RePlay Pavement Preservation and Life-Cycle Cost Analysis (Phase 2)

Agricultural Utilization Research Institute

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Table of Contents

Table of Contents 2
Figures 3
Tables 3
Executive Summary 4
Introduction 4
Data Preparation 4
Statistical Analysis 6
  Assumptions 6
  Methods 7
  Results 8
  Benefit of Additional Data 11
Life-Cycle Cost Analysis 13
  Input Values Determination 14
  Service Life 15
  Economic Analysis Results 19
Conclusions and Recommendations 21
References 21

Figures

Figure 1. Distribution of pavement condition index by treatment type. 5
Figure 2. Relationship between pavement condition index and structural age of pavement. 6
Figure 3. Plot of pavement deterioration over time for a) untreated section; b) RePlay section 8
Figure 4. Plot of pavement deterioration over time for RePlay-treated segments with a) one treatment; b) two treatments 9
Figure 5. Plot of pavement deterioration over time for seal coat segments 11
Figure 6. Comparison of seal coat-treated segment deterioration to RePlay-treated segment deterioration 12
Figure 7. 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)) 15
Figure 8. Three theoretical RePlay implementation scenarios used in Phase 1 16
Figure 9. Data-driven scenarios developed for Phase 2 17
Figure 10. Service life prediction model for RePlay scenarios: 18
Figure 11. Economic analysis results for Phase 2 20

Tables

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. 5
Table 2. Deterioration rate of pavement by treatment group and age group 13
Table 3. 95 Percent confidence intervals for each treatment group and age 13
Table 4. Input values changes from the Phase 1 14

Executive Summary

Potential for cost savings is an important driver for new asphalt pavement preservation techniques. This study evaluated the cost effectiveness of RePlay Agricultural Oil and Preservation Agent® ("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 that public agencies can use to reduce maintenance costs of low-volume roads.

Introduction

This memorandum documents an update to a study evaluating the cost effectiveness of RePlay as an asphalt pavement preservation agent as compared to no treatment beyond routine maintenance. The update includes an additional round of survey data from the City of Hutchinson, MN completed in 2020. RePlay Agricultural Oil Asphalt seal and PRESERVATION AGENT® is a patented product created and manufactured by BioSpan Technologies, Inc, Washington, Missouri, USA. The memorandum is separated into two sections with both using the same data from Hutchinson. The first section describes statistical analysis on the pavement preservation potential of RePlay. This Phase 2 report includes a special review of segments that have been treated twice with RePlay and the change in deterioration rate over time. 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 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 in the first phase of the project: missing construction records, variability in recorded treatments of older pavement, and limited records of degraded pavement. The same data cleaning process was applied to new data provided in Phase 1 as was applied in Phase 1. The process is described as follows.

Numerous instances of missing construction records were identified due to unexplained increases in 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 first phase of the study and a case study completed by the Agricultural Utilization Research

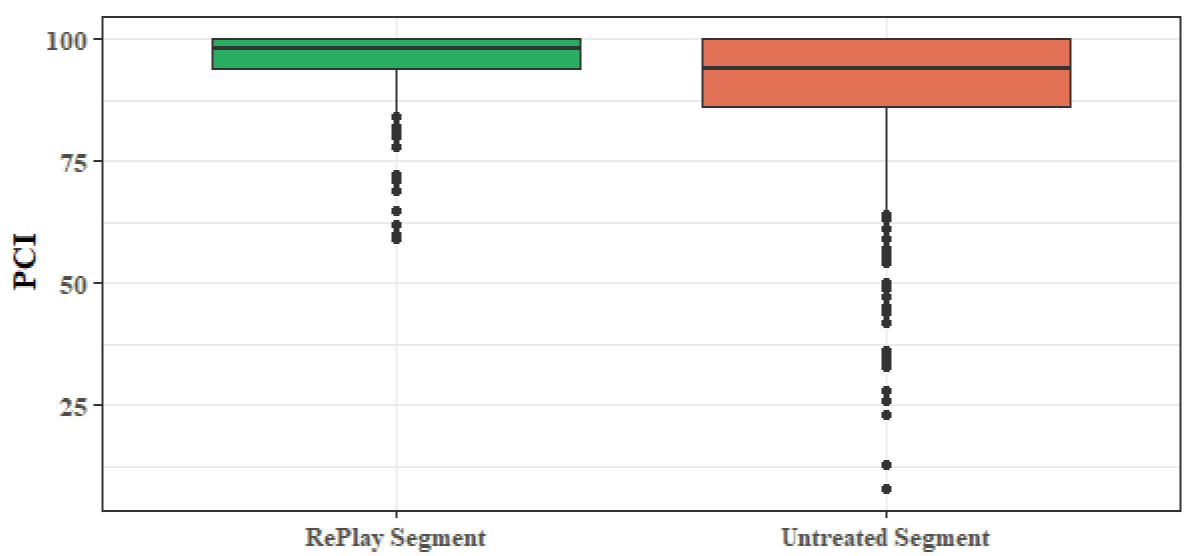
Institute (AURI), data was filtered to only include segments with structural pavement work completed since 2000 to address variability in recorded treatments on older pavement. Data was further filtered to include untreated segments in addition to those treated with RePlay. Segments having been treated with seal coat and thin mill overlays were removed. Note that treatments including patching techniques and crack seals may have been applied to both RePlay- and untreated segments on an as-needed basis. These treatments impact PCI and are reflected in results. The resulting data was grouped into two categories: untreated and RePlay. This filtering resulted in data coverage for 459 segments with 1187 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	845	312
RePlay	402	158

