RePlay Pavement Preservation and Life-Cycle Cost Analysis

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Executive Summary

Potential for cost savings is an important driver for new asphalt pavement preservation techniques. This study evaluated the cost-effectiveness of RePlay, a biobased asphalt pavement preservation agent. Results of statistical analysis performed using data from Hutchinson, MN show that RePlay slows the rate of degradation of asphalt. Findings from this statistical analysis were applied to a life cycle cost analysis. Using the State of Minnesota as a case study, the life-cycle cost analysis was conducted with sensitivity analysis. The results show RePlay to be a financially viable bituminous surface treatment and public agencies could use it to reduce the maintenance cost of low-volume roads.

Introduction

This memorandum documents a study to evaluate the cost-effectiveness of RePlay as an asphalt pavement preservation agent as compared to no treatment. The memorandum is separated into two sections with both using data from the City of Hutchinson, MN. The first section describes statistical analysis on the pavement preservation potential of RePlay. The second section uses the results of the statistical analysis to perform a life cycle cost analysis. In addition to the work described here, SRF has completed background research, data cleaning, and data manipulation to inform subsequent analyses with the Hutchinson dataset. Uncertainties identified through statistical analysis have informed the choice to employ stochastic life cycle cost analysis. The following sections provide an overview of the data preparation process, results of statistical analysis, and results of life cycle cost analysis.

Data Preparation

Data provided by Goodpointe Technology formed the core of the dataset used for analysis. This data included crack survey records in addition to construction and preservation treatment records. A few key challenges were identified with the data: missing construction records, variability in recorded treatments of older pavement, and limited records of degraded pavement.

Numerous instances of missing construction records were identified due to unexplained increases in the pavement condition index (PCI). Segments with seemingly missing construction records were initially reviewed to check for information on adjacent segments. When no information could be gained through this process, segments were sent to John Olson from the City of Hutchinson to fill in gaps.

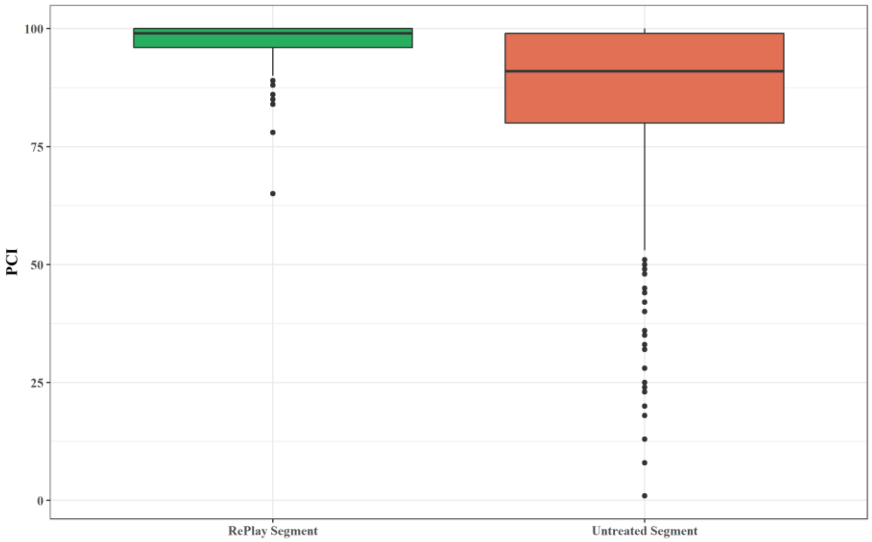
Many pavement treatments were included in the original dataset from Goodpointe. For consistency with the case study completed by AURI and to address variability in recorded treatments on older pavement, data was filtered to only include segments with structural pavement work completed since 1990. Data was further filtered to only include untreated segments in addition to those treated with RePlay. Segments having been treated with a seal coat, patching techniques, crack seals, and thin mill overlays were removed. The resulting data was grouped into two categories: untreated and RePlay. This filtering resulted in data coverage for 332 segments with 1,275 survey records (referred to as observations). Table 1 shows the number of segments and observations in each treatment type. Note that the totals in the table do not sum to the total number of segments or observations. This is due to all segments beginning as "untreated" before being treated.

Table 1 Data availability by treatment type. Note that the discrepancy between these totals and overall data coverage totals is due to overlap between untreated and RePlay treated segments.

Treatment Type	Number of Observations	Number of Segments
Untreated	1,420	417
RePlay	247	112

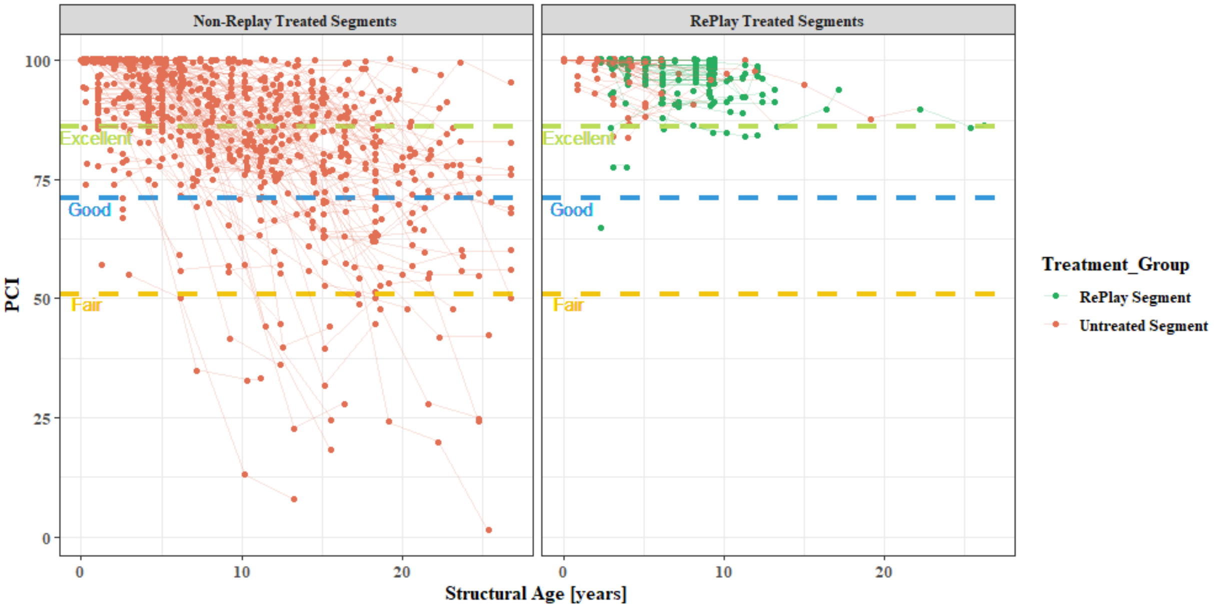
Figure 1 categorizes observations in the working dataset and shows distributions of PCI values by treatment group. While this figure does show segments treated with RePlay to have a higher, denser distribution than untreated segments, it does not show how this distribution changes with time.

