performance data were collected from the projects constructed since the inception of the program. There is now a need to evaluate the performance of preservation treatments and develop performance prediction models for future planning and programming.

This study evaluated the performance of preservation treatments used by districts as part of IDOT's pavement preservation program. The performance data was then used to develop pavement condition prediction models for each preservation treatment. Two methodologies were followed in developing the models. The first is solely based on the collected data. It was found that single-pass and double-pass micro-surfacing treatments were the only ones with sufficient data to develop models. As a result, a two-slope model was used to develop models for both micro-surfacing treatments. The models start from a condition rating survey (CRS) of 9.0 and deteriorate following a two-slope curve, with a break point at the third year. According to the data-driven prediction model, the service life of both micro-surfacing treatments to reach a CRS of 4.5, which would be the indication for resurfacing, is 7–8 years, on average.

An alternative method was also used to develop models when data was not sufficient enough to develop prediction models. A multi-criteria decision-making method known as the analytic network process (ANP) was used to integrate expert opinion into model development. A questionnaire was created based on the preservation method and distributed among local experts in Illinois. The questionnaires had specific objectives, including determining the deterioration rate and its variation and determining the significance of individual factors affecting treatment performance. This information was used to develop a deterioration prediction model with a specific form consistent with the CRS prediction models, with the addition of factors commonly accepted as influencing how the treatment performs and remains effective. The model form has a linear slope adjusted by the existing condition of the pavement, traffic, and truck percentage.

According to the expert-elicited modeling results, chip seal, slurry seals, and Half-SMART treatments were among the shortest-lived treatments, with an average time of 3–4 years to reach a CRS of 4.5. Single-pass and double-pass micro-surfacing could extend the service life to approximately 6–7 years,

respectively. This information was found to be consistent with the predictions of data-driven prediction models (7–8 years). The average service life extension is more than 7 years for cape seal treatments, whereas cold in-place recycling treatments, along with surface overlays and surface treatments, can extend pavement service life by approximately 8–10 years. It was also found that the performance of the ultra-thin bonded wearing course UTBWC treatment can be comparable to that of the micro-surfacing treatments, by extending the pavement service life by 6 years on average with a wider range of variability. However, there were no data collected for UTBWC type of treatments for consistency checks.

The existing condition of the pavement prior to the treatment appeared to be the most influential factor affecting the rate of treatment deterioration. As a result of factors including existing pavement condition and traffic conditions (traffic and truck percentage), the variability in the treatment service life was approximately 1–4 years, depending on the treatment type.

The proposed model is capable of capturing project-specific conditions to include most of the influential factors into future performance of treated pavements. The final proposed models were developed based solely on expert opinions obtained from the questionnaires. The model form and results are consistent with the expectations, engineering intuition, and earlier treatment performance results. This model form and coefficients can be used to evaluate the effectiveness of the pavement preservation program since its inception. They can also be used for planning and programming future treatments with available funds. At the same time, verifying or fine-tuning the coefficients of the models with reliable data collected from the preservation projects, is highly recommended.

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 BACKGROUND

The term *preservation treatment activities* refer to a proactive approach employing network-level, long-term strategies to enhance pavement performance. The best way to achieve this is by using an integrated, cost-effective set of practices that extend service life, improve safety, and meet motorist expectations. Local and state transportation agencies utilize preservation programs to manage their pavement networks by using cost-effective measures. The ultimate goal is to extend the service life of pavements and maintain or improve the overall condition of the road network.

The longevity of pavement preservation treatments and added service life of the existing pavement, are the key ingredients to the success of pavement preservation programs. The effectiveness of a pavement preservation treatment depends primarily on selecting the right treatment at the right time and for the right pavement. The Illinois Department of Transportation's (IDOT's) Bureau of Design and Environment (BDE) manual provides guidance in selecting preservation treatments for the state-maintained roadways (IDOT, 2010).

The implementation of a pavement preservation program was initiated in fiscal year (FY) 2005 at IDOT by requiring districts to spend a specific amount of their annual funding for projects using one of four specific pavement preservation treatments (Wolters et al., 2009). The four treatments were bituminous surface treatment (BST), also known as chip seal; slurry seal; micro-surfacing; and cape seal. In the first year of the program, nearly $3 million was allocated for use in the state, with approximately $300,000 spent in each of the nine districts throughout the state. Pavement preservation funding was increased to $7 million per year in 2008, with approximately $800,000 required to be spent by each of the nine districts on the allowable treatments (Wolters et al., 2009). Since then, the funding level and the variety of pavement preservation treatments have fluctuated.

Since the beginning of the preservation program, several years of data were accumulated to assess the performance of these treatments. In the study conducted by Applied Pavement Technology (APTech) (2011), the performance of pavement preservation projects completed between fiscal years 2005 and 2010 was included. The number of projects analyzed was 98. The study included field surveys, data collection from the Illinois Roadway Information System (IRIS) database, and an analysis of treatment effectiveness. The service life extension provided to the existing pavement was reported for cape seal; chip seal; and single-pass and double-pass micro-surfacing. In general, for all treatment types, the service life extensions were reported to be lower than typically expected. The data and results exhibited inconsistencies between expectations and the pavement condition reported. Therefore, the study recommended further investigation to understand the exact reasons for poor performance.

This report is part of the ICT project R27-150, Revised Condition Rating Survey Models to Reflect All Distresses. This volume of the project's report presents the development of prediction models for preservation treatments. This study aims to analyze data obtained from preservation projects since FY 2005 and evaluate the performance of preservation treatments. More data has become available since FY 2010, as more projects were completed and more condition data became available for the projects completed prior to 2010. In addition, this study targets developing a performance prediction model using the same overall condition index CRS. The prediction models will help IDOT to quantify the benefits or tradeoffs as a result of implementing a pavement preservation program.

1.2 OBJECTIVES AND RESEARCH METHODOLOGY

The objective of this study is to develop performance prediction models for preservation activities commonly used by IDOT.

Research methodology included the following:

- Prepare, organize, and analyze historical data collected for each pavement treatment (PT) activity, using the historical condition since 2000.
- Arrange data with similar behavior into different groups based on their district, surface type, etc.
- Establish an approach to develop prediction models based on the available historical condition.
- Establish an approach to develop prediction models in the case(s) for which historical condition data is insufficient or inadequate.
- Evaluate the effectiveness of each preservation treatment, using the models developed.

1.3 REPORT ORGANIZATION

The remainder of this report is organized as follows: Chapter 2 presents the data collected from IDOT and the processing steps used. Chapter 3 introduces the model development and results. Chapter 4 summarizes conclusions and provides recommendations.

CHAPTER 2: DATA PREPARATION

2.1 PRESERVATION TREATMENT TYPES AND DEFINITIONS

Chapter 52 of the *Bureau of Design and Environment Manual* provides detailed information regarding use of pavement preservation strategies for maintaining pavement condition. Table 2.1 shows a summary of the treatments for flexible and rigid pavements.

Table 2.1. Pavement Preservation Treatments for Flexible and Rigid Pavements

Treatments for flexible pavement	Treatments for rigid pavement
Crack filling and sealing	Crack sealing
Fog seals	Joint resealing
Sand seals	Diamond grinding
Slurry seals	Diamond grooving
Micro-surfacing	Ultra-thin bonded wearing course (UTBWC)
Bituminous surface treatments (chip seals)	Full-depth repair
Cape seals	Partial-depth repair
Cold in-place recycling (CIR)	
Hot in-place recycling (HIR)	
Surface Maintenance at the Right Time (SMART) overlay	
Half-SMART overlay	
Ultra-thin bonded wearing course (UTBWC)	
Cold milling	

The following are definitions, from Chapter 52 (IDOT 2010), of the treatments used in this study:

- *Half-SMART*: Half-SMART overlays consist of a nominal 0.75-in. (19-mm) layer of hot-mix asphalt (HMA) level binder followed by a bituminous surface treatment (BST).
- *Chip seal*: Includes types A1 and A2. Also known as *bituminous surface treatment (BST)*, it is a layer of asphalt emulsion applied directly to the pavement surface, followed by the application of aggregate chips, which are then immediately rolled to embed the chips into the emulsion.
- *Slurry seal*: Slurry seals are a mixture of crushed, well-graded aggregate (e.g., fine sand, mineral filler) and asphalt emulsion that is spread over the entire pavement surface with either a squeegee or spreader box attached to the back of a truck.
- *Micro-surfacing*: Applied in a process similar to slurry seals, micro-surfacing consists of a mixture of latex-modified emulsified asphalt, mineral aggregate, mineral filler, water, and additives. Micro-surfacing material is mixed in specialized, compartmentalized, self-powered trucks and placed on the pavement using an augured screed box.
- *UTBWC*: An ultra-thin bonded wearing course is formed in a single-pass process with the application of a heavy, polymer-modified asphalt emulsion tack coat and a gap-graded, polymer-modified 0.4- to 0.8-in. (10- to 20-mm) HMA layer.

- *Cape seal*: The treatment consists of a chip seal (BST), followed within a few days by a micro-surfacing treatment to cover the chips and seal them in.
- *CIR*: Cold in-place recycling (CIR) is an in-situ process used to recycle the top 2 to 4 in. (50 to 100 mm) of an existing HMA pavement to construct a new HMA layer. As the name suggests, the recycling process is conducted without the addition of heat. The two alternative scenarios considered are CIR1 (combination of CIR with one of the other surface treatments) and CIR2 (CIR with 2 to 4 in. [50 mm to 100 mm] HMA overlay).

2.2 DATA COLLECTION AND PREPARATION

Pavement condition data for preservation contracts since FY 2005 were received from IDOT. The number of preservation contracts has increased since FY 2010. Table 2.2 summarizes data received from IDOT since FY 2005 regarding the total number of projects. Although it was in the list of treatments, there were no data collected for UTBWC type of treatments.

Table 2.2. Data Received from IDOT Regarding Number of Projects

Treatment type	Number of contracts
Micro-surfacing, single-pass	66
Micro-surfacing, double-pass	24
Half-SMART	6
Seal coat[1]	9
Slurry seal	7
Cape seal	27
Chip seal	31
Cold in-place recycling	9

[1] Seal coat is not part of the approved preservation treatments at IDOT but used or recorded by districts inadvertently. Therefore, no models are developed for seal coat treatment.

A database to include pavement condition data from 2000 to 2014 was prepared and used for developing treatment prediction models. The database included different treatment types, with some section-specific information. Table 2.3 shows typical information for each section that has experienced a treatment.

Table 2.3. Sample Treatment Data Record

District	Inventory number	Contract #	From MP	To MP	Treatment type	Treatment fiscal year	CRS	Pavement distress	…
2	004 20525 000000	64A31	2.1	4.96	Microsurf, double- pass	2005	7.6	O2T1S1	…

…	Surface type	Latest construction date	Functional class	AADT count	Heavy commercial count	Rut depth (in)	IRI * (in/mile)	Faulting height (in)
…	640	1999	40	18,400	1,700	0.03	72	0.11

*International Roughness Index (IRI)

A raw data analysis showed that most of the sections are asphalt-surfaced pavements with a rigid base. Figure 2.1 shows a histogram and percent distribution of data for each surface type.

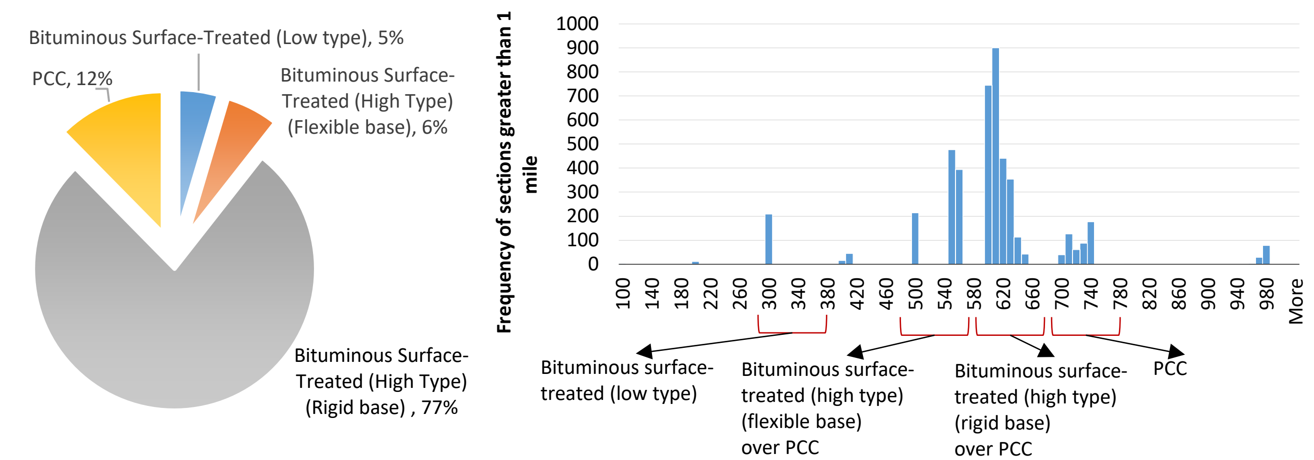


Figure 2.1. Pavement surface type distribution and histogram.

A rigorous data cleaning was performed according to the cleaning and filtering procedure as described in Chapter 2 of Volume 1 for this study. In summary, the data cleaning process included the following:

- Filter the data based on inventory number.
- Clean the data to include only the time series of a specific inventory number and mile post.
- Consider only the data points that deteriorated with time.
- Calculate and record the slope for every two data points from same section.
- Remove the data points exhibiting unrealistically slow or rapid decline of CRS.

Also, the following additional manual cleaning procedure was used to further clean the database.

- CRS with respect to age makes no sense. This finding may be due to an incorrect age record or incorrect CRS input.
- CRS at age 0 or 1 is smaller than the pre-treatment CRS. This finding may be due to an incorrect record of CRS.
- CRS value does not match the distress record.
- Risers are showing successive data points with increasing CRS values, with no information about possible maintenance activity.

Similar data inconsistencies were demonstrated in the report prepared by Applied Pavement Technology (APTech, 2011). Specifically, the prediction of treatment effectiveness is inconclusive and unrealistic when data is used as a group from all of the sections. As a result, extra effort was taken in this study to clean the database from all sorts of potential inconsistencies. Some of these inconsistencies are obvious and were removed without any objection. Other inconsistencies are relatively subjective and deletion is based on engineering intuition and is summarized by the assumptions addressed above.