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. RePlay segments have less age variation than untreated segments.

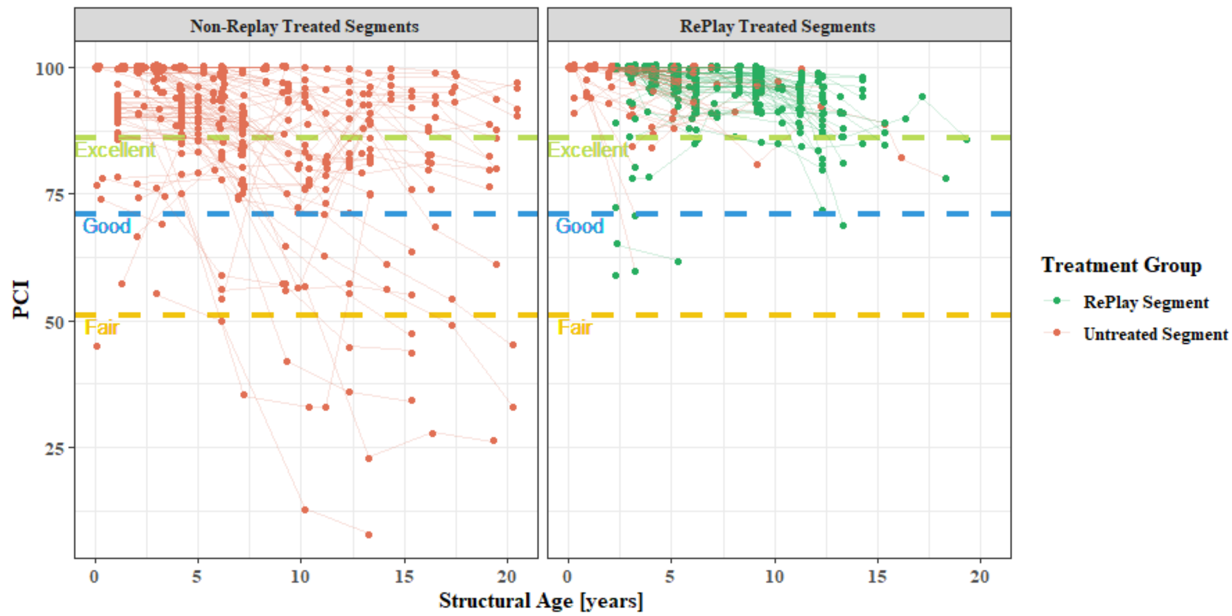
Figure 1. Distribution of pavement condition index by treatment type.



The different treatment groups show different levels of degradation over time. Figure 2 shows PCI value versus 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." A few segments fall into the "Good" and "Fair" categorizations. 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

Statistical analysis was conducted to provide insight into the deterioration of pavements in different treatment groups. Specifically, segments with one or more RePlay treatment have been compared to untreated segments for input into service-life calculation. To provide additional context, segments that have been chip sealed have been analyzed separately. Because of additional data availability, deterioration rates from different time periods have been estimated to more accurately represent pavement deterioration over time. The effect of multiple RePlay treatments has also been reviewed and compared to overall results. This section steps through assumptions, methodology, and results of these comparisons.