Figure 1. Distribution of pavement condition index by treatment type.



The different treatment groups show different levels of degradation over time. Figure 2 shows the PCI value versus the structural age of each observation. Lines connect observations of individual segments to capture change over time. Untreated segments show a greater range of degradation over time. Most RePlay segments maintain PCI values that are considered "Excellent" with virtually all segments maintaining PCI values considered at least "Good." The breakpoints of these categories are designated by dashed lines and labeled. Lack of recorded degradation presents a challenge for estimating the life span of pavement treated with RePlay.

Figure 2. Relationship between pavement condition index and structural age of pavement. Segments with multiple survey records relate to lines.



Statistical Analysis

Despite challenges with the dataset, statistical analysis was conducted to answer the question, how does RePlay impact the lifespan of pavement as compared to untreated segments? This section steps through assumptions, methodology, and results of comparisons of RePlay to untreated segments.

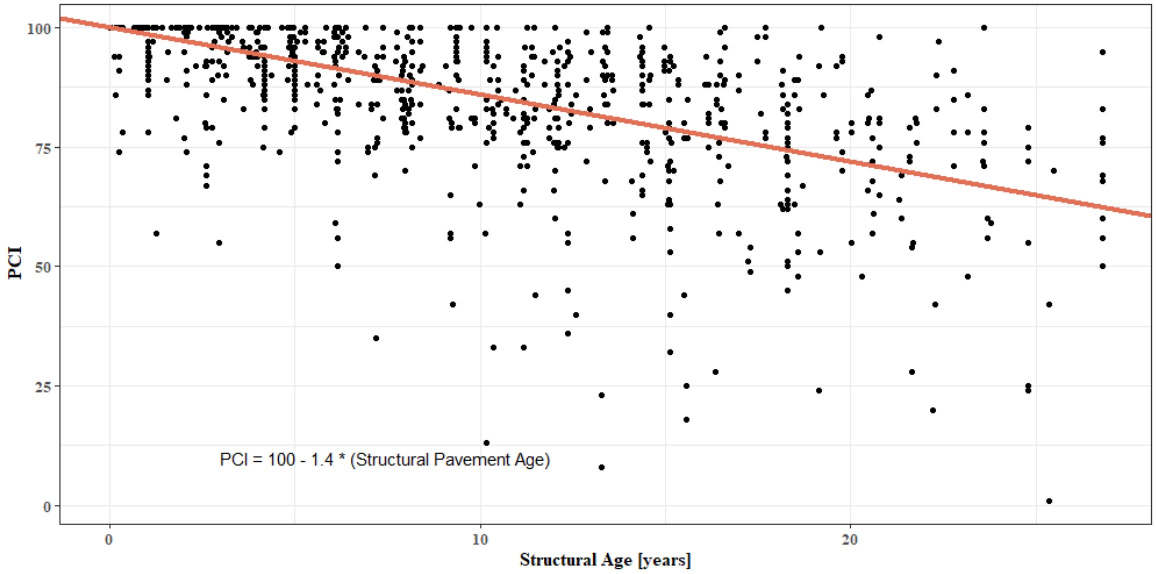
A few assumptions are implicit to this analysis. Factors including weather, traffic volumes, and heavy truck movements can have a significant impact on pavement longevity. Because all segments in this study are in the same area (Hutchinson, MN), weather impacts are assumed to be constant for all segments. Available traffic volume data were reviewed with the conclusion that no segments have substantially higher volumes than others (high volume roadways in Hutchinson tend to be Portland cement concrete which was not considered as a part of this study). This information and the assumption that none of the segments incorporated into the study are truck routes were corroborated by Hutchinson engineer, John Olson.

Models of degradation of pavement over time were fitted to the Hutchinson dataset using R. The linear model "lm" function of R uses the Least Squares Method to calculate regression models. Linear regression models produced the best fit of specifications tested.

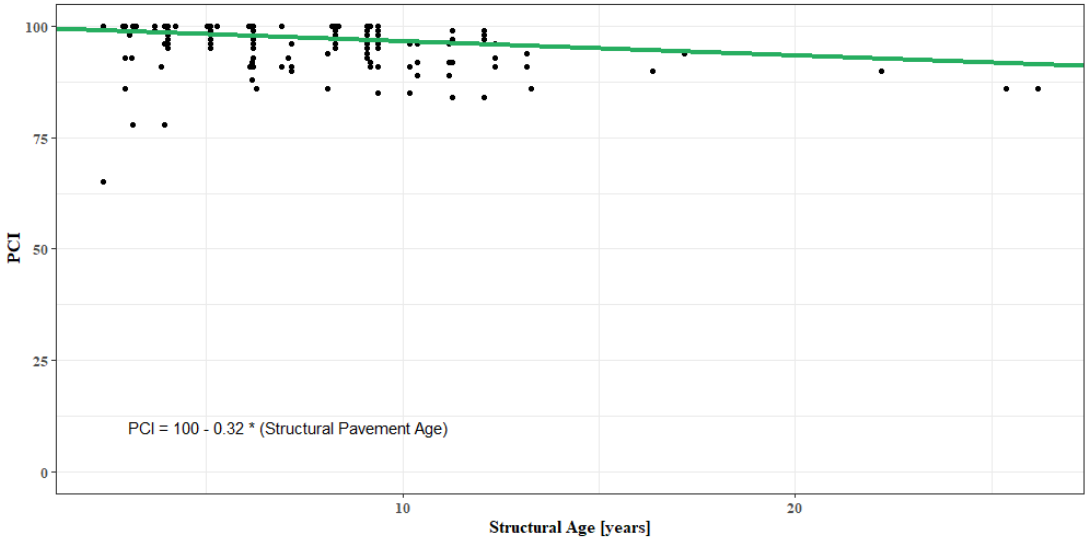
Due to the recency of RePlay use (the earliest treatments in Hutchinson took place in 2012), establishing the entire life span of pavement segments treated with RePlay is challenging. In addition to this challenge, there are no segments in the dataset that have been surveyed following a second (or third) RePlay treatment. To address this issue, the rates of pavement degradation for untreated and RePlay segments have been estimated for data available with the understanding that the degradation rate will change over time. Figure 3 shows the data and fitted curves for each treatment group. Further discussion of how these results are used to evaluated cost-effectiveness can be found in the life cycle cost analysis section.

Figure 3. Plot of PCI values over time; a) untreated section; b) RePlay section

(a) Untreated



(b) RePlay



The models in Figure 3 show a distinct difference in the rate of pavement decline for different treatment groups. RePlay treated segments have a lower rate of decline with –0.32 change in PCI per year while untreated groups have a rate of –1.4 change in PCI per year. This indicates that on average for the data available, pavement segments treated with RePlay deteriorate more slowly than those not treated.