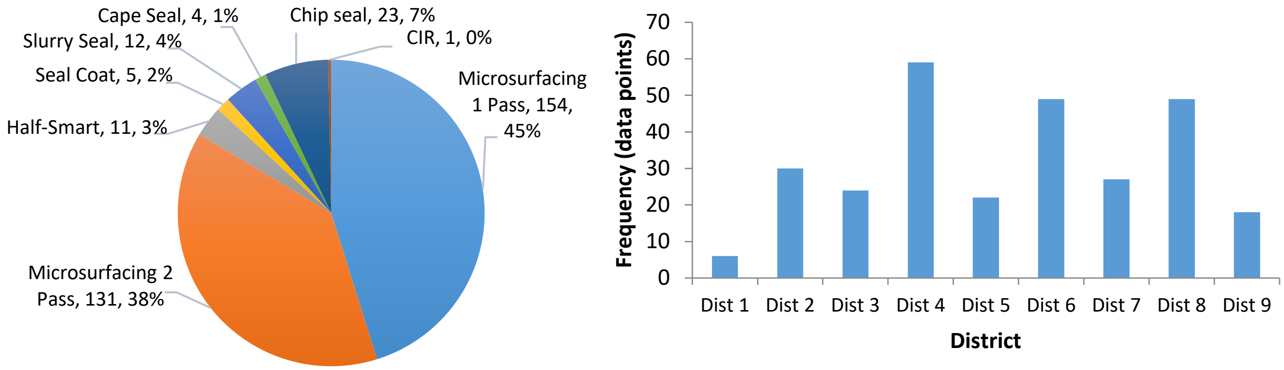
In consultation with the technical review panel (TRP), various treatments were grouped according to their functional similarity and availability of data. Table 2.4 shows available treatments in the database, as well as the final combined categories prepared for model development.

Table 2.4. Existing Treatments in Database and Groupings

Existing treatment category	Treatment names and application, as appearing in the database	Grouped treatment categories
Micro-surfacing	Microsurf, 1 pass,2 pass, Micro surfacing (Shldrs)	Micro-surfacing, single-pass
		Micro-surfacing, double- pass
Half-SMART	Half-SMART, A-1 Chip Seal & Half-SMART	Half- SMART
Seal coat[1]	Sealcoat, seal coat of inside and outside shldrs, seal coating drv lane ramp shldrs	Seal coat
Slurry seal	Slurry Seal, Slurry seal on shoulders	Slurry seal
Cape seal	Capeseal, Cape seal / BST A-2, cape seal on frontage roads	Cape seal
A-1 chip seal	A-1 Chip Seal, BST A-1, BS A-1	Chip seal
A-2 chip seal	BST A-2, BS A-2	
A-1A-2 chip seal	BSA-1/A-2 Slurry seal on shoulders	
CIP	CIP 4" cover w/Seal coat, CIP-cover w/ Seal Coat CIP RECYCLING 3.0 / 4.0 w/cape seal	CIR

[1] Seal coat is not part of the approved preservation treatments at IDOT but used or recorded by districts inadvertently. Therefore, no models are developed for seal coat treatment.

A CRS time series for each treated section was prepared and divided into before and after treatment data points. Prediction model development can only be carried out using after treatment data. Most of the treated sections received micro-surfacing treatment. Figure 2.2(a) shows the summary data distribution for different treatments, using post-treatment data points. Figure 2.2(b) shows the histogram of micro-surfacing treatment per district. More than 80% of the data reflects the use of micro-surfacing treatment. Districts 4, 6, and 8 have used the micro-surfacing treatment the most. Table 2.5 also shows the summary of the data before and after cleaning.



(a) **(b)**

Figure 2.2. Distribution of post-treatment data based on (a) treatment type and (b) micro-surfacing treatment, per district.

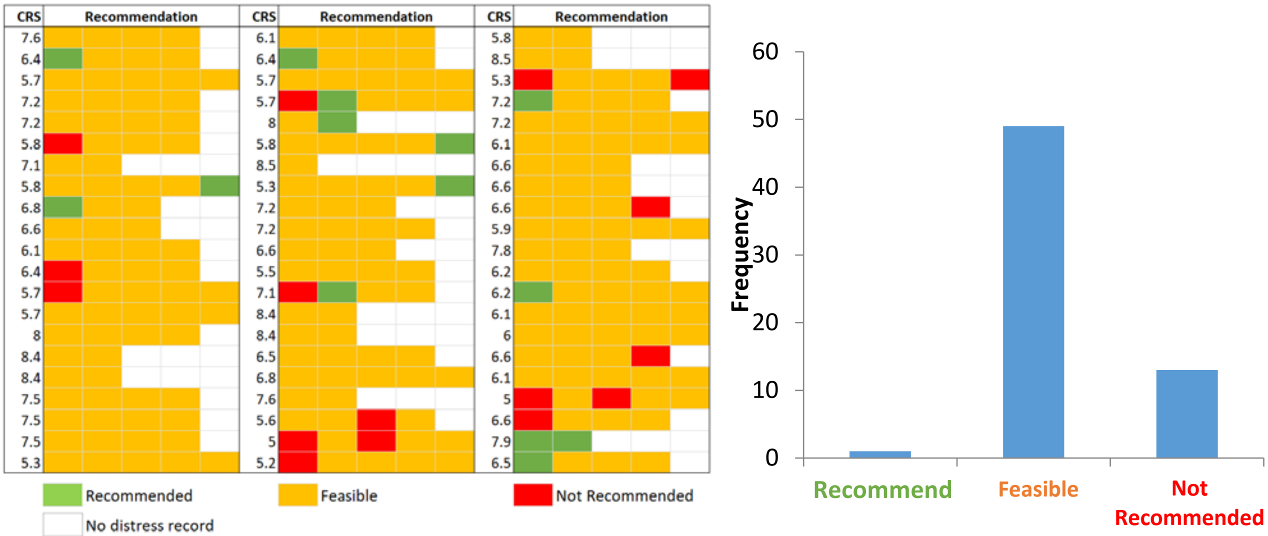
Table 2.5. Summary of Data Before and After Cleaning

Treatment type	Number of data points before cleaning	Number of data points after cleaning and preprocessing	Average slope
Micro-surfacing, single-pass	830	154	-0.75
Micro-surfacing, double-pass	819	131	-0.64
Half-SMART	75	11	-0.51
Seal coat	39	5	—
Slurry seal	114	12	-0.35
Cape seal	202	4	—
Chip seal	739	23	-0.35
CIR	46	1	—

2.3 EVALUATION OF THE EXISTING CONDITION OF SECTIONS

The guidelines for selection of preservation treatments are introduced in Chapter 52 of the *Bureau of Design and Environment Manual* (IDOT, 2010). Guidance is provided to select various preservation treatments based on the existing condition of pavement. An analysis was conducted to determine the appropriateness of some of the selected treatments. Before developing any model, this analysis can help to identify “unfit” sections and assure the model developed will be based on the sections that received the right type of treatment. As such, very fast or slow deteriorating sections can be associated with possible unfit sections. It is important to know whether or not the model development includes the existing condition of pavement prior to the treatment.

Figure 2.3(a) shows a colormap indicating the appropriateness of the micro-surfacing treatment for each section (each row in the figure) according to the IDOT guidelines. The analysis was conducted on the sections right before they received the treatment. The data is grouped in three columns, with each row containing five slots for a distress record. The values next to each row show the CRS before treatment, and the color of each cell indicates the appropriateness of the treatment for that distress, according to the guideline. According to Chapter 52, the recommended, feasible, and not recommended guidelines only provide guidance for treatment selection based upon attributes (e.g., distress levels, ride, friction, traffic levels, relative cost). It is recommended “where multiple distresses exist, examine the appropriate treatment(s) to address each distress type. Use the recommended treatments in combination with engineering judgment to make final treatment decisions” (IDOT, 2010). Therefore, the assumption for this study is that whenever there is a single, not recommended distress, the section is identified as “Not Recommended”. If all distresses are identified as feasible, the section is considered as “Feasible”. If all distresses are at the recommended severity and frequency level, the section is considered as “Recommended”. It can be noted that most of the sections are feasible choices for micro-surfacing treatment, with very few “unfit” sections, as also shown in the histogram plot in Figure 2.3(b). However, it is also important to note that the way the CRS is calculated may also contribute to the outcome. The cap of five distresses and relatively less emphasis on distresses of the structural type (as discussed in Chapter 5 of Volume 1 for this study), may have obscured a proper evaluation of the existing condition of sections as to their appropriateness. According to the data available, except for some of the distresses (shown in red), the overall appropriateness analysis shows that the micro-surfacing treatment appears to be feasible for all sections. Therefore, model development can be carried out with the current database without removing any sections due to unacceptable existing conditions.



(a) (b)

Figure 2.3. Appropriateness analysis of micro-surfacing treatment using (a) colormap and (b) frequency analysis.

The existing overall condition of pavements prior to micro-surfacing is shown in Figure 2.4. According to definition, the notched box shows first and third quartiles (Q1 and Q3), with whiskers covering 1.5 interquartile range (1.5 IQR). The mid notched-line shows the median of the data. It can be seen that the majority of the sections were at a CRS range of 5.5 to 7, on average, one or two years before the treatment was applied.

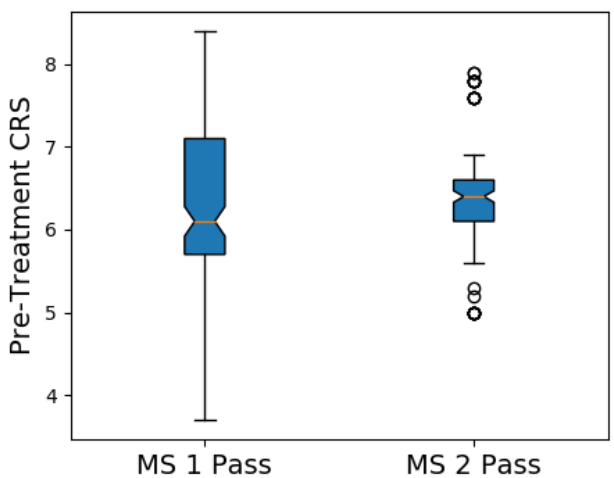


Figure 2.4. Boxplot of micro-surfacing, single- and double-pass.

2.4 SUMMARY

The data received from IDOT consisted of over 190 preservation contracts. According to an initial investigation of the data, many of these contracts are micro-surfacing, followed by chip seal and cape seal.

The data contained CRS, distress type and severity, and traffic information, along with the section's location and inventory number. A rigorous data cleaning procedure was conducted to make the database ready for model development. Inconsistencies in the CRS records were eliminated, based on assumptions presented in the chapter. Data cleaning reduced the available number of data points significantly.

The existing condition of the pavement was assessed for appropriateness of the selected treatment for each section. According to the preservation treatment selection guidelines from Chapter 52 of the *Bureau of Design and Environment Manual* (2010), many of the micro-surfacing sections were found to have distress levels considered feasible enough to use the selected treatment. However, it was noted that this evaluation may be misleading due to the models used in calculating CRS, in terms of the weights assigned to functional and structural distresses.

CHAPTER 3: MODEL DEVELOPMENT

This chapter introduces the modeling approach and results of the models developed for the preservation treatments.

3.1 MODELING APPROACHES

Different modeling approaches were discussed in Chapter 3 of the Volume 1 report for this study. A similar two-slope model was used to develop models consistent with the rest of the interstate and non-interstate asphalt- and concrete-surfaced pavements. With the given availability of the data, it was only possible to develop such models for the micro-surfacing sections. However, since the goal is to develop models for each of the treatments introduced in Chapter 2, an approach was used to fill the data gap with expert opinion. An analytical approach was employed using questionnaire responses to develop model coefficients. The analytic network process (ANP), which is a method of expert knowledge extraction, was adopted to develop prediction models for treatments with little or no data.

Additional variables were considered in the development of preservation treatment models. The effectiveness of any preservation treatment is very much dependent on the existing pavement condition, traffic, truck percentage, and other site-specific factors. Therefore, some of these factors were considered as independent variables in the model development.

3.1.1 Two-Slope Model

A linear equation relating age to CRS can be defined as:

$$CRS_{predicted} = CRS_{current} - m \times t \qquad 3.1$$

Where t is time and m is the slope of the model before and after break points calculated either by using representative-slope method or fitting a line. Models were developed using the weighted averaging method where length of each section is used as a weighting factor to accommodate variabilities in section lengths.

There are two methods in developing and finding the slope. In the first method, a line is fitted to all data points using the age of the sections as independent variables and the CRS as dependent variables. The first approach requires reliable age information, also referred to as the “continuous modeling approach” in Chapter 3 of Volume 1. In the second approach, called the “representative-slope approach,” the time series data for every two successive points is taken and the slope between them is calculated. The final slope is the average of all slope values. When a less reliable age record is available, the representative-slope approach is preferred, as it uses every successive data point, regardless of its age value. The prediction models introduced in Volume 1 using the two-slope model were developed using the representative-slope method.

Both of the modeling approaches were applied to the micro-surfacing treatment because sufficient data was available. After a rigorous data cleaning and filtering process, a database was prepared with the CRS time series for model development. Figure 3.1 shows the time series plot of micro-surfacing, single- and double-pass. In obtaining time series data, every section with at least two successive CRS records after the application of the treatment, was kept in a separate database for model development. The CRS record right after treatment was set to an artificial 9.0. The time series progression shows a clear reduction of the CRS in the first couple of years, partly due to an initial assignment of CRS, and slowing down afterwards.