Assumptions

The same set of assumptions from Phase 1 of this assessment have been applied in Phase 2. Factors including pavement subbase and structure, construction technique, weather, traffic volumes, and heavy truck movements can have a significant impact on pavement longevity. This study is based on real world data, limiting control over these factors. 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 was 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 was corroborated by Hutchinson City Engineer, John Olson.

Methods

Models of degradation of pavement over time were fitted to the Hutchinson dataset using R. The linear model "lm" function of R uses a least squares method to calculate regression models. Linear regression models produced the best fit of specifications tested. In each model, the intercept is held constant at 100 to reflect the true value of PCI when pavement is placed.

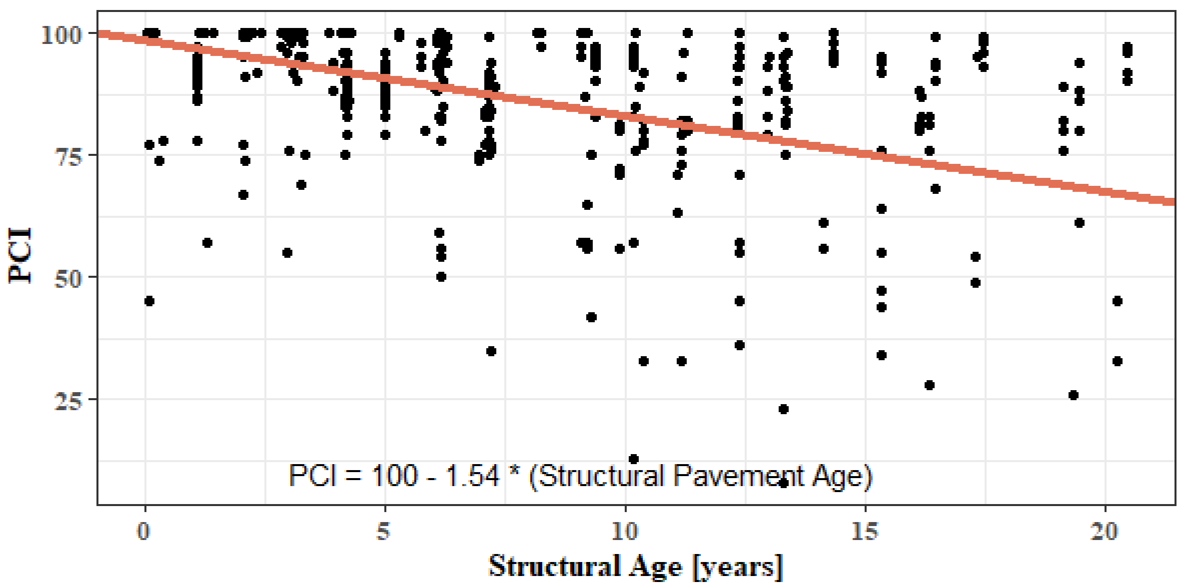
Due to the recency of RePlay use (the earliest treatments in Hutchinson took place in 2012), establishing the entire life span of pavement segments treated with RePlay is challenging. The dataset available for this Phase 2 study includes survey records of 61 segments that have had a second RePlay treatment. Degradation rate of these segments independent of others has also been estimated. The rates of pavement degradation for untreated, RePlay, and chip sealed segments have been estimated for data available with understanding that degradation rate will change over time. To address this issue in Phase 2, degradation rates have been estimated for segments in three distinct age groups.