Life Cycle Cost Analysis

This study sought to explore the cost-effectiveness of applying RePlay to an untreated asphalt concrete surface specifically in the state of Minnesota. Life cycle costs analyses (LCCA) were conducted for typical residential roadways in Minnesota, one LCCA for roadway surfaces treated with RePlay and one LCCA for untreated surface conditions.

The approach proposed in this study utilizes equivalent uniform annual cost (EUAC) analysis, which permits the elimination of many assumptions required when using the more common, and problematic net present worth LCCA (Walls and Smith 1998).

The issues associated with deterministic EUAC models like sensitivity to discount rate and volatility of underlying commodity prices will be addressed by developing a sensitivity analysis. Factors included in the sensitivity analysis will be presented. In addition, assumptions regarding the service, construction cost, discount rate, etc. will be discussed in the following sections.

Input Values Determination

The first step in the LCCA is to determine which input values have associated uncertainty and will have a significant impact on the results (Peshkin, D. et al., 2004; Pittenger et al., 2012). Such values should be included in the sensitivity analysis while all others are treated deterministically to simplify the analysis (Pittenger et al., 2012). Initial construction costs, discount rates, and service life of pavement treatment methods will be included in the sensitivity analysis. All other costs (e.g., pavement marking) associated with both approaches (treated non-treated) were assumed to be the same and following FHWA guidelines were all dropped from the analysis.

Service Life

"Service life considered the most superior performance measure because all other long-term effectiveness measures are computed on the basis of service life" (FHWA, 2007). Service life uncertainty creates sensitivity in LCCA results (Peshkin, D. et al., 2004) and makes it a good candidate for sensitivity analysis.

Untreated Asphalt Concrete Service Life

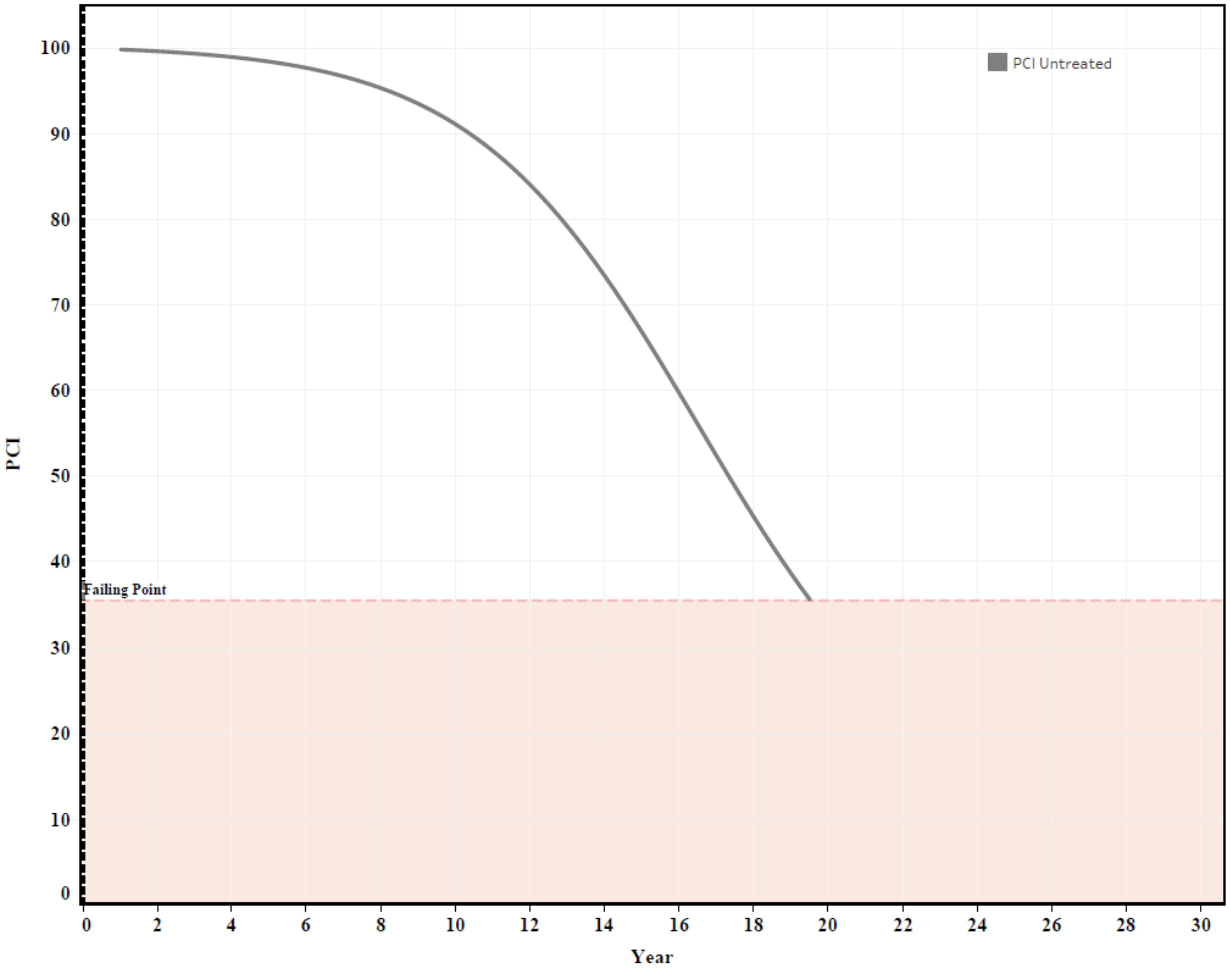
The accurate prediction of pavement network conditions and performance is important for efficient management of the transportation infrastructure system. At this end, many studies have been conducted to model asphalt concrete surface deterioration over the years. A previous research study was adopted and used to estimate the remaining service life of the untreated pavement. The objective of this research study was to develop a methodology for calculating a pavement condition index (PCI) based on historical distress data collected in the databases from Long-Term Pavement Performance (LTPP) program and Minnesota Road Research (Mn/ROAD) project (Wu, 2015). Pavement performance master curve construction and verification based on the PCIs were also developed as part of this research effort (Wu, 2015).