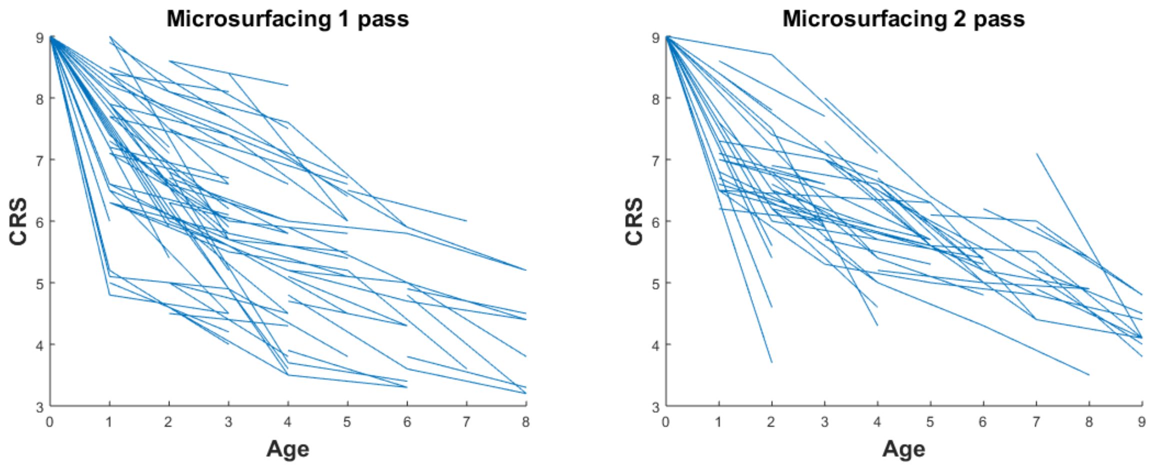


Figure 3.1. Time series plot of micro-surfacing, single- and double-pass.

Because the age record for the treatment itself was reliable after cleaning, a direct fitting to the time series data was possible. Before fitting the model to all data, a cluster analysis was conducted to possibly regroup the data based on district, surface type, CRS value before treatment, average daily traffic (ADT), truck percentage, and current International Roughness Index (IRI) value (Arthur and Vassilvitskii, 2007; Lloyd, 1982). These are used as variables in the modeling. The input variables were selected as criteria to divide the database into clusters, for which the sections in each cluster are believed to behave similarly. Therefore, an independent and unique equation can be developed for each cluster. The results of the cluster analysis did not reveal significant differences between various numbers of clusters, as well as variables. As a result, all data were considered in one group under single-pass and double-pass micro-surfacing treatments. Therefore, one prediction model for each treatment was developed.

Different techniques were used to directly fit the data to the existing CRS age time series data, and potential independent variables were explored using regression techniques. The ultimate goal was to find the slope in Equation 3.1 (previous page) and the variables affecting the deterioration. An alternative to direct fitting, the representative-slope method, was also used. This method is more straightforward and applicable in this case, and it is also consistent with the model development followed for other types of pavement. The results from the representative-slope method will be presented next.

3.1.2 Representative-Slope

An alternative to the direct-fitting approach, the representative-slope approach, was adopted. In this approach, the time series data for every two successive points is taken and the slope between them is calculated. The final slope is the average of all slope values before and after a break point. Given the relatively fast deterioration rate of the newly treated sections (Figure 2.4), the break point is selected as 2, 3, or 4 years, whichever would give the best prediction accuracy. Therefore, using the representative-slope approach, a bi-slope model can be developed with age as the break point. It should be noted that a CRS value can also be selected as a break point similar to the CRS models developed for various asphalt- or concrete-surfaced pavements investigated in Volume 1. However, due to a relatively short service life of treatment activities and the higher variance of data around a specific CRS value shortly after the treatment, finding the breakpoint CRS can pose some challenges. Therefore, it was noticed that the best approach was to use "age" as the break point rather than CRS. This effect can also be seen in the high discrepancy of data on the *y*-axis in the deterioration curve, as shown in Figure 2.4 and Figure 3.1.

It should be noted that in the modeling process, age was either not used as a variable, or the predictions were limited to short periods. The recorded age data is not accurate, so any model involving the time variable would be unreliable, especially for long-term predictions.

Tables 3.1 and 3.2 show the slope values for a set of possible break points. According to the model accuracy and prediction results in terms of the goodness-of-fit measure and the root mean square error (RMSE), a break point of 3 years was chosen for final model development. Figure 3.2 shows the two-slope model's scatter plot for micro-surfacing, single-pass and double-pass. The model performance is reported using the RMSE and the goodness-of-fit (R-squared) measures on all data.

Table 3.1. Two-Slope Model Parameters and Statistics for Micro-surfacing, Single-Pass

Equation	**CRS = 9.0 – *m* × *t***					
Break point (years)	2 years		3 years		4 years	
Time (*t*)(years)	$t < 2$	$t \geq 2$	$t < 3$	$t \geq 3$	$t < 4$	$t \geq 4$
Slope (*m*)	-0.94	-0.42	-0.86	-0.36	-0.80	-0.36
Standard deviation	0.83	0.31	0.78	0.26	0.76	0.24
Time to reach CRS = 4.5	8.2		8.4		7.7	
RMSE	0.94		0.96		1.02	
R^2	0.7		0.74		0.73	

Table 3.2. Two-Slope Model Parameters and Statistics for Micro-surfacing, Double-Pass

Equation	**CRS = 9.0 – *m* × *t***					
Break point (years)	2 years		3 years		4 years	
Time (*t*) (years)	$t < 2$	$t \geq 2$	$t < 3$	$t \geq 3$	$t < 4$	$t \geq 4$
Slope (*m*)	-0.69	-0.51	-0.67	-0.46	-0.65	-0.42
Standard deviation	0.63	0.30	0.55	0.28	0.54	0.29
Time to reach CRS = 4.5	8.1		8.4		8.6	
RMSE	0.95		0.94		0.96	
R^2	0.7		0.72		0.64	

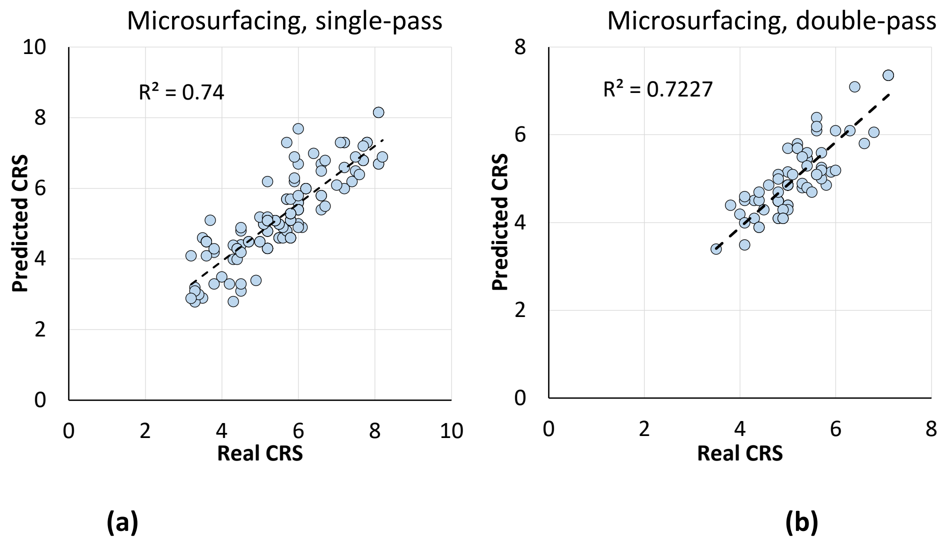


Figure 3.2. Final two-slope model prediction versus real CRS for micro-surfacing, (a) single-pass and (b) double-pass (break point is 3 years).

Similarly, a representative-slope was calculated for other treatments. Table 3.3 provides a summary of the total number of time series data points and corresponding average slopes for treatments other than micro-surfacing. Since there were no data collected for UTBWC type of treatments, the representative slope for this treatment was not calculated. In addition, there were enough data to calculate the representative slope for CIR type of treatments. As shown in the table, the number of data points for developing models for treatments other than micro-surfacing is not sufficient. Therefore, an alternative approach was followed to develop models for the preservation treatments when data is not available or not reliable for model development. To be consistent, the same alternative modeling approach was applied to micro-surfacing as well.

Table 3.3. Number of Time Series Data Points for Preservation Treatments Other than Micro-surfacing

Treatment	Number of data points	Mean slope	min	max
Half-SMART	6	-0.51	-1.60	-0.05
Seal coat	5	-1.8	-4.00	0.01
Slurry seal	12	-0.32	-1.05	0.01
Cape seal	4	-0.35	-0.55	-0.25
Chip seal	16	-0.33	-0.85	0.01

3.1.3 Evaluation of Independent Variables

Using the available data, potential effects of the factors affecting CRS progression (such as traffic, truck percentage, and existing CRS) were also evaluated. Similar to the earlier study (APTech, 2011), the data did not reveal any significant differences according to changes in these variables. Potential causes of such results not consistent with engineering rationale and expectations were discussed in the earlier study by APTech (2011). Some of these were as follows:

- The way the CRS is calculated can obscure the measurement of treatment effectiveness. More emphasis is given to the functional rather than the structural distresses. Therefore, most of the sections appeared to be feasible for the treatment. However, in reality, they may not be very good candidates for the treatment.
- Lack of accurate pre-treatment data
- Insufficient resolution of the CRS record capturing the condition of the treated section. In many of these cases, the section treated was a small segment of a larger CRS section.

Our goal in this study was to develop a rational treatment prediction model with the available data, to the extent possible. However, it was shown that available data can be either insufficient or not consistent with engineering expectations. Therefore, different alternatives were explored to tackle this problem, which will be discussed next.

3.2 EXPERT DECISION SUPPORT SYSTEM

Multi-criteria decision-making (MCDM) techniques can capture subjective data and handle qualitative factors, as well as quantitative variables. These techniques are also well suited for eliciting expert knowledge for situations in which there is lack of sufficient data. In MCDM, a discrete set of explicit alternatives should be prioritized using methods to compare, select, or rank conflicting alternatives that involve incommensurate attributes (Levy, 2005). MCDM approaches can be useful decision support systems (DSS) in pavement management when the decision problems are complex and have multiple criteria or objectives. There are many techniques used for MCDM problems. Among them are the analytic hierarchy process (AHP) and the analytic network process (ANP) developed by Saaty (1980; 1996; 2004). These methods allow users to assess the relative weight of multiple criteria against given criteria in an intuitive manner. In case quantitative ratings are not available (i.e., effect of traffic or existing CRS on the treatment's performance, missing model for a treatment), policy makers or assessors can still recognize whether one criterion is more important than another. This capability is the main advantage of pairwise comparisons in these methods.

3.2.1 Analytic Network Process (ANP)

The ANP is the generalization of the AHP, with dependencies and feedback among criteria or alternatives. This technique aims to address the restriction of hierarchical structure in the AHP technique. This method, unlike AHP, involves the interaction and dependence of higher-level elements on lower-level elements, and therefore makes a *network* structure rather than *hierarchy*. In addition, the importance of the criteria and alternatives mutually determine one another (Saaty and Vargas 2006). One of the fundamental ideas in support of ANP is that the ANP priorities are not just alternatives but also groups or clusters of elements (Isaai, et al. 2011). Figure 3.3 compares AHP and ANP model structures schematically. For more details and mathematical calculation of the technique, refer to Saaty (2004).

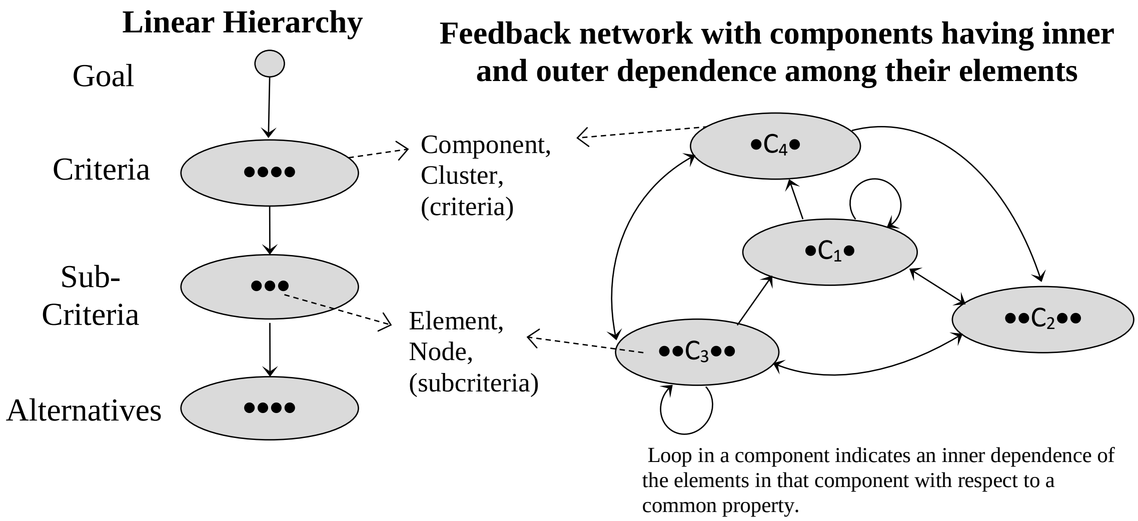


Figure 3.3. Comparison of AHP and ANP models.

The main results of an ANP model are the overall priorities of the alternatives, criteria, and subcriteria obtained by synthesizing the priorities from the pairwise comparisons conducted by experts. The final result is a priority vector that gives the priority of each alternative, with the components adding up to a value of 1. Each expert does the pairwise comparison and each judgment is assigned a number on a scale. One common scale adopted from Saaty (2004) is shown in Table 3.4. Another important feature of this method is that one may establish a procedure to involve criteria and subcriteria in decision making for the modeling process using the priorities obtained from the network. In mathematical modeling, these priorities can be translated into weights of the explanatory variables (criteria or subcriteria).

Table 3.4. The Rating Scale Used in the ANP Model (Saaty, 2004)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed

According to Saaty, (2004), the ANP model comprises the following steps:

1. Identifying the components and elements of the network and their relationships

2. Conducting pairwise comparisons on the elements (this step requires questionnaires)
3. Placing the resulting relative importance weights (eigenvectors) in pairwise comparison matrices within the supermatrix (unweighted supermatrix)
4. Conducting pairwise comparisons on the clusters (each criterion)
5. Weighting the blocks of the unweighted supermatrix, by the corresponding priorities of the clusters, so that it can be column-stochastic (weighted supermatrix)
6. Raising the weighted supermatrix to limiting powers until the weights converge and remain stable (limit supermatrix)

3.2.2 Implementation of ANP

The ANP method provides the mathematical framework for the current study to elicit expert knowledge to derive the CRS prediction models for various treatments. The main criteria were determined, and an ANP network was designed. Figure 3.4 shows the network in the SuperDecisions software environment.