Results

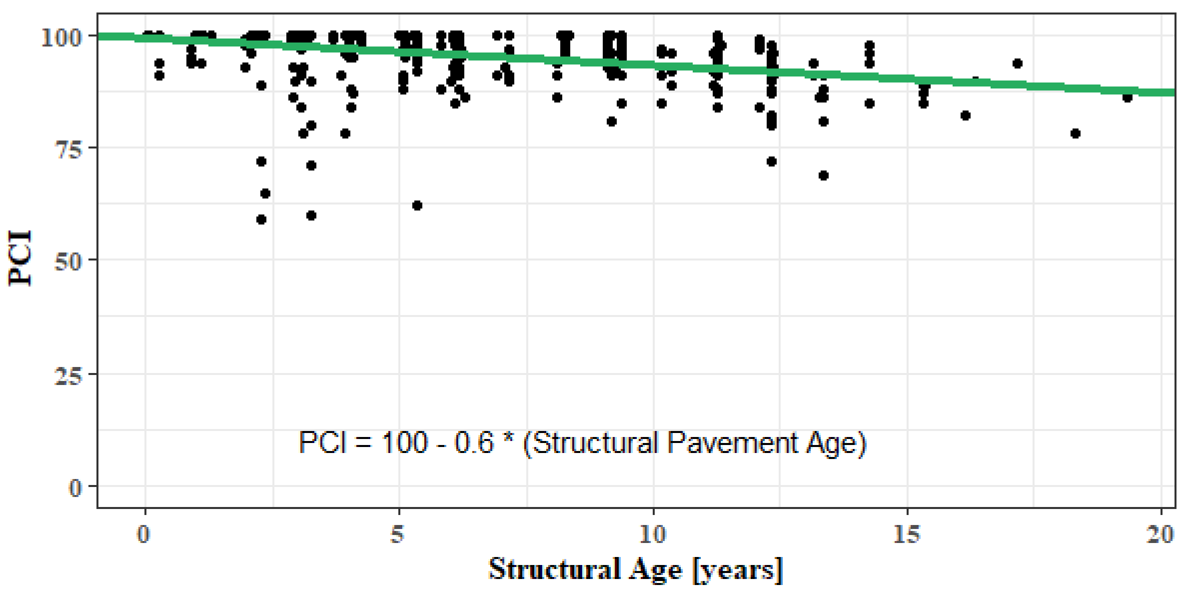
Figure 3 shows data and fitted curves for each treatment group as a whole.

Figure 3. Plot of pavement deterioration over time for a) untreated section; b) RePlay section

(a) Untreated



(b) RePlay



The models in

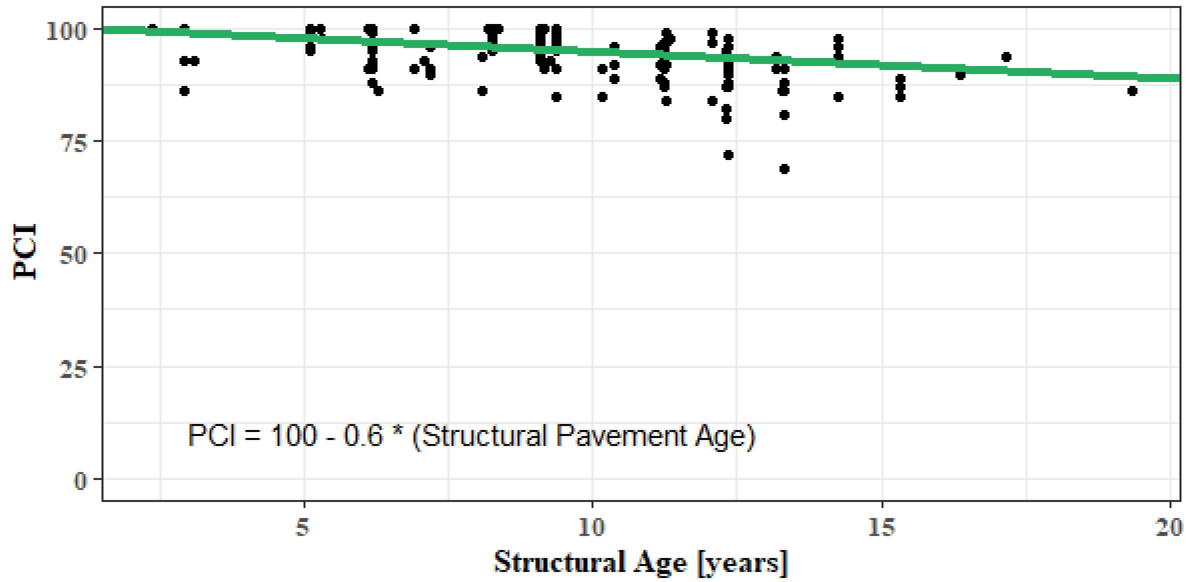
Figure 3 show a distinct difference in rate of pavement decline for different treatment groups. RePlay treated segments have a lower rate of decline with –0.6 change in PCI per year while untreated groups have a rate of –1.54 change in PCI per year. This indicates that on average for the data available, pavement segments treated with RePlay deteriorate more slowly than those not treated. It must, however, be noted that the untreated group contains more observations on older pavement.