In this effort, a Minnesota pavement network consisting of 54 pavement sections (or 83 subsections), was used first (Wu, 2015). The state of Minnesota is in a wet freeze climatic region, and all the test sections were constructed on arterial or interstate asphalt roadways. The traffic data collected in the LTPP database shows that there are 42 sections with average daily truck traffic less than 5000 according to estimated data from 1990 to 2005. Therefore, the Minnesota pavement network consists of nearly homogeneous test sections in terms of traffic and climate condition. The model developed relating pavement condition to time (reduced time) is given by:

$$PCI = 11.52\ \frac{88.86}{1 + \exp\left(0.33T - 5.45\right)}$$

The figure below shows a schematic of the asphalt pavement performance master curve developed based on the aforementioned formula:

Figure 4. PCI changes through the time for a generic untreated surface (developed based on the previous study on modeling remaining service life of the asphalt concrete (Wu, 2015))

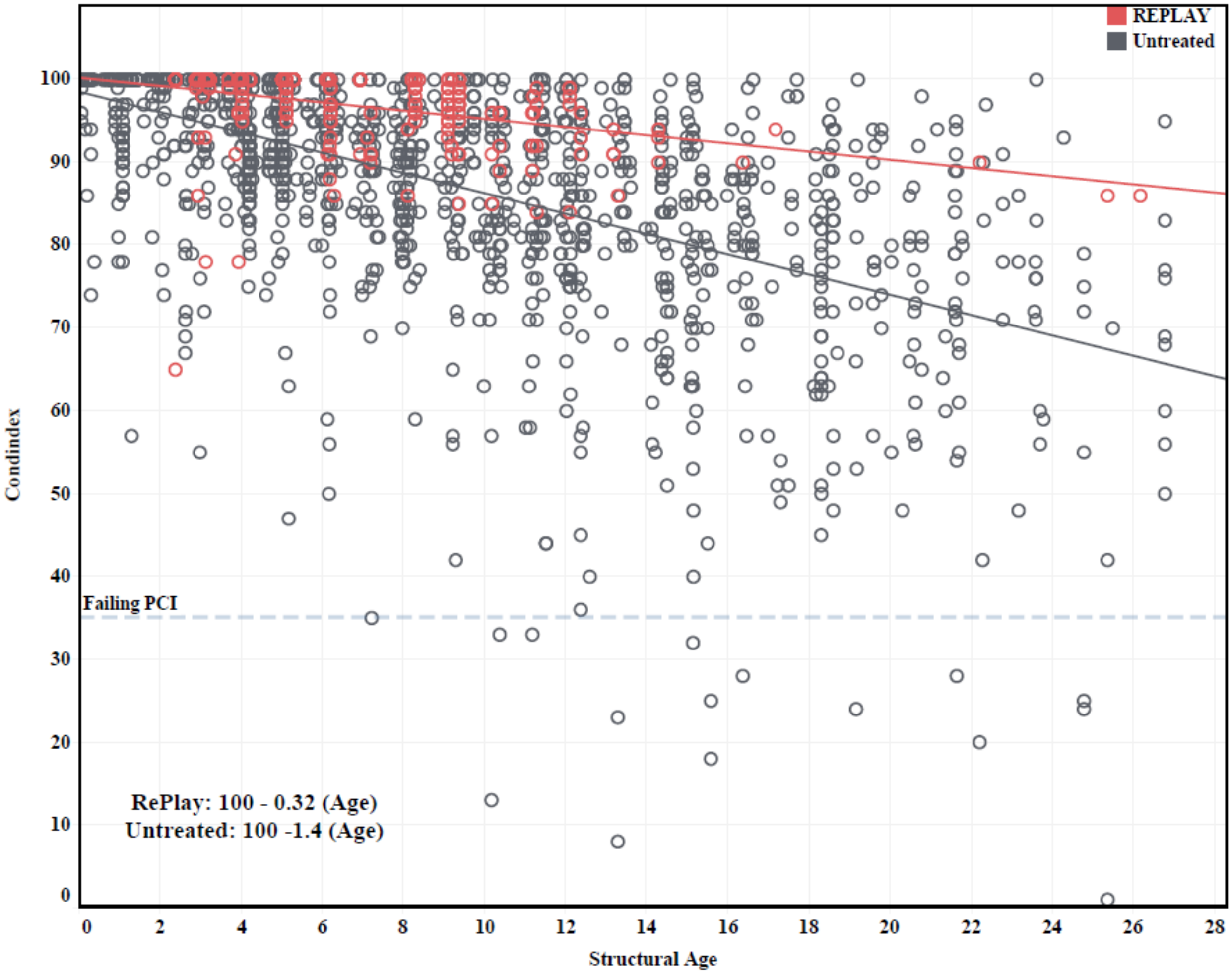


As shown in Figure 4, the definition of failing criteria was a PCI below 35 in this study. This model will be used in the following section to estimate the service life of a surface that is treated with RePlay.

RePlay Service Life

In the data analysis section, there were efforts to find the deterioration rate of RePlay treated surface and untreated surface. As shown in the following figure, the surface with RePlay treatment has an almost four times lower deterioration rate rather than an untreated surface.

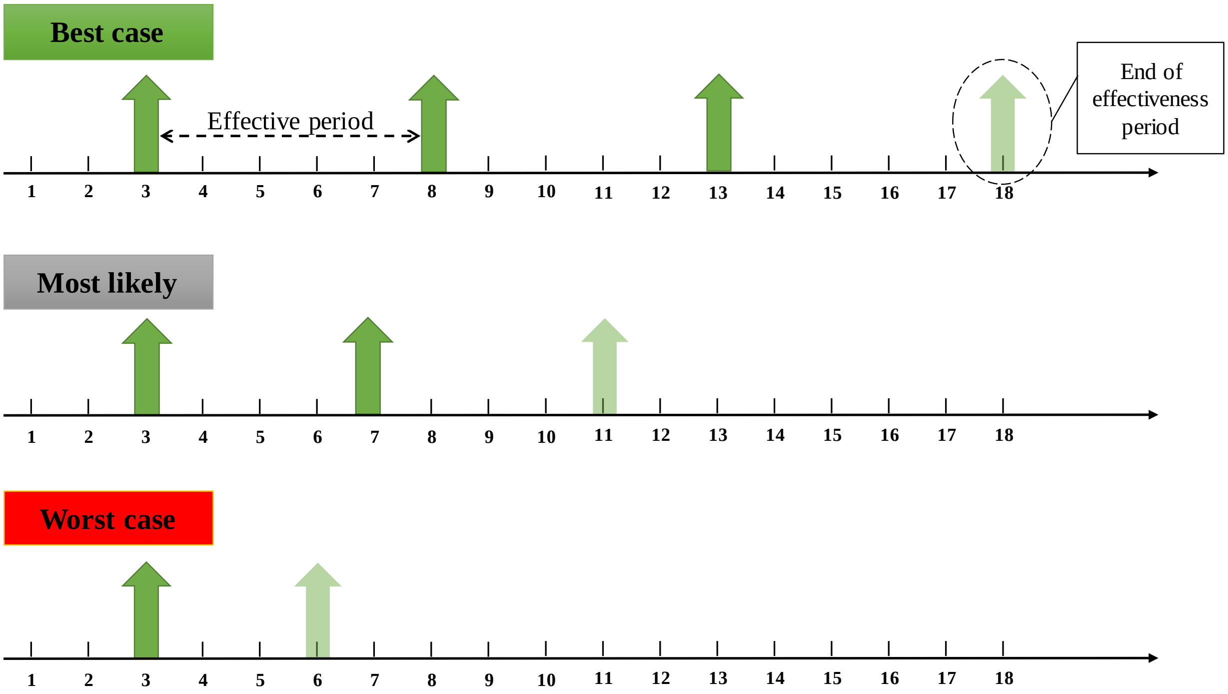
Figure 5. Deterioration rate of RePlay vs. untreated surface



Moreover, RePlay's effectiveness period may relate to various factors such as the existing pavement surface condition, ADT, truck traffic percentage, etc. Note that the effectiveness period was defined as a period that RePlay treatment would be able to reduce the deterioration rate of the asphalt surface.