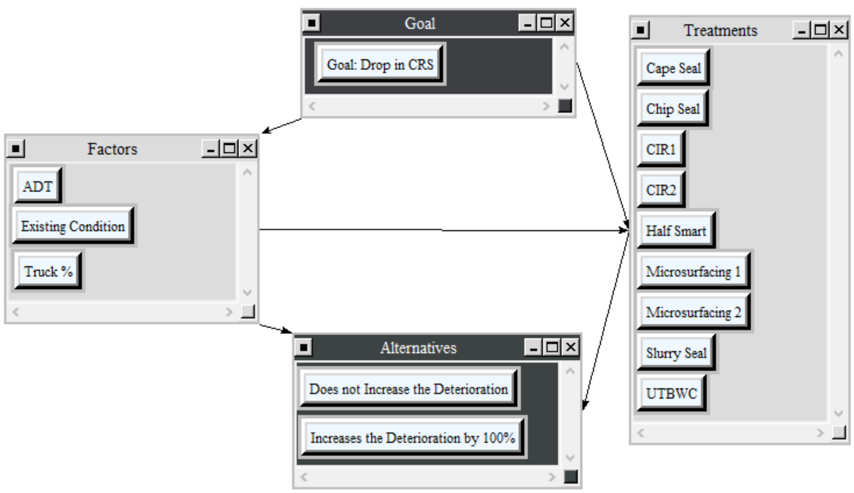


Figure 3.4. The ANP model developed in the SuperDecisions software environment.

The goal cluster is the starting point and indicates the goal of the network where other clusters are compared under this goal. Two main clusters were identified as the "Factors" and "Treatments." The factors cluster contains the main subcriteria affecting the deterioration of the treatments, including average daily traffic (ADT), existing surface condition before treatment, and percent truck traffic. Assuming the same geographical location for different treatments and neglecting the minor environmental variations in the state, environment was not included in the analysis.

3.2.3 Model Development Procedure

A procedure was established to translate the raw expert answers into a prediction modeling scheme. In this procedure, as shown in Figure 3.5, the three subcriteria (ADT, existing condition [CRS'], and truck percentage [Tr%]) are considered as the explanatory variables of the proposed deterioration model. The same deterioration model with one slope was assumed, as shown in Equation 3.2. The notion is based on the adjustment factor definition, i.e., adjusting the deterioration model slope using a combined adjustment factor involving the three subcriteria (factors). The choice of a one-slope model as opposed to a two-slope model is explained as follows. The rationale behind the two-slope approach was that the second part of the CRS deterioration curve has a flatter slope due to various maintenance activities slowing further deterioration of the pavement. In the case of treatments, the service life is shorter and the likelihood of any maintenance activities on the treated surfaces is low. Therefore, one may expect that the one-slope model with a linear deterioration may be suited for pavement preservation treatments.

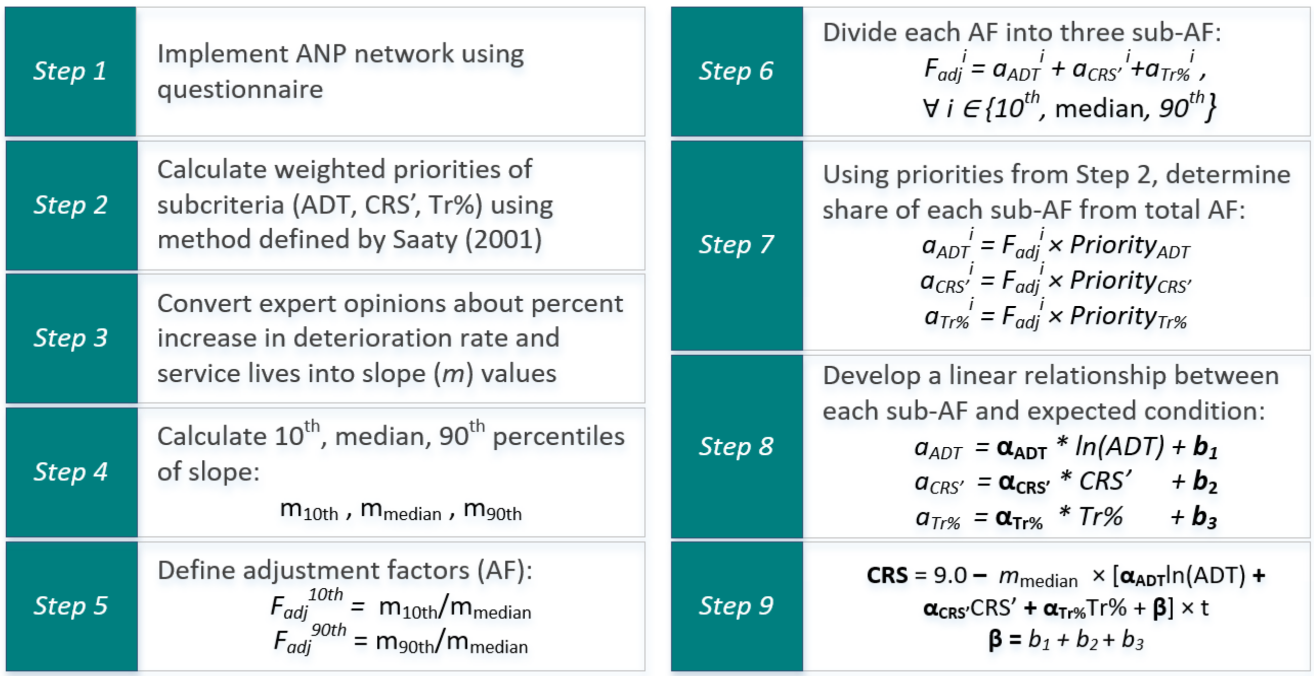


Figure 3.5. Summary of the procedure to develop a prediction model from the ANP model.

The linear deterioration model with slope *m* is defined as:

$$CRS_{predicted} = CRS_{current} - m \times t$$
$$m = m_{avg} \times F_{adj} \quad 3.2$$

where m_{avg} is the average slope.

F_{adj} is a combined adjustment factor to include the effects of the existing CRS, traffic, and truck percentage, calculated using the deviation from the average slope, representing the influence of major factors, including existing CRS, traffic, and truck percentage.

The raw outcomes of the ANP model that are used in this procedure are the priorities of factors (subcriteria) (Step 2) and percent increase in the deterioration rate of specific treatments under given conditions. Next, these percentages are analyzed and converted into slope values using an assumed average deterioration rate and the expected service life estimations from experts (Step 3). After investigating the slope and service life distributions, and considering the total number of responses for each treatment, the 10th and 90th percentiles were used as the lower and higher bounds; and the median was used as the average value of the deterioration rate (Step 4). Alternatively, a range of literature values can be used to define these bounds. In Step 5, lower and higher bound adjustment factors are defined. Using priorities obtained in Step 2, each of the lower bound, mean, and higher bound AFs can be broken down into three sub-adjustment factors for the three subcriteria of ADT, truck percentage, and existing condition (Steps 6 and 7). In Step 8, given a minimum and maximum range of subcriteria (defined also in the questionnaire), a linear relationship can be developed to relate the adjustment factors to the subcriteria. The final deterioration model is the adjusted slope resulting from the summation of all three sub-AFs for the three subcriteria (Step 9).

3.2.3.1 Collection of Expert Opinion through Questionnaires

Following Step 1 of the procedure (Figure 3.5), an online questionnaire was designed based on the possible pairwise comparisons from the ANP network and distributed among IDOT and state engineers. The questionnaire distributed to IDOT districts and counties is provided in Appendix A.

The questionnaire targeted collecting information from the experts answering the following major questions:

- Average yearly deduct from the CRS (slope of deterioration)
- Variations in the slope
- Relative importance of factors affecting slope for each treatment
- Relative comparison of deterioration under different scenarios of traffic, truck percentage, and existing CRS

An example of typical questions is shown in Figure 3.6.

8 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **UTBWC** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

9 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **Cape Seal** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

10 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **CIR** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 3.6. Typical comparative questions used in the questionnaire comparing two factors (A and B) chosen from the modeling variables: ADT, existing condition, and truck traffic.

These questions are trying to elicit expert knowledge about the importance of each factor (i.e., ADT, truck percentage, and existing condition) on the performance of the UTBWC, Cape Seal, and CIR treatments, using the scale provided in Table 3.4.

Overall, 32 responses were collected, 15 complete and 17 incomplete. All information, regardless of the degree of completeness, was used.

The overarching goal of the questionnaire was to (1) determine the slope from raw deterioration rate rankings by experts and its variation; (2) determine the significance of each factor; and (3) develop a deterioration model to include all factors.

3.2.3.2 Analysis of Questionnaire Responses

One of the outcomes of the ANP method is the priority of criteria and subcriteria (Step 2). It entails analyzing expert-answered questions and following the ANP method of network analysis, which uses the eigenvalue method to calculate the relative weights of elements in each pairwise comparison matrix (Saaty, 2004). Raw pairwise comparisons are converted to a relative importance (priority) measure of each factor. Figure 3.7(a) shows the priorities of the subcriteria according to the expert opinions. Each bar represents one expert opinion and the marker shows the average importance of each subcriteria over all experts. The error bars show the range of two standard deviations of the data. Also, Figure 3.7(b) shows the average priorities for each treatment, averaged over all expert opinions. It was observed that the existing condition (CRS') is the most significant factor affecting the performance of each treatment. ADT and truck percentage have relatively the same importance. This observation will need to be reflected in the models. Example calculations for relative importance factors and other parameters will be provided in the following sections. It is also important to note that although there were no data collected for the application of UTBWC, this treatment was added to the questionnaire and model development based on expert opinion.

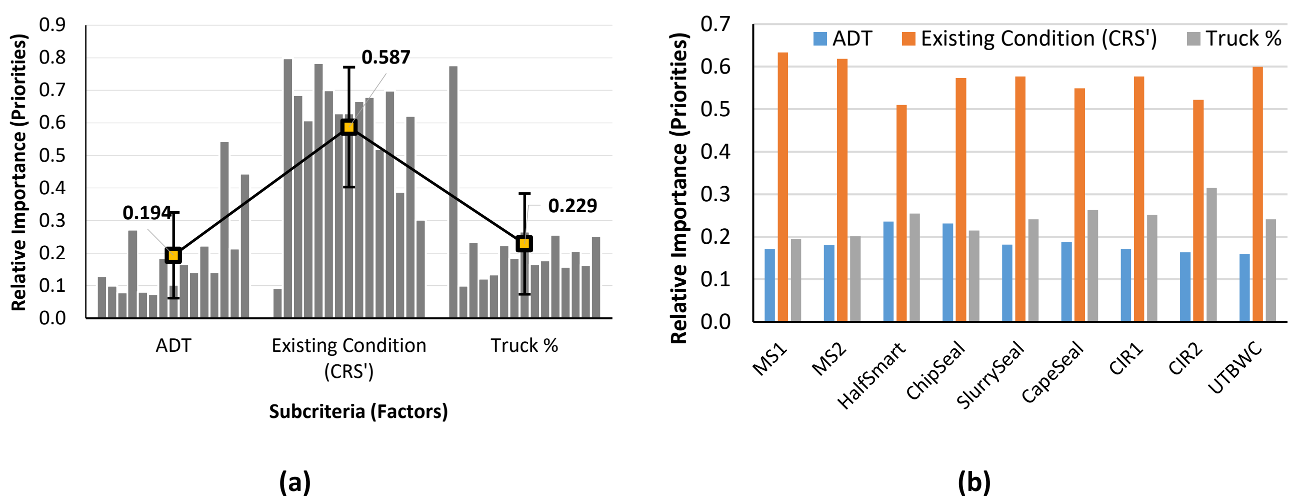


Figure 3.7. Priorities of subcriteria (factors) according to expert opinions: illustrated (a) for each expert averaged over all treatments and (b) for each treatment averaged over all experts.

Expected treatment service life estimates based on direct expert opinions are provided in Table 3.5. The first row for each treatment shows the number of experts and the second row is the percent of total responses. In developing models, while mean slope/service life values were obtained from an expert-based data analysis using ANP model. The 10th and 90th service life ranges were obtained from direct expert estimates and existing literature compiled in Table 3.6. The service life estimates require support by additional expert knowledge because service life plays a critical role in determining the range of slope values.