Figure 4 shows the deterioration of pavement on segments by number of RePlay treatments. The estimated deterioration rate of these segments is not differentiable from the deterioration rate of RePlay segments overall. While the two-treatment group contains more observations of older segments (as expected), the single treatment group contains a few observations on segments whose condition deteriorated relatively quickly. It is possible that these segments would have been in the two-treatment group, but their state of deterioration precluded them from receiving a second treatment.

Figure 4. Plot of pavement deterioration over time for RePlay-treated segments with a) one treatment; b) two treatments

(a) One RePlay treatment

(b) Two RePlay treatments



Chip Seal Analysis

The statistical analysis completed for untreated and RePlay-treated segments was repeated for chip sealed segments. The Hutchinson dataset contains 219 observations and 88 segments that have been chip sealed, making the data less prevalent than untreated and RePlay-treated. When comparing RePlay and untreated segments to chip seal segments it is important to contextualize the differences in the intent of treatments. Chip seal adds an additional layer of material to a pavement surface, creating at least a temporary increase in PCI. This layer provides protection to the pavement structure below. As evidenced in Figure 5, chip seal is generally applied to older pavements than RePlay. Chip seal segments show a slower deterioration rate than untreated segments and a faster deterioration rate than RePlay segments. Figure 6 shows a comparison of chip seal-treated segments to RePlay-treated segments.

Figure 5. Plot of pavement deterioration over time for seal coat segments

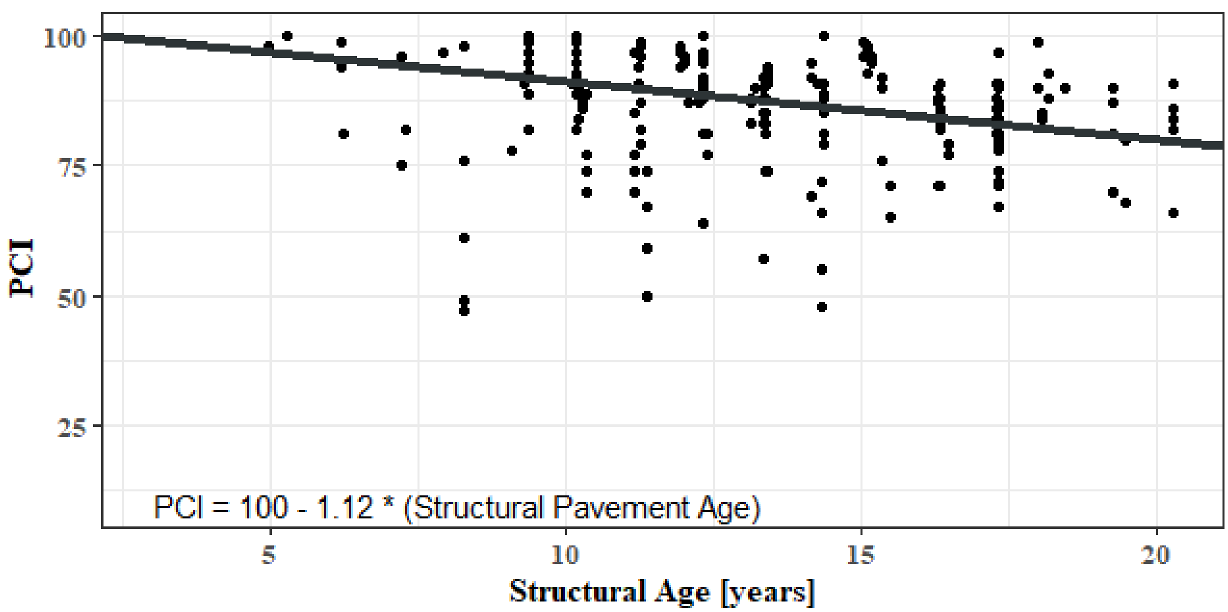