Some studies reported RePlay's effective period from three to five years (Medina and Clouser, 2009; Shatec Engineering Consultants LLC, 2017; Yang et al., 2020, 2018). In addition, to cover a wide range of RePlay implementation practices, three possible scenarios were developed as (as shown in the following figure) for RePlay implementation.

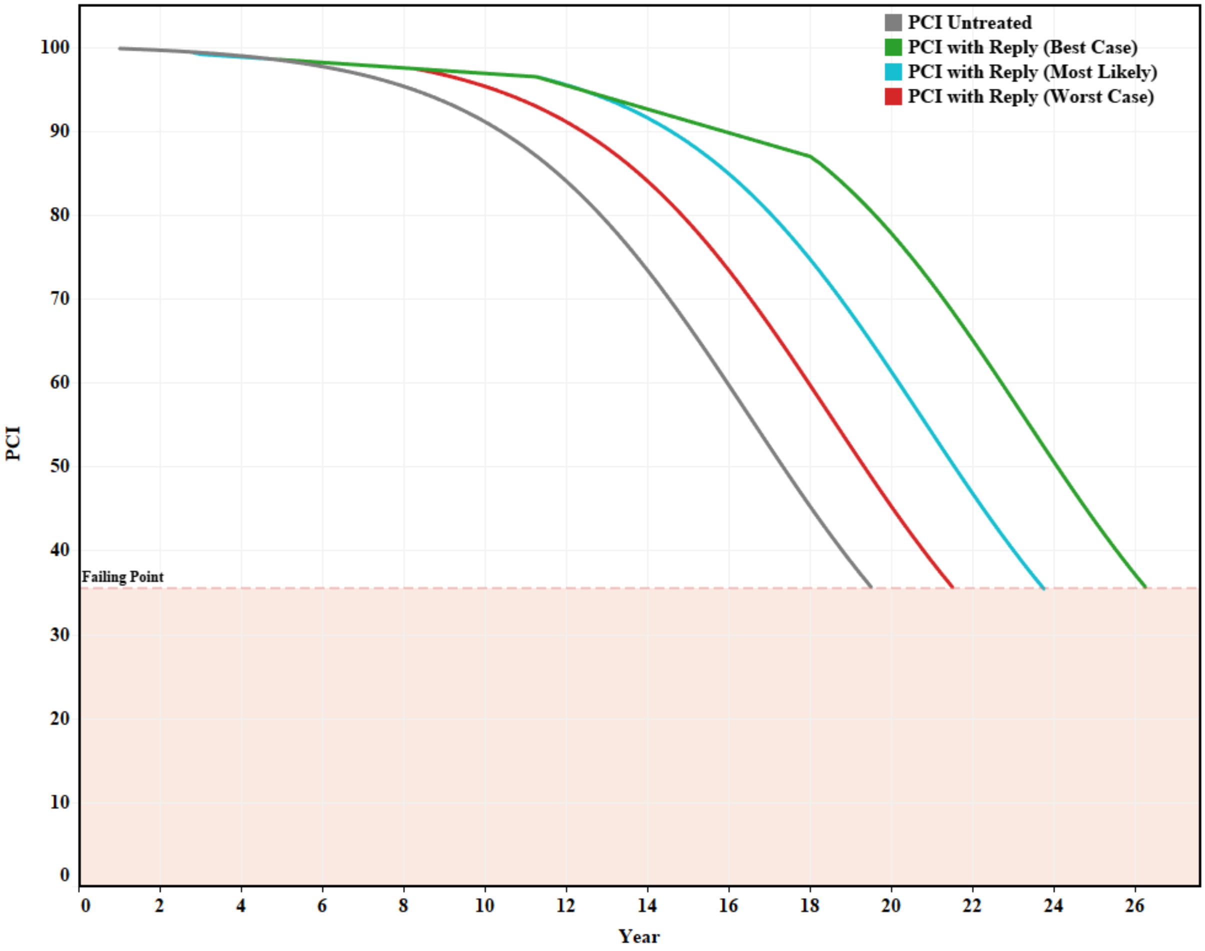
Figure 6. Three possible RePlay implementation scenarios



As shown in Figure 6, a five-year effective period with three RePlay applications was used for the best-case scenario, four-year effective period with two RePlay applications for most likely, and three-year effective period with one RePlay application for the worst-case scenario.

To estimate the longevity of the asphalt surface under each of the scenarios, modifications were made to the untreated asphalt service life model. It was assumed that during RePlay's effective periods, the deterioration rate of the surface would be almost four times lower than the untreated condition. During the effective periods, linear approximation was used for deterioration rate adjustments (with a slope of 4.3). Figure 7 presents the result of the modified model for each scenario.

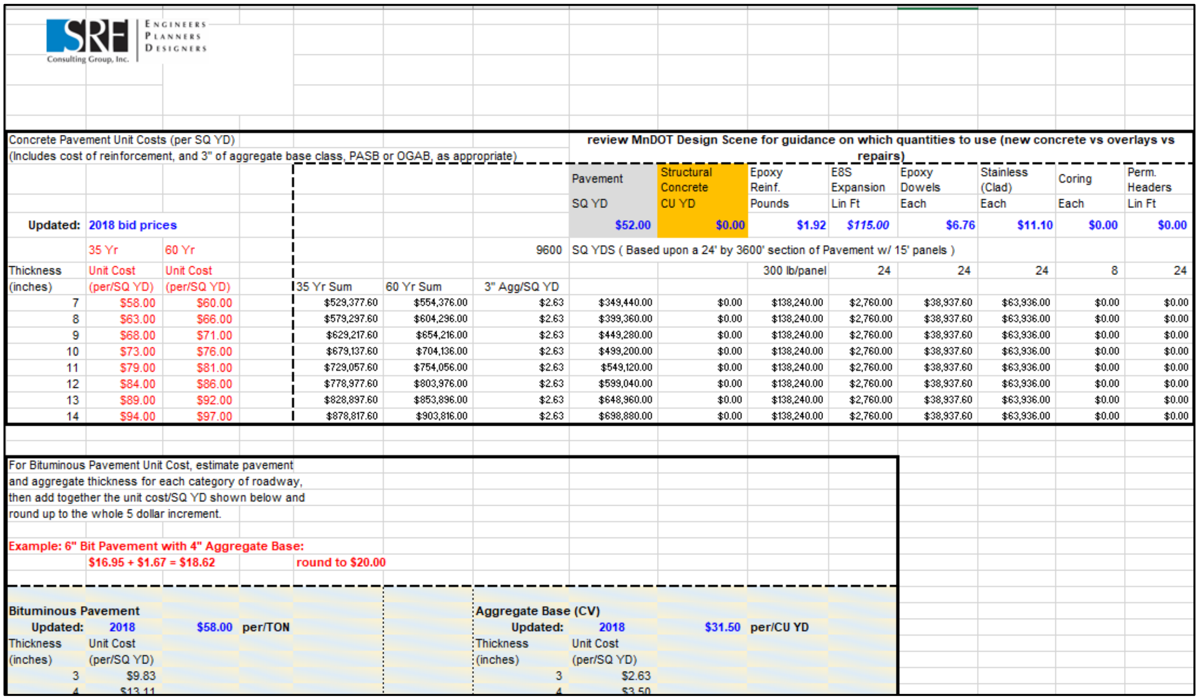
Figure 7 Service life prediction model for RePlay scenarios