Table 3.5. Service Life Estimates Based on Direct Expert Opinion

Treatment	Service Life (years)										Standard deviation	Responses	Weighted average
	< 3	3	4	5	6	7	8	9	10	> 10			
Micro-surfacing, single- pass	2	0	0	9	4	1	3	0	1	1	2.62	21	6.0
	10%	0%	0%	43%	19%	5%	14%	0%	5%	5%			
Micro-surfacing, double- pass	0	2	0	3	4	4	3	0	2	2	1.48	20	7.1
	0%	10%	0%	15%	20%	20%	15%	0%	10%	10%			
Half-SMART	3	2	3	3	3	0	2	0	0	0	1.36	16	4.5
	19%	13%	19%	19%	19%	0%	13%	0%	0%	0%			
Chip seal	1	6	8	8	1	1	1	0	0	0	3.17	26	4.4
	4%	23%	31%	31%	4%	4%	4%	0%	0%	0%			
Slurry seal	3	1	3	3	2	1	1	0	1	0	1.12	15	4.8
	20%	7%	20%	20%	13%	7%	7%	0%	7%	0%			
Cape seal	1	0	0	5	0	1	4	1	2	2	1.62	16	7.5
	6%	0%	0%	31%	0%	6%	25%	6%	13%	13%			
CIR1	2	0	0	1	1	2	2	0	2	10	2.79	20	9.2
	10%	0%	0%	5%	5%	10%	10%	0%	10%	50%			
CIR2	1	1	0	0	0	0	0	0	3	14	4.13	19	10.7
	5%	5%	0%	0%	0%	0%	0%	0%	16%	74%			
UTBWC	1	0	1	1	0	2	1	0	3	1	0.89	10	7.5
	10%	0%	10%	10%	0%	20%	10%	0%	30%	10%			

Table 3.6. Literature-Reported Service Life Values for Various Treatments

State	Crack filling/ sealing	Fog seals	Slurry seal	Micro-surfacing	Chip seals	Cape seal	SMART	Half- SMART	UTBWC	Reference
Illinois	2–8	1–3	3–6	4–7	4–6	4–7	7-1–0	5–7	7–12	IDOT, 2010,
Minnesota	2–3	1–2	3–5	5–8	3–6	—	—	—	> 7 (Malaki, 2007)	Johnson, 2000
Nebraska	3–5	1–4	3–8	3-8	3–6	—	—	—	—	NDOR, 2002
Ohio	2–3 (David, 2001)	1		5–9 (Rajagopal, 2010)	4–7 (Rajagopal, 2010)	—	—	—	—	—
Pennsylvania	3–-5	1–3		4–7	3–5	—	—	—	> 5 (Ji et al., 2015)	Gopal, 2010
South Dakota	2–4	1–3		4–7	6–8	—	—	—	—	—
Indiana	1–3			8	4	—	—	—	9	INDOT, 2013
Wisconsin	1–3	1–2		4–8	3–7	—	—	—	5–8	Wisconsin, 2014
Michigan	1–3 (3 yrs, Hajj, 2010)	—		3–5	3–6	—	—	—	3–6	MDOT, 2010
Kansas	—	—	1–9		1–9	—	—	—	6	Liu, 2010 (Musty and Hossain, 2014)

3.2.3.3 Example Model Development

Following the model development steps, prediction models were developed for each treatment. In this section, the model development steps are provided in detail, with the single-pass micro-surfacing (MS1) treatment as an example. The service life ranges provided in the previous section are used to calculate the range of slope values for treatments. The slope was calculated as the slope of the line from the CRS of 9 to 4.5. For example, according to the literature and expert opinions, the range of service life for MS1 treatment can be assumed to be between 3.5 and 8 years. This translates into corresponding slope values of 1.29 and 0.56 to reach a CRS of 4.5.

Analyzing the ANP model, the priorities of deterioration rate of each treatment can be calculated. For example, for Expert 1, the final ANP model analysis result indicates that for all varying ADT, truck percentage, and existing condition, the priority of deterioration of MS1 treatment by 100% is 0.26. Using the range of slope values calculated for MS1, the average slope can then be calculated:

$$m_{MS1}^{E1} = (0.26) \times 1.29 + (1 - 0.26) \times 0.56 = 0.75$$

Table 3.7 shows the analyzed slope values from experts for each treatment, as well as the average priorities of each subcriteria averaged over all experts. Empty cells show that no response was collected from experts for that specific treatment.

Using the average slope values, the service lives were calculated and are shown in Figure 3.8. Each bar in the figure shows the mean value of failure time, and the error bars show the 10th and 90th percentiles (obtained from expert-based ANP analysis). The average values are in agreement with the expert-estimated service lives, as shown in Table 3.5.

An adjustment factor is defined to adjust the slope values according to various conditions that experts were asked about:

$$CRS = 9.0 - m \times \left(F_{adj}\right) \times t$$

Following Steps 5 through 7, adjustment and sub-adjustment factors can be calculated. For example, according to Table 3.7, the median value of the slope for MS1 is 0.9, with 0.56 and 0.9 as the 10th and 90th percentiles, respectively. Adjustment factors are then defined as:

$$F_{adj}^{10th} = {}^{m_{10th}}/_{m_{median}} = \frac{0.56}{0.9} = 0.63$$

$$F_{adj}^{median} = {}^{m_{median}}/_{m_{median}} = \frac{0.9}{0.9} = 1$$

$$F_{adj}^{90th} = {}^{m_{90th}}/_{m_{median}} = \frac{0.9}{0.9} = 1$$

Table 3.7. Analyzed Slope Values for Each Treatment, from Experts

Expert code		MS1	MS2	Half-SMART	Chip seal	Slurry seal	Cape seal	CIR1	CIR2	UTBWC
E1		0.75	0.64	0.90	1.13	0.90	0.90	0.38	0.38	0.45
E2		0.90	0.64	0.75	1.50	3.00	0.50	0.38	0.38	0.45
E3		0.90	0.75	3.00	1.13	1.50	0.56	0.38	0.38	—
E4		0.56	0.56	0.75	0.90	0.64	—	0.38	0.38	—
E5		—	—	—	1.50	—	—	-—	—	—
E6		—	—	—	1.50	—	—	—	—	—
E8		0.90	0.75	1.13	1.13	1.13	0.64	0.45	0.38	1.13
E9		0.56		0.56	0.56	—	0.45	0.56	0.45	—
E10		—	—	—	0.90	—	—	0.38	—	—
E11		0.75	—	—	1.50	—	—	—	—	—
E12		0.45	0.45	—	0.90	—	0.45	0.90	0.38	—
E13		0.75	0.56	0.90	0.90	0.90	0.90	0.64	0.45	0.64
E14		0.90	0.56	—	0.90	—	—	—	0.38	—
E15		0.56	0.38	0.75	1.13	0.56	0.56	0.56	0.38	0.38
E16		-—	—	—	—	—	—	—	—	—
E17		3.00	1.50	3.00	0.90	1.13	0.90	3.00	1.50	0.90
E18		—	0.64	—			—	—	—	—
E19		0.64	0.45	1.50	1.13	0.75	0.56	0.45	0.45	0.56
E20		0.90	0.90	—	1.13	—	0.38	0.38	0.38	—
E21		0.75	0.75	—	0.90	—	—	0.75	—	—
E22		0.38	0.38	0.56	0.64	0.45	0.38	0.38	0.38	0.45
E23		—	—	—	0.90	—	—	0.38	0.38	—
E24		3.00	1.50	1.50	3.00	3.00	3.00	3.00	3.00	3.00
E25		0.90	0.90	1.13	1.13	3.00	0.90	0.64	0.38	—
E26		—	—	—	1.50	—	—	0.38	0.38	—
E27		0.90	0.64	1.13	1.50	1.13	0.56	0.38	0.38	0.64
E28		0.90	0.75	0.90	0.75	0.75	—	—	—	—
E29		0.90	0.90	3.00	1.13	0.90	0.90	—	—	—
10th Quantile		0.56	0.44	0.90	0.90	0.65	0.41	0.38	0.38	0.44
Median		**0.90**	**0.64**	**1.01**	**1.13**	**0.90**	**0.56**	**0.41**	**0.38**	**0.60**
90th Quantile		0.90	0.96	2.63	1.50	1.80	0.90	1.11	0.66	1.31
Average priority	**ADT**	0.171	0.181	0.236	0.232	0.181	0.188	0.171	0.163	0.16
	Existing condition (CRS')	0.634	0.618	0.510	0.573	0.577	0.549	0.577	0.522	0.60
	Truck %	0.195	0.201	0.254	0.215	0.241	0.263	0.252	0.315	0.24

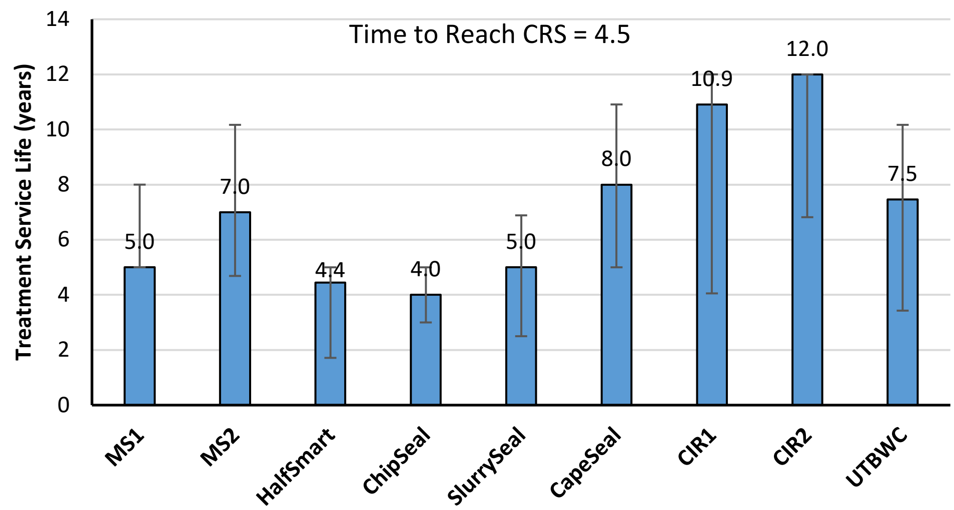


Figure 3.8. Service life estimates of each treatment, based on average slope values, with the 10th and 90th percentiles.

Each adjustment factor (F_{adj}^{i}) represents a given condition that experts were asked about. For example, the lower bound adjustment factor (F_{adj}^{10th}), which tends to lower the deterioration rate (m), can be related to the lower bound of ADT (ADT = 100), a good existing condition (CRS' = 7.0), and lower truck traffic (Tr% = 5%). Similarly, the median (F_{adj}^{median}) and upper adjustment bound (F_{adj}^{90th}) can be related to the average and extreme conditions. For this purpose, each adjustment first needs to be further divided into sub-adjustment factors for each factor (ADT, CRS', and Tr%).

Given the priorities of each factor, the adjustment factor can be divided into sub-adjustment factors:

$$F_{adj}^{i} = a_{ADT}^{i} + a_{CRS'}^{i} + a_{Tr\%}^{i} \quad , \quad \forall\, i \in \{10th, median, 90th\}$$

where,

$$a_{ADT}^{i} = F_{adj}^{i} \times Priority_{ADT}$$

$$a_{CRS'}^{i} = F_{adj}^{i} \times Priority_{CRS'}$$

$$a_{Tr\%}^{i} = F_{adj}^{i} \times Priority_{Tr\%}$$

For example in Table 3.7, the MS1 priority of factors according to Expert 1 (E1) are ADT = 0.17, CRS' = 0.63, and Tr% = 0.2; then the ADT factors are calculated:

$$a_{ADT}^{10th} = F_{adj}^{10th} \times Priority_{ADT} = 0.63 \times 0.17 = 0.11$$

$$a_{ADT}^{median} = F_{adj}^{median} \times Priority_{ADT} = 1 \times 0.17 = 0.17$$

$$a_{ADT}^{90th} = F_{adj}^{90th} \times Priority_{ADT} = 1 \times 0.17 = 0.17$$

Table 3.8 shows the result for all factors.

Table 3.8. Calculation of Adjustment Factors

	Factors			F_{adj}	Sub-Adjustment Factors		
	ADT	CRS'	Tr%		a_{ADT}	$a_{CRS'}$	$a_{Tr\%}$
Lower bound (10th)	100	7	0.05	0.63	0.11	0.40	0.12
Median	5,000	5	0.15	1	0.17	0.63	0.20
Higher bound (90th)	30,000	3.5	0.4	1	0.17	0.63	0.20

Knowing that a_{ADT}^{10th} corresponds to the lower bound ADT (ADT = 100), a_{ADT}^{median} to average condition (ADT = 5000), and a_{ADT}^{90th} to extreme condition (ADT = 30000), a linear relationship was defined to relate the adjustment factor to the value of the factor:

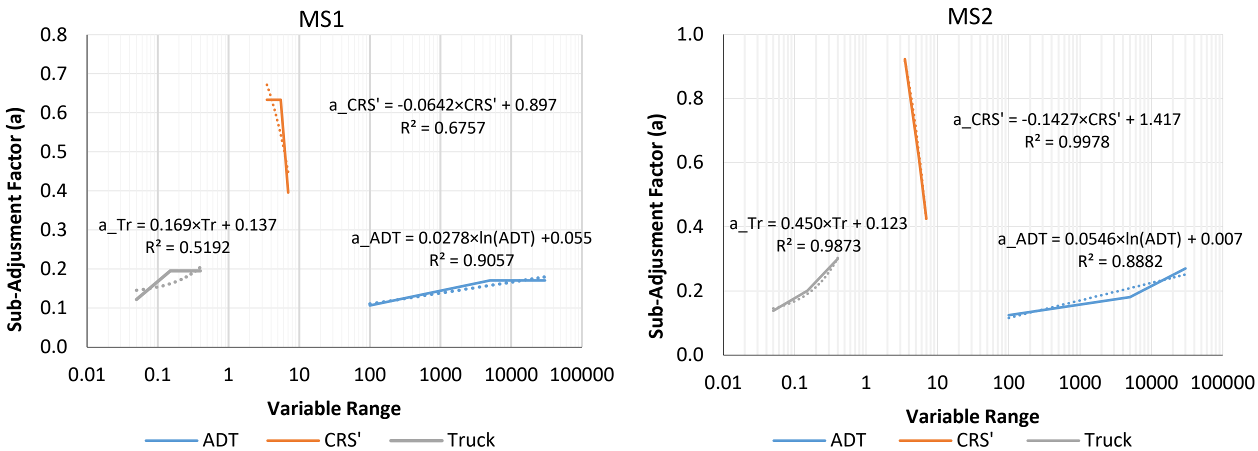
$$a_{ADT} = \boldsymbol{\alpha_{ADT}} \times ln(ADT) + \boldsymbol{b_1}$$

Similarly, for the other two factors:

$$a_{CRS'} = \boldsymbol{\alpha_{CRS'}} \times CRS' + \boldsymbol{b_2}$$

$$a_{Tr\%} = \boldsymbol{\alpha_{Tr\%}} \times Tr\% + \boldsymbol{b_3}$$

Figure 3.9 shows an example of such a relationship for single-pass and double-pass micro-surfacing. Input ranges include ADT from 100 (min) to 30,000 (max), existing condition CRS from 7.0 (min or best condition) to 3.5 (max or worst condition), and truck percentage from 5% (min) to 40% (max).



(a) **(b)**

Figure 3.9. Example of linear relationship developed between sub-adjustment factors and variable ranges for each factor and for (a) micro-surfacing, single-pass (MS1); and (b) micro-surfacing, double-pass (MS2).