Construction cost

The estimated construction cost of pavement was based on current industry practices using the SRF pavement cost estimator tool (Figure 8). Note that only activities associated with resurfacing the roadway with asphalt concrete were considered here. Other items such as subbase/base treatment were not involved in the cost estimation.

Figure 8. Screenshot from SRF pavement cost estimation tool



Concrete Pavement Unit Costs (per SQ YD)
(Includes cost of reinforcement, and 3" of aggregate base class, PASB or OGAB, as appropriate)

review MnDOT Design Scene for guidance on which quantities to use (new concrete vs overlays vs repairs)

						Pavement	Structural Concrete	Epoxy Reinf.	E8S Expansion	Epoxy Dowels	Stainless (Clad)	Coring	Perm. Headers
						SQ YD	CU YD	Pounds	Lin Ft	Each	Each	Each	Lin Ft
Updated:	**2018 bid prices**					**$52.00**	**$0.00**	**$1.92**	***$115.00***	**$6.76**	**$11.10**	**$0.00**	**$0.00**
	35 Yr	60 Yr			9600	SQ YDS (Based upon a 24' by 3600' section of Pavement w/ 15' panels)							
Thickness	Unit Cost	Unit Cost						300 lb/panel	24	24	24	8	24
(inches)	(per/SQ YD)	(per/SQ YD)	35 Yr Sum	60 Yr Sum	3" Agg/SQ YD								
7	$58.00	$60.00	$529,377.60	$554,376.00	$2.63	$349,440.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
8	$63.00	$66.00	$579,297.60	$604,296.00	$2.63	$399,360.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
9	$68.00	$71.00	$629,217.60	$654,216.00	$2.63	$449,280.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
10	$73.00	$76.00	$679,137.60	$704,136.00	$2.63	$499,200.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
11	$79.00	$81.00	$729,057.60	$754,056.00	$2.63	$549,120.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
12	$84.00	$86.00	$778,977.60	$803,976.00	$2.63	$599,040.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
13	$89.00	$92.00	$828,897.60	$853,896.00	$2.63	$648,960.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00
14	$94.00	$97.00	$878,817.60	$903,816.00	$2.63	$698,880.00	$0.00	$138,240.00	$2,760.00	$38,937.60	$63,936.00	$0.00	$0.00

For Bituminous Pavement Unit Cost, estimate pavement and aggregate thickness for each category of roadway, then add together the unit cost/SQ YD shown below and round up to the whole 5 dollar increment.

Example: 6" Bit Pavement with 4" Aggregate Base:
$16.95 + $1.67 = $18.62 **round to $20.00**

Bituminous Pavement
Updated: **2018** **$58.00** **per/TON**

Thickness (inches)	Unit Cost (per/SQ YD)
3	$9.83
4	$13.11

Aggregate Base (CV)
Updated: **2018** **$31.50** **per/CU YD**

Thickness (inches)	Unit Cost (per/SQ YD)
3	$2.63
4	$3.50

The pavement construction cost (including the replacement) was estimated to be 35 (\$/yd^2). The following assumptions were made for the pavement cost estimation:

- A "typical" local pavement section of 6" bituminous and 6" of aggregate.
- SRF average for estimating pavement removal is $7.50 / SY
- Cost using spreadsheet = $19.66 + $5.25 = $24.91 => round to $25 / SY
- Total for pavement replacement = $7.50 + $25.00 = $32.50 => round to $35 / SY

Similar to the asphalt surface, cost estimation conducted for the RePlay used historical data. According to variation in the binder cost, three possible cost values were estimated for RePlay and incorporated into the sensitivity analysis. The cost estimation details were tabulated in the following table.

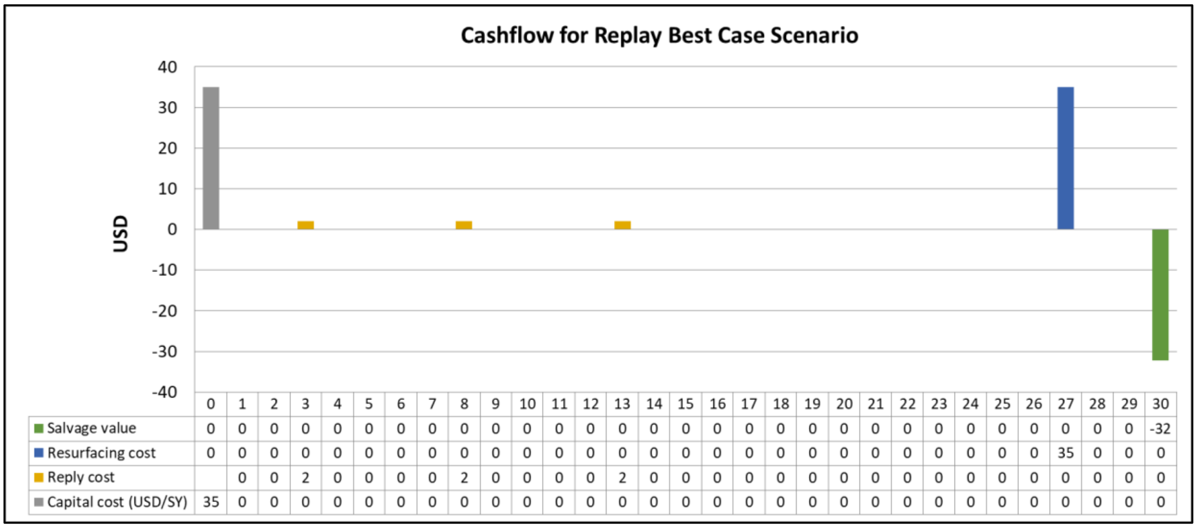
Table 2. RePlay construction cost estimation

Item	Quantity	Unit cost	Comments
Labor (Crew)	1 SY	\$0.04 – \$0.10	3-person crew: Foreman, (1) Laborer & (1) Operator
Material	1 SY	\$1.60 – \$2.40	Pricing varies based on market conditions
Equipment	1 SY	\$0.04 – \$0.10	2 pieces of equipment: Distributer Truck & Pick-Up
Total	1 SY	(\$1.70, \$2.00, \$2.50)	

Equivalent uniform annual cost (EUAC) analysis

A life cycle cost analysis using the EUAC approach was developed in Excel spreadsheets. Figure 9 demonstrates the visual representation of the cash flow analysis associated with the RePlay best-case scenario (three treatments with a five-year effective period). To capture the uncertainty associated with the discount rate, three discount rates (3%, 5%, and 7%) were considered and included in the sensitivity analysis.