3.2.3.4 Final Model Forms and Coefficients

Finally, following Step 8, sub-adjustment factors were summed to develop the prediction models including all three factors. Equation 3.3 presents the form of the model to include average deterioration affected by the three major factors.

$$CRS = 9.0 - m \times (\boldsymbol{\alpha_{ADT}} ln(ADT) + \boldsymbol{\alpha_{CRS'}} CRS' + \boldsymbol{\alpha_{Tr\%}} Tr\% + \boldsymbol{\beta}) \times t \qquad 3.3$$

where m is the average slope, and $\boldsymbol{\beta}$ is the sum of intercepts:

$$\boldsymbol{\beta} = \boldsymbol{b_1} + \boldsymbol{b_2} + \boldsymbol{b_3}$$

Table 3.9 shows the final prediction model for all treatments.

Table 3.9. Final CRS Prediction Models from Expert Knowledge Extraction ANP Method

Treatment type	CRS prediction model
Micro-surfacing, single-pass	CRS = 9.0 – **0.90** × (**0.028** * ln(ADT) – **0.064** × CRS' + **0.17** × Tr + **1.089**) × t
Micro-surfacing, double-pass	CRS = 9.0 – **0.64** × (**0.055** * ln(ADT) – **0.143** × CRS' + **0.45** × Tr + **1.547**) × t
Half-SMART	CRS = 9.0 – **1.01** × (**0.138** * ln(ADT) – **0.257** × CRS' + **1.31** × Tr + **2.132**) × t
Chip seal	CRS = 9.0 – **1.13** × (**0.046** * ln(ADT) – **0.088** × CRS' + **0.32** × Tr + **1.313**) × t
Slurry seal	CRS = 9.0 – **0.90** × (**0.083** * ln(ADT) – **0.214** × CRS' + **0.89** × Tr + **1.925**) × t
Cape seal	CRS = 9.0 – **0.56** × (**0.060** * ln(ADT) – **0.137** × CRS' + **0.65** × Tr + **1.511**) × t
Cold in-place recycling and surface treatment (CIR1)	CRS = 9.0 – **0.41** × (**0.105** * ln(ADT) – **0.304** × CRS' + **1.36** × Tr + **2.529**) × t
Cold in-place recycling and HMA overlay (CIR2)	CRS = 9.0 – **0.38** × (**0.042** * ln(ADT) – **0.118** × CRS' + **0.74** × Tr + **1.593**) × t
Ultra-thin bonded wearing course (UTBWC)	CRS = 9.0 – **0.60** × (**0.082** * ln(ADT) – **0.253** × CRS' + **1.02** × Tr + **2.173**) × t

3.3 MODEL SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to investigate the maximum and minimum prediction ranges using the models developed. An estimate of the maximum service life can be achieved using the minimum input ranges (ADT = 100, CRS’ = 7.0, and Tr% = 5%), and the minimum service life estimate can be achieved using the maximum input ranges (ADT = 30000, CRS’ = 3.5, and Tr% = 40%). All other possible combinations of input values will result in service life estimates between the maximum and minimum bounds. Figure 3.10 shows the prediction range for each treatment. Service life results are summarized in Table 3.10.

There is wide range of variability in the model responses when the conditions are in favor or against the application of a treatment. In general, cold in-place recycling treatment has the longest service life expectation, followed by cape seal; double-pass micro-surfacing; and ultra-thin bonded wearing course overlays (UTBWC). There is a considerable difference between cold in-place recycling scenarios with a HMA surface course (CIR2) and surface treatment (CIR1). Chip seal, slurry seal, and half-SMART are among the treatments with the shortest service lives, ranging from 3–4 years on average.

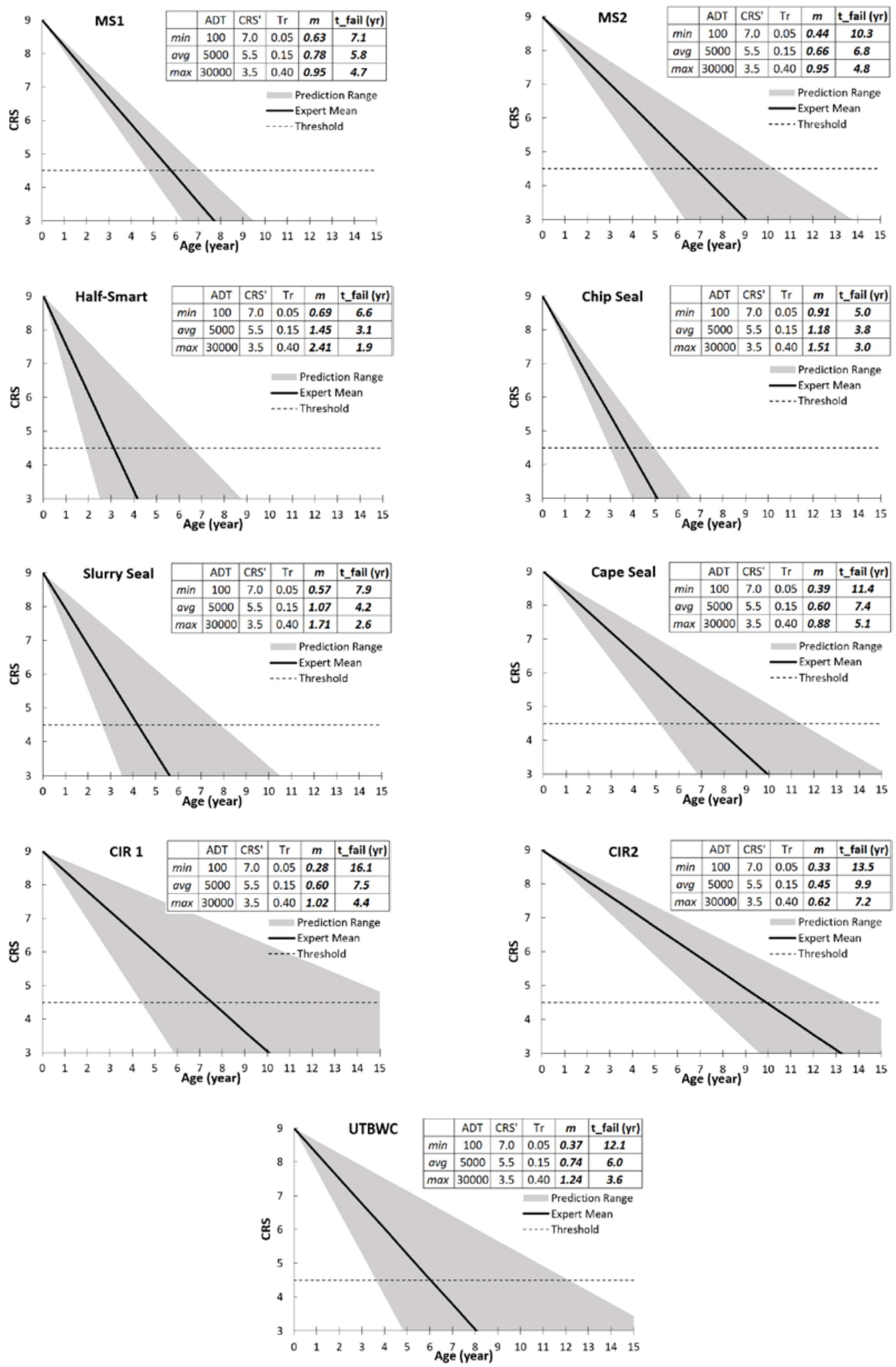


Figure 3.10. Prediction range for each treatment.

Table 3.10. Average, Minimum, and Maximum Service Life Comparisons

Treatment	Average service life to reach CRS = 4.5	Minimum service life to reach CRS = 4.5	Maximum service life to reach CRS = 4.5	Average service life to reach CRS = 6.0	APTech report (2011)
Micro-surfacing, single-pass	5.8	4.7	7.1	3.9	3–4
Micro-surfacing, double-pass	6.8	4.8	10.3	4.5	2-4
Half-SMART	3.1	1.9	6.6	2.1	NA
Chip seal	3.8	3.0	5.0	2.5	1–3
Slurry seal	4.2	2.6	7.9	2.8	NA.
Cape seal	7.4	5.1	11.4	5.0	3–5
CIR1	7.5	4.4	16.1	5.0	NA
CIR2	9.9	7.2	13.5	6.6	NA
UTBWC	6.0	3.6	12.1	4.0	NA

The results are consistent with the engineering expectations, as well as the results reported earlier. According to the APTech report in 2011, chip seal service life was anywhere between 1.5–2.8 years and provided the lowest service life extension. According to the models proposed, the service life for a chip seal can be as low as 3.0 years; and it is among the treatments with the lowest service life. By contrast, cape seal was found to have maximum service life extension. The proposed model also suggests that the longest service life can be achieved by cape seals, when compared to micro-surfacing and chip seals. The micro-surfacing service life was reported as 3.8 years in 2011, whereas the service life range proposed by the new model is 4.7–7.1 years. This discrepancy may indicate that conditions at the time of these treatment were less than favorable for the sections. However, it is unreasonable to estimate the service life for any of these treatments as anything less than 2 or 3 years under any scenario including the three factors. As also explained in the report by APTech in 2011, the calculated service lives are less than expected due to data inconsistencies and potential factors associated with CRS calculations.

In addition, an individual input variable sensitivity analysis was conducted to investigate the sensitivity of the prediction results for each variable. In this method, one variable at a time is increased from its minimum to maximum value while other variables are kept at their average value. Figure 3.11 shows an example prediction range plot based on existing condition (CRS') and the combined effect of ADT and truck percentage for single-pass and double-pass micro-surfacing. Figure

3.12 also shows the sensitivity of the model in terms of service life based on each factor for both single-pass and double-pass micro-surfacing. It is clear from the plot that the model is more sensitive to the existing condition. This can also be seen in Figure 3.13 where existing condition has the most significant impact on service life ranges for all treatments.

The results indicate that the predicted ranges are within the expected values. Moreover, it is apparent that the effect of the existing condition on the predicted CRS is higher than the effect of the other two factors.

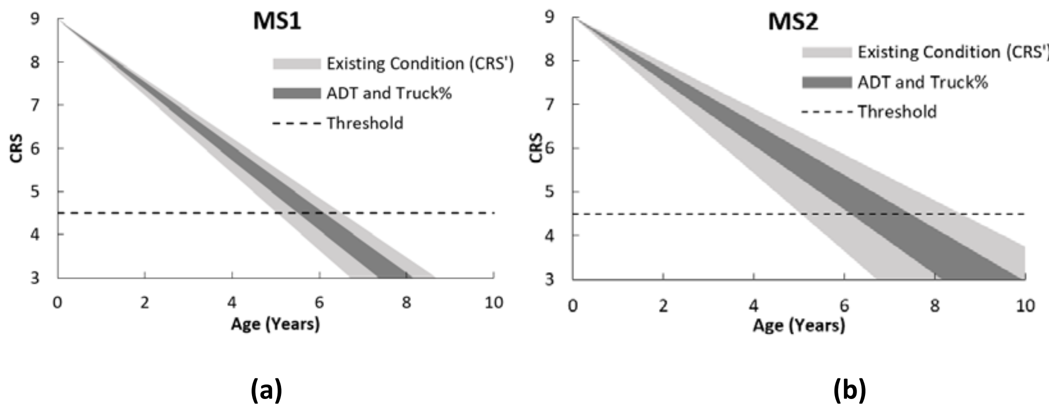


Figure 3.11. Prediction range plot based on varying existing condition (CRS') and the combined effect of ADT and truck percentage for micro-surfacing, (a) single-pass and (b) double-pass.

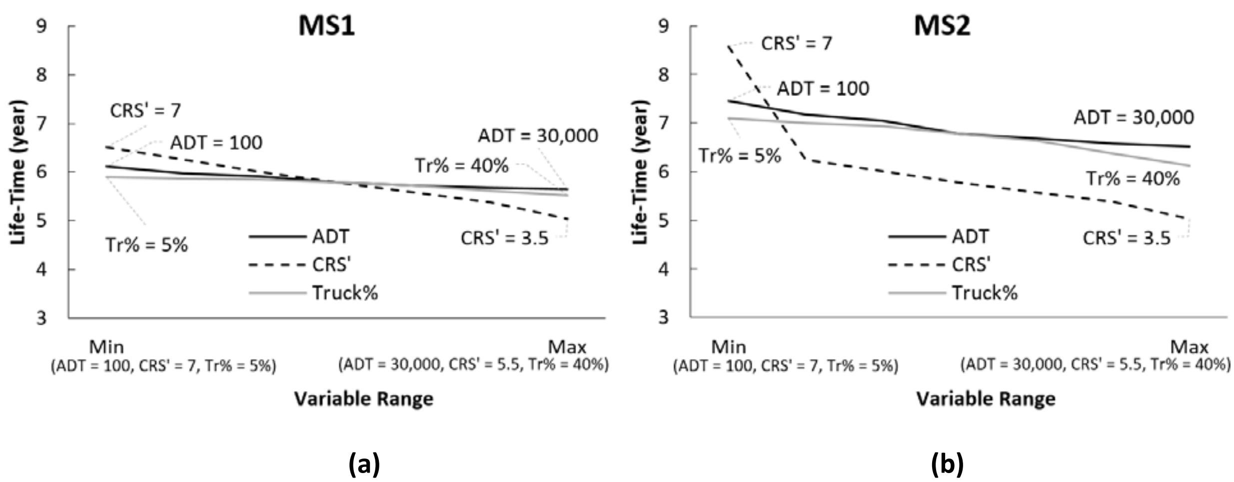


Figure 3.12. Sensitivity analysis of service life estimates based on each factor for micro-surfacing, (a) single-pass and (b) double-pass.