Figure 9. Cashflow analysis example

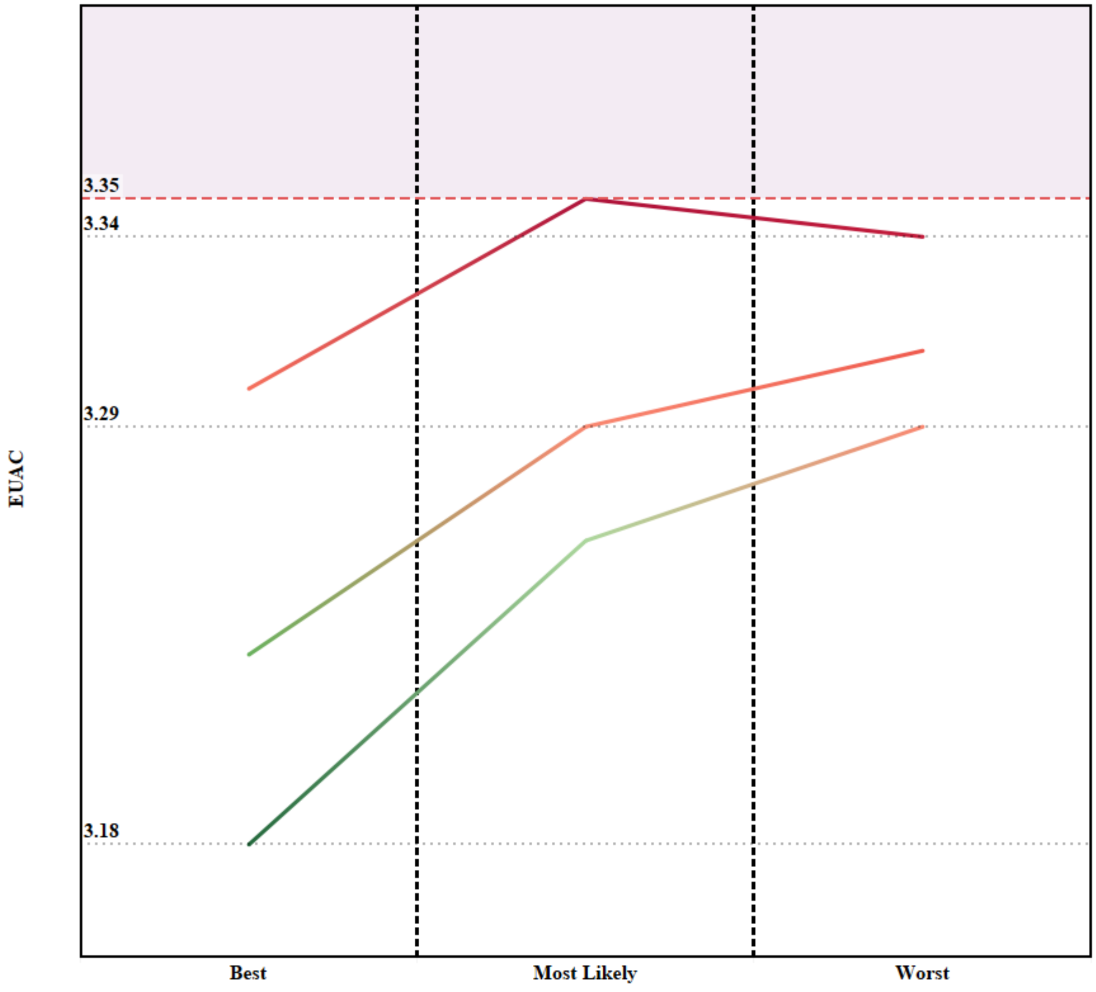


	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
🟩 Salvage value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-32
🟦 Resurfacing cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0
🟨 Reply cost		0	0	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
▪ Capital cost (USD/SY)	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

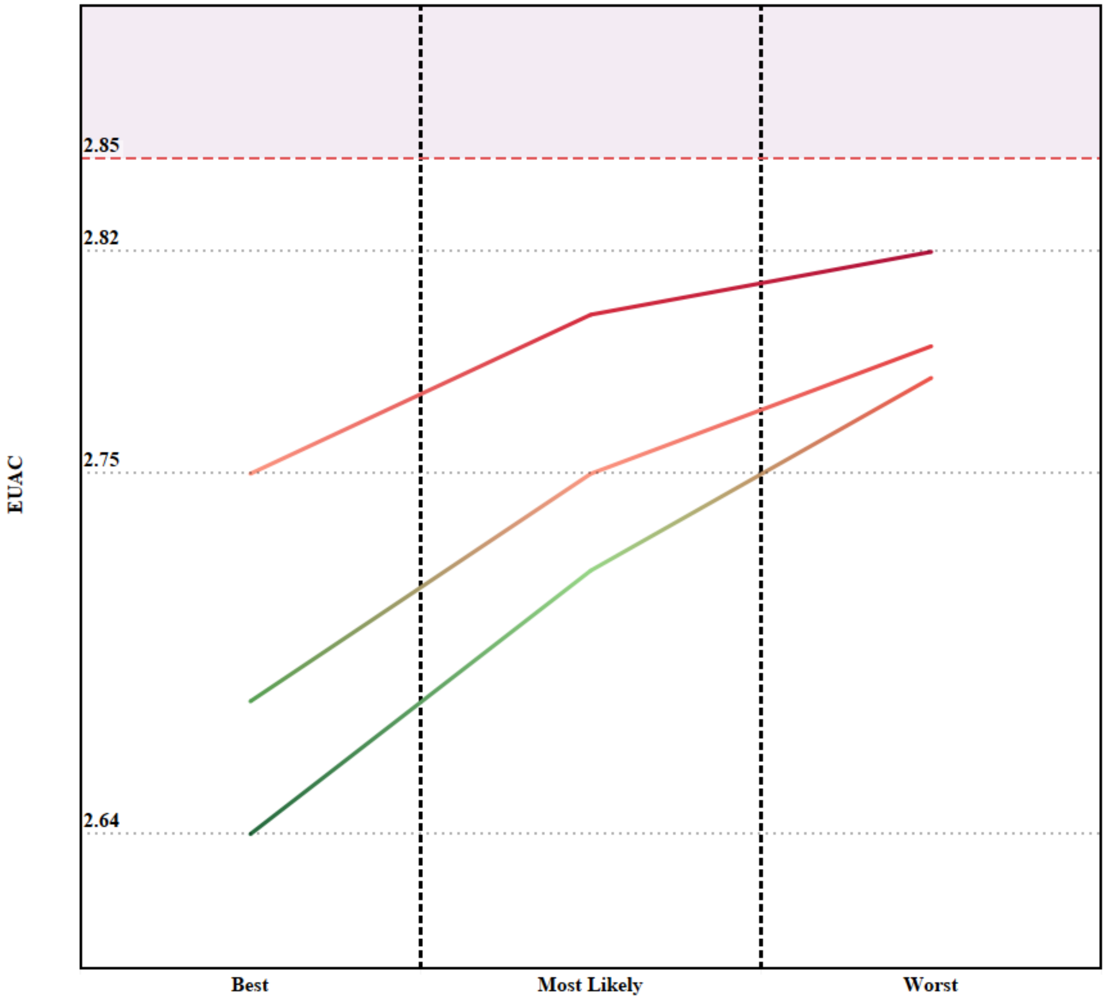
Result of the life cycle costs analysis (LCCA)