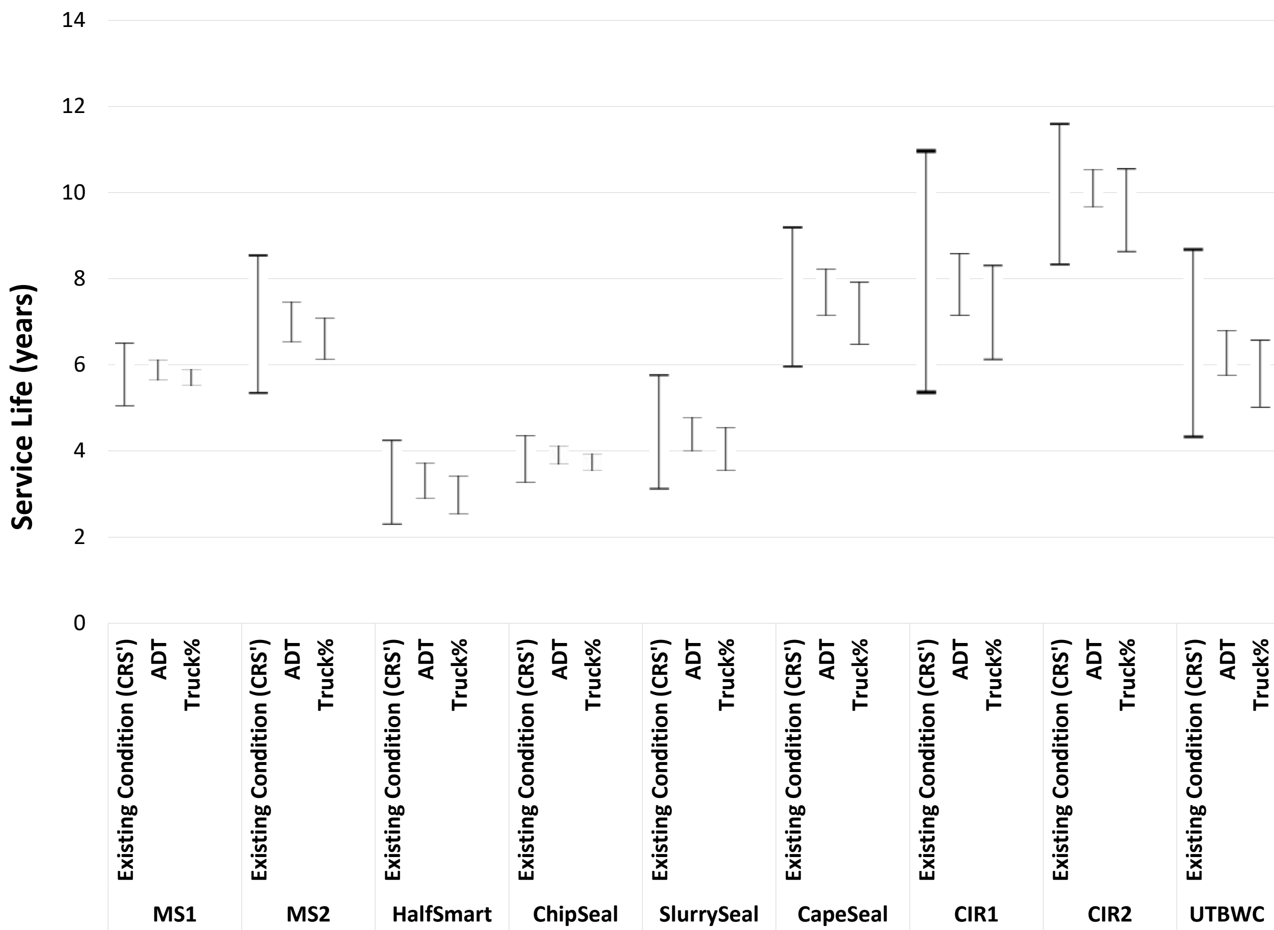


Figure 3.13. Service life ranges based on each factor for all treatments.

CHAPTER 4: SUMMARY AND CONCLUSIONS

A preservation program with dedicated funding has been initiated and in use by IDOT since FY 2005. The level of funding for preservation treatments and distribution to districts increased significantly since its inception. The IDOT preservation manual guides the districts in selecting preservation treatments for selected projects, using the appropriated available funding. Treatment effectiveness and service life are keys to the success of a pavement preservation program. The amount of data over the years contributed from an increasing number of projects accumulated which now allows for an evaluation of treatment effectiveness. Performance of various preservation treatment projects constructed from 2000 to 2014 were evaluated to develop pavement condition prediction models similar to the CRS prediction models used for the asphalt- and concrete-surfaced pavements.

According to the available data, the micro-surfacing treatment had enough data to develop data-based models. The two-slope model was used to develop models for single- and double-pass micro-surfacing. The models start from a CRS of 9.0 and deteriorate following a two-slope model, with a break point at the third year. According to the data-based prediction model, the service life to reach a CRS of 4.5, which would be the indication for resurfacing, is 7 to 8 years. However, for other treatments, there were not enough data to develop similar models. Therefore, a multi-criteria decision-making method known as analytic network process (ANP) was used to elicit expert knowledge. A questionnaire was developed based on the method and distributed among local experts in Illinois. The questionnaires had specific objectives, including determining the deterioration rate and its variation, and determining the significance of individual factors affecting treatment performance. This information was used to develop a deterioration-prediction model including the existing condition of pavement, traffic, and truck percentage.

In developing models using the ANP method, literature-reported as well as direct expert-based estimations of service life values were used to obtain the extreme range of the prediction model. Therefore, the models are ensured to result in predictions within the range of expected values. Nevertheless, the deterioration rate (slope) of each treatment varies within the expected range, depending on the given ADT, existing condition, and truck percentage levels. According to the modeling results, chip seal, slurry seal, and half-SMART treatments were among the shortest-lived treatments, with an average service life of 3 to 4 years to reach a CRS of 4.5. Micro-surfacing for single-pass and double-pass could extend the service life to approximately 6 or 7 years, respectively. This was found to be consistent with the data-based prediction modeling results (7–8 years). The cape seal treatment average service life extension is more than 7 years, whereas cold in-place recycling treatment with either HMA overlay or surface treatment can extend pavement service life by approximately 8 to 10 years. It was also found that the UTBWC treatment's performance can be comparable to that of the micro-surfacing treatments, by extending the pavement service life by 6 years on average with a wider range of variability. However, there were no data collected for UTBWC type of treatments for consistency checks.

Depending on the existing condition of pavement, traffic, and truck percentage, treatment service life varied. The effect of the existing pavement condition on CRS deterioration is much more pronounced than that of traffic and truck percentage. Micro-surfacing for a single-pass treatment can extend pavement service life by 7.1 years under favorable conditions (good pavement condition, low traffic and truck percentage); whereas the service life can be reduced to 5.8 when the existing pavement condition is poor and traffic is high. The half-SMART type of treatment appeared to be most sensitive to changes in the existing condition of pavement and traffic. The service life to reach a CRS of 4.5 was found to be 1.9 and 6.6 years under the least and most favorable conditions, respectively.

The proposed CRS prediction model allows for quantifying treatment effectiveness taking into account the existing condition of pavement prior to the treatment and traffic-related factors. The final proposed models were developed based solely on expert opinions obtained from the questionnaires. The model form and results are consistent with the expectations, engineering intuition, and individual section results reported earlier (APTech, 2011). This model form and coefficients can be used to evaluate the effectiveness of the pavement preservation program initiated in FY 2005 and for planning and programming of future treatments with available funds. However, it is strongly recommended to verify or fine-tune the coefficients of each one of these models with reliable data collected from the projects. Because the data collected from the IRIS could not be used to monitor the performance of these treatments very accurately, it is recommended to monitor the performance of these sections with independent surveys and high-resolution distress evaluation representing smaller segments of the treated area.

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APPENDIX A: SAMPLE QUESTINAIRRE FOR EXPERT KNOWLEDGE EXTRACTION BASED ON ANP METHOD

Pavement Treatment Performance Questionnaire

This questionnaire is prepared by **Illinois Center for Transportation** for the ICT project R27-150. Please contact Hasan Ozer (*hozer2@illinois.edu*) or Travis Lobmaster (*Travis.Lobmaster@illinois.gov*) for any questions.
Deadline to complete this survey is **February 1 (Wednesday)**.

Thank you for your participation. Your feedback is important.

Purpose:

ICT R27-150 Project "Revision of Pavement Condition Survey Models" is seeking your responses to an online survey. The objective of the survey is to collect expert opinion data related to performance of various pavement preservation treatments. The survey contains the following sections:

- *Treatment definitions*
- *Guide to fill out the questionnaire*
- *Comparable judgement questions for various scenarios affecting performance of treatment.*

The survey does not require data-based specific answers; however you can refer to the historical performance datasets or reports in your region. The outcome of the survey will be used to support development of performance prediction models. The duration to complete the survey is about **20 minutes**.

Please provide your contact Information below:

Full Name

Job title

Company/Organization

City/Town

State

Date (M/D/Y)

Definitions

The following provides definition of the treatments used in this questionnaire. For more detailed description and other considerations please refer to the IDOT Bureau of Design and Environment Manual Chapter 2 - Pavement Preservation

* If your definition and application of the treatment is different than that of IDOT, please briefly explain the differences or provide the name of the specification in the boxes below.

Microsurfacing: Applied in a process similar to slurry seals, micro-surfacing consists of a mixture of latex-modified emulsified asphalt, mineral aggregate, mineral filler, water, and additives. Micro-surfacing material is mixed in specialized, compartmented, self-powered trucks and placed on the pavement using an augured screed box.

Different definition or method of application?

Half Smart: Half-SMART overlays consist of placing a nominal 0.75 in. (19 mm) layer of HMA level binder followed by a *Bituminous Surface Treatment* (BST).

Different definition or method of application?

Chip Seal: Includes types A1 and A2. Also known as *Bituminous Surface Treatment (BST)*, is applied directly to the pavement surface followed by the application of aggregate chips which are then immediately rolled to imbed chips.

Different definition or method of application?

Slurry Seal: Slurry seals are a mixture of crushed well-graded aggregate (e.g., fine sand, mineral filler) and asphalt emulsion that is spread over the entire pavement surface with either a squeegee or spreader box attached to the back of a truck.

Different definition or method of application?

UTBWC: Ultra-Thin Bonded Wearing Course (UTBWC) is formed in one pass with the application of a heavy, polymer-modified asphalt emulsion tack coat and a gap-graded, polymer-modified 0.4 in. to 0.8 in. (10 mm to 20 mm) HMA layer.

Different definition or method of application?

Cape Seal: The treatment consists of a Chip Seal (BST), followed within a few days by a microsurfacing treatment to cover the chips and seal them in.

Different definition or method of application?

CIR: Cold in-place recycling (CIR) is an in-situ process used to recycle the top 2 in to 4 in. (50 mm to 100 mm) of an existing HMA pavement to construct a new HMA layer. As the name suggests, the recycling process is conducted without the addition of heat.
CIR1 is a combination of CIR with one of the other surface treatments
CIR2 is CIR with 2 to 4 in. (50 mm to 100 mm) asphalt overlay

Different definition or method of application?

Definitions (continued)

Where necessary, Condition Rating Survey (CRS) may be used to indicate the overall condition of the pavement section. CRS is a rating system from 1.0 to 9.0 according to the following categories. Also, a matching scale out of 100 is provided within parentheses.
CRS 1.0 to 4.5 (0 to 25 out of 100) = Poor
CRS 4.6 to 6.0 (25 to 50 out of 100) = Fair
CRS 6.1 to 7.5 (50 to 75 out of 100) = Good
CRS 7.5 to 9.0 (75 to 100 out of 100) = Excellent

Please answer the following questions:

Are you familiar with CRS rating system?

☐ Yes ☐ No

Does your company/organization use this rating system?

☐ Yes ☐ No

If other rating system is being used please indicate below.

Guide to Fill Out the Questionnaire

There will be a total of 12 questions. Please answer the questions to the best of your knowledge using the following scale:

1 = Equal Importance; Two activities contribute equally to the objective
2 = Weak or slight
3 = Moderate importance; Experience and judgement slightly favor one activity over another
4 = Moderate plus
5 = Strong importance; Experience and judgement strongly favor one activity over another

6 = Strong plus
7 = Very strong or demonstrated; An activity is favored very strongly over another; its dominance demonstrated in importance practice

8 = Very, very strong
9 = Extreme importance; The evidence favoring one activity over another is of the highest possible order of affirmation

For example, a typical question is shown as follows along the answer provided.

Question: With respect to **Microsurfacing** applications, rate the comparative importance of the three following factors: ADT, Pre-Treatment CRS and Truck Traffic.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Hint: The questions asks you to make a comparative judgement between ADT vs. Existing Condition or ADT vs. Truck Traffic, or Truck traffic vs. Existing Condition on the selection and performance of microsurfacing applications.
The pairwise comparison is made between the two factors A and B at a time with the importance scale from 1 (equal importance) to 9 (extreme importance), according to the previous scale definition.
For example, for the first pairwise comparison selection of 8 (A) would mean that factor A (ADT) is very, very strongly important than factor B (Existing Condition) and in contrast, 8 (B) would mean factor B (Existing Condition) is very, very strongly important than factor A (ADT).

Expected Life-time

Please provide the expected life (time elapsed after treatment application until the next major rehabilitation or reconstruction) in years for each treatment below.

	<3 yrs	3 yrs	4 yrs	5 yrs	6 yrs	7 yrs	8 yrs	9 yrs	10 yrs	>10 yrs
Microsurfacing 1 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 2 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half-Smart	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
UTBWC	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Scenario-Based Performance Estimation

Please answer the following scenarios considering a base case where pavement section is a 2-lane rural cross section pavement (ditches rather than curb and gutter) with design lane ADT of 5,000 and 15% trucks (750 truck traffic) that has a CRS of 5.5 (fair) and is a candidate for the treatment in question. This section is expected to deteriorate on an average rate between **0.2** to **0.4** unit CRS (**2.5** to **5.0** units out of 100) per year.

1 Comparing the base case with two different **ADT** of the design lane of 500 (very low) and 10,000 (very high), after application of the following treatments **how much faster** the section with higher traffic would deteriorate as compared to the pavement with lower traffic?

	<10%	+10%	+20%	+30%	+40%	+50%	+60%	+70%	+80%	+90%	+100%
Microsurfacing 1 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 2 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half-Smart	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
UTBWC	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

2 Comparing the base case with two different **truck volume** of the design lane of 50 (very low) and 2,500 (very high), after application of the following treatments **how much faster** the section with higher truck traffic would deteriorate as compared to the pavement with lower truck traffic?