The sensitivity analysis was conducted on the variables that consist of high-level uncertainty. As discussed in the previous sections, these variables include the discount rate, RePlay cost, number of treatments, as well as effectiveness period of RePlay. Figure 10 demonstrates the result of economic analysis. For this analysis, the untreated life cycle cost was taken as an economic criterion. Figure 10 indicates that in all the combinations of the possible scenarios using RePlay incurred a lower cost rather than the base case scenario (untreated/do nothing).

Figure 10. Outcome of LCCA -RePlay vs. untreated- a) discount rate = 3%; b) discount rate = 5%; c) discount rate = 7%



(a)



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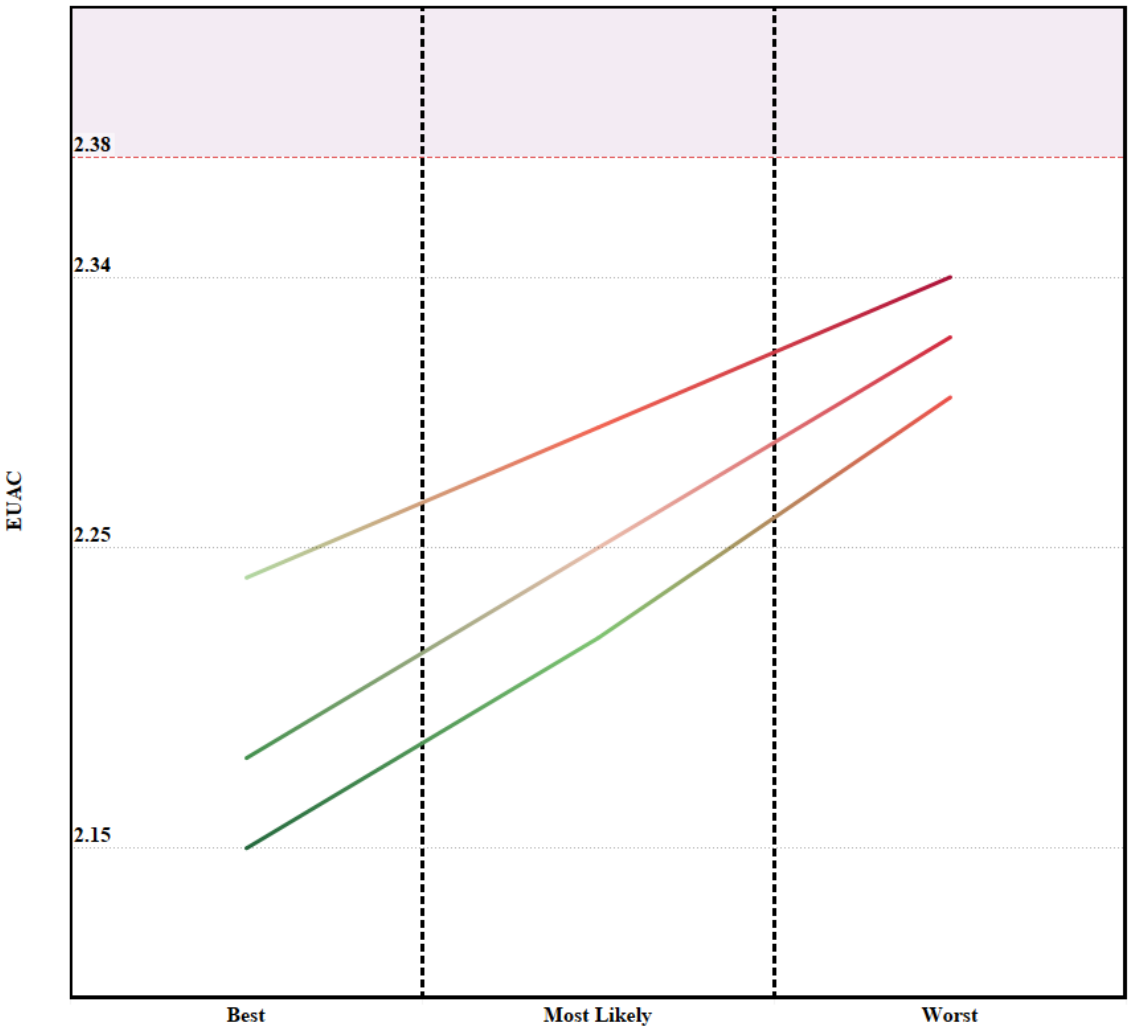

(c)

Conclusions and Recommendations

This memorandum documents assumptions, methods, and results of statistical analysis and subsequent life cycle cost analysis of RePlay, a biobased asphalt pavement preservation agent. Data from the City of Hutchinson, MN was cleaned and used to establish the initial rate of pavement decline for untreated pavement segments and RePlay treated segments. A stochastic life cycle cost analysis was conducted for different scenarios to determine the cost-effectiveness of using RePlay.

Statistical analysis revealed that segments treated with RePlay have a statistically significant lower rate of pavement degradation compared to untreated segments. Combining the rates of degradation from the statistical analysis with a model for untreated asphalt pavement degradation, estimates of RePlay service life were developed (worst to best-case scenarios). The service life analysis demonstrated that RePlay could increase the longevity of road surfaces by 2-7 years. The development of degradation rates was, however, limited by the relatively short period of time the dataset represents. Future analyses could extend this study as new data is available.

Using the State of Minnesota as a case study, the results of the economic analysis demonstrated the use of RePlay leads to a reduction in the life cycle cost of maintaining asphalt concrete surfaces. The technology is being used successfully in the State of Minnesota as well as other states, including Pennsylvania and Iowa. Public agencies may use Replay to reduce the maintenance cost of low-volume roads.

Since the methodology followed in this study provides agencies with a sensitivity analysis that the preferred alternative produces the lowest life cycle cost, recommendations that may result from this research are not only established in fundamental LCCA theory but can also provide public transportation agencies with an added level of confidence in predicting the financial results of pavement treatment alternatives.

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