	<10%	+10%	+20%	+30%	+40%	+50%	+60%	+70%	+80%	+90%	+100%
Microsurfacing 1 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 2 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half-Smart	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
UTBWC	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

3 Comparing the base case with two different **existing condition** of "good" (CRS 6.1 to 7.6) (50-75/100) and "poor" (CRS 1.0 to 4.5) (0-25/100), after application of the following treatments **how much faster** the section with poor condition would deteriorate as compared to the pavement with good condition?

	<10%	+10%	+20%	+30%	+40%	+50%	+60%	+70%	+80%	+90%	+100%
Microsurfacing 1 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 2 pass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half-Smart	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slurry Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
UTBWC	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

General Questions to Identify Model Variables and Significance

4 Compare and rate the importance of the three factors (ADT, truck, and existing condition) on the performance of **Microsurfacing single or double pass** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

5 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **Half Smart** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

6 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **Chip Sea**l treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

7 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **Slurry Seal** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

8 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **UTBWC** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

9 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **Cape Seal** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

10 Compare and rate the importance of the three factors (ADT, truck traffic, and existing condition) on the performance of **CIR** treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
ADT (A) vs. Existing Condition (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ADT (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Existing Condition (A) vs. Truck Traffic (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Treatment Performance Pairwise Comparisons

11 Compare the following pair of treatments to indicate which treatment **would deteriorate faster** when they are applied to the sections with similar, traffic and environmental conditions?

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
Cape Seal (A) vs. Chip Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal (A) vs. CIR (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal (A) vs. Half Smart (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal (A) vs. Microsurfacing 1pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal (A) vs. Microsurfacing 2pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal (A) vs. UTBWC (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cape Seal (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal (A) vs. CIR (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal (A) vs. Half Smart (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal (A) vs. Microsurfacing 1pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal (A) vs. Microsurfacing 2pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal (A) vs. UTBWC (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chip Seal (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR (A) vs. Half Smart (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR (A) vs. Microsurfacing 1pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR (A) vs. Microsurfacing 2pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR (A) vs. UTBWC (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half Smart (A) vs. Microsurfacing 1pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half Smart (A) vs. Microsurfacing 2pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half Smart (A) vs. UTBWC (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Half Smart (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 1pss (A) vs. Microsurfacing 2pss (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 1pss (A) vs. UTBWC (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 1pss (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 2pss (A) vs. UTBWC (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Microsurfacing 2pss (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
UTBWC (A) vs. Slurry Seal (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CIR1 (A) vs. CIR2 (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

12 Compare the effect of factors (ADT, truck traffic, and existing condition) or type of treatment (Microsurfacing, Chip Seal, etc.) on the deterioration rate). Which one would be more important? Factors or the type of treatment.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)
Factros (A) vs. Treatment Type (B)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Thank you for completing this survey!

Please leave any comments below:

APPENDIX B: QUESTIONNAIRE RESPONSES

Direct responses from the questionnaire are analyzed and provided as follows:

- Are you familiar with CRS rating system?

	Yes	No	Standard Deviation	Responses
All Data	**22 (69%)**	10 (31%)	6	32

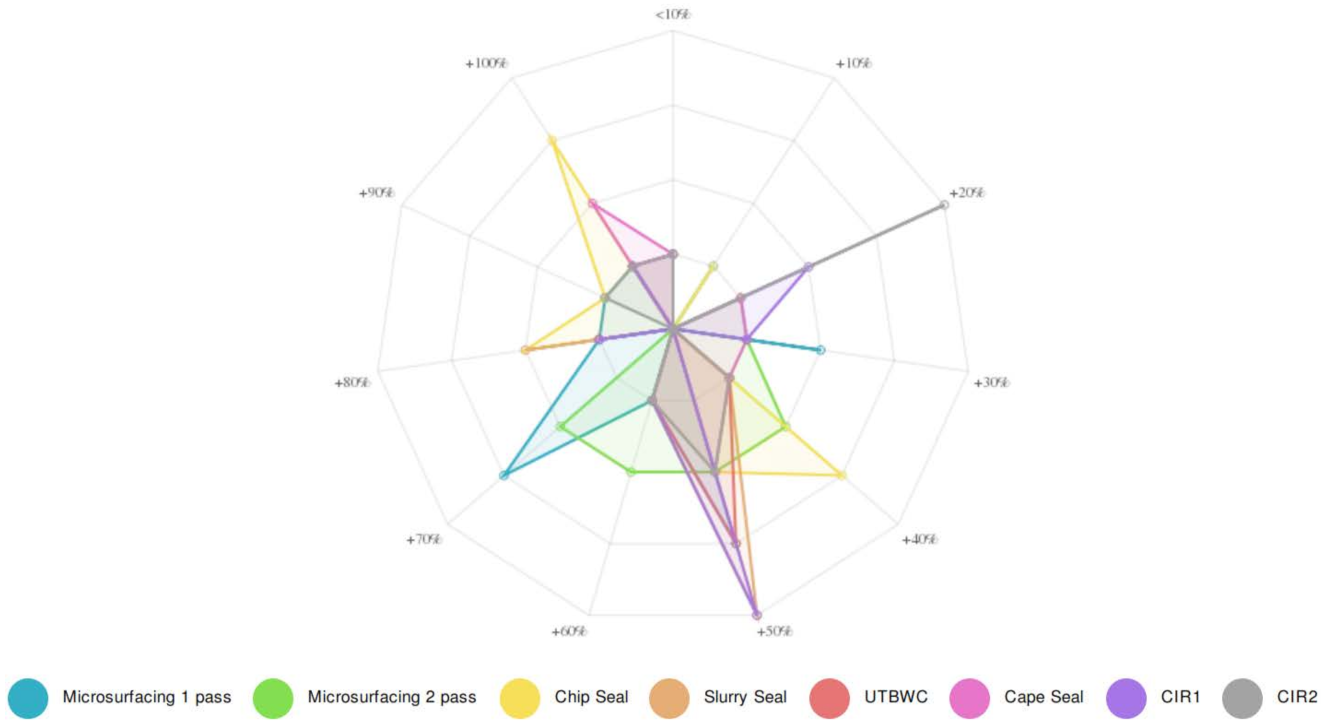
Does your company/organization use this rating system (CRS)?

	Yes	No	Standard Deviation	Responses
All Data	8 (25%)	**24 (75%)**	8	32

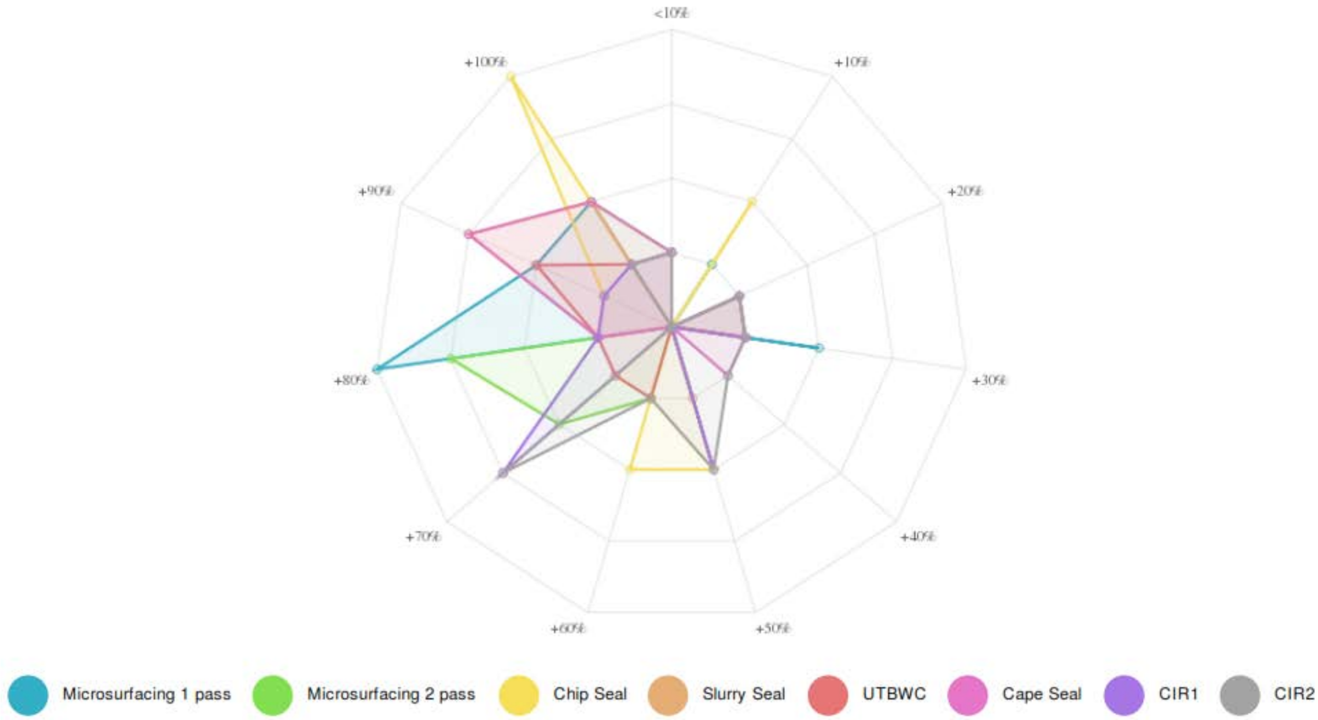
If other rating systems is being used please indicate:

- **PCI 0 to 100**
- **PASER. Now that I know about it, I will probably start using it.**
- **Not using one at this time**
- **0 to 100 rating based on consultant developed software.**
- **In house system similar to CRS**
- **PASER. (BLR 45-4.02(a))**
- **International Rating**
- **Modified PCI**
- **0-20 very poor, 20-40 poor, 40-60 good, 80-100 very good**
- **Poor, fair, good**
- **PCI, PCR, LTPP**

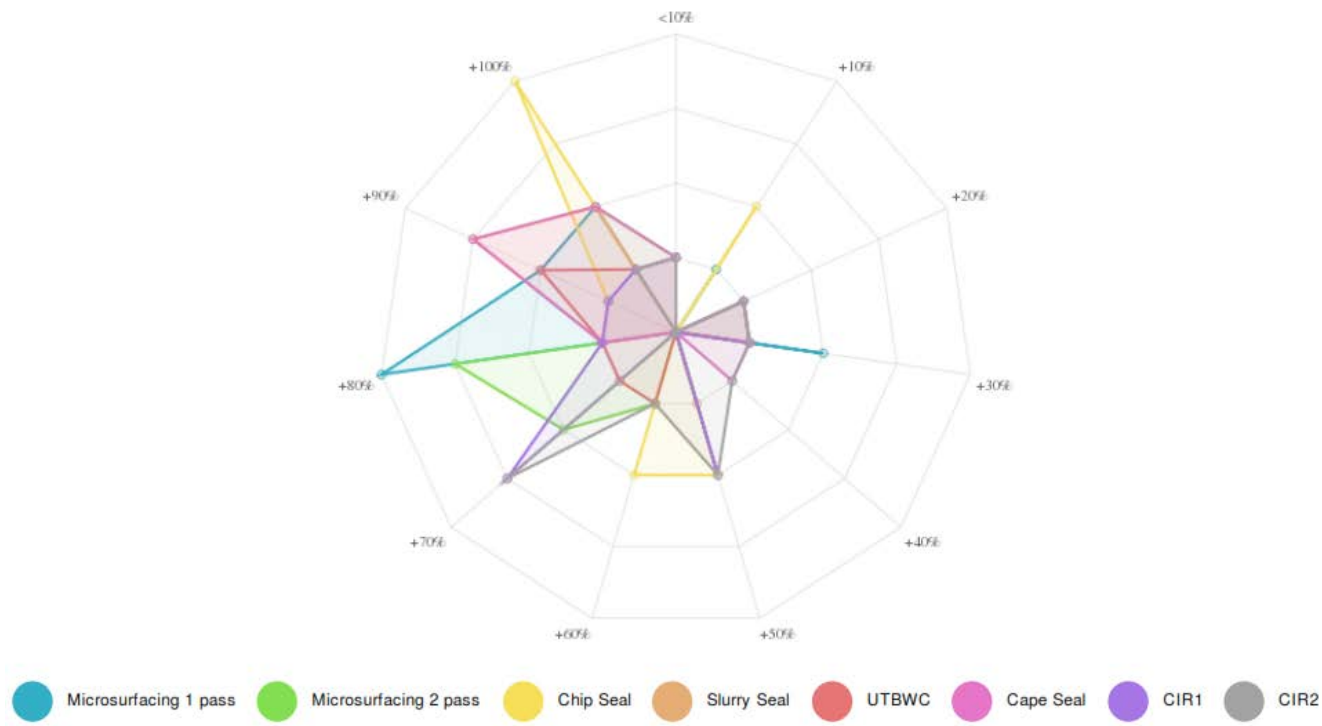
- Comparing the base case with two different ADT of the design lane of 500 (very low) and 30,000 (very high), after application of the following treatments how much faster the section with higher traffic would deteriorate as compared to the pavement with lower traffic?



- Comparing the base case with two different truck volume of 50 (very low) and 2,500 (very high), after application of the following treatments how much faster the section with higher truck traffic would deteriorate as compared to the pavement with lower truck traffic?



- Comparing the base case with two different existing condition of “good” (CRS 6.1 to 7.6) (50-75/100) and “poor” (CRS 1.0 to 4.5) (0-25/100), after application of the following treatments how much faster the section with poor condition would deteriorate as compared to the pavement with good condition?



Compare the effect of factors (ADT, truck traffic and existing condition) and type of treatment (Micro-surfacing, chip seal etc.) on the deterioration rate. Which one would be more important? Factors or type of treatments.

	9 (A)	8 (A)	7 (A)	6 (A)	5 (A)	4 (A)	3 (A)	2 (A)	Equal Importance	2 (B)	3 (B)	4 (B)	5 (B)	6 (B)	7 (B)	8 (B)	9 (B)	Standard Deviation	Responses	Weighted Average
Factros (A) vs. Treatment Type (B)	0 (0%)	0 (0%)	1 (8%)	0 (0%)	2 (15%)	3 (23%)	0 (0%)	0 (0%)	**6 (46%)**	0 (0%)	1 (8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1.55	13	7.38 / 17
																				7.38 / 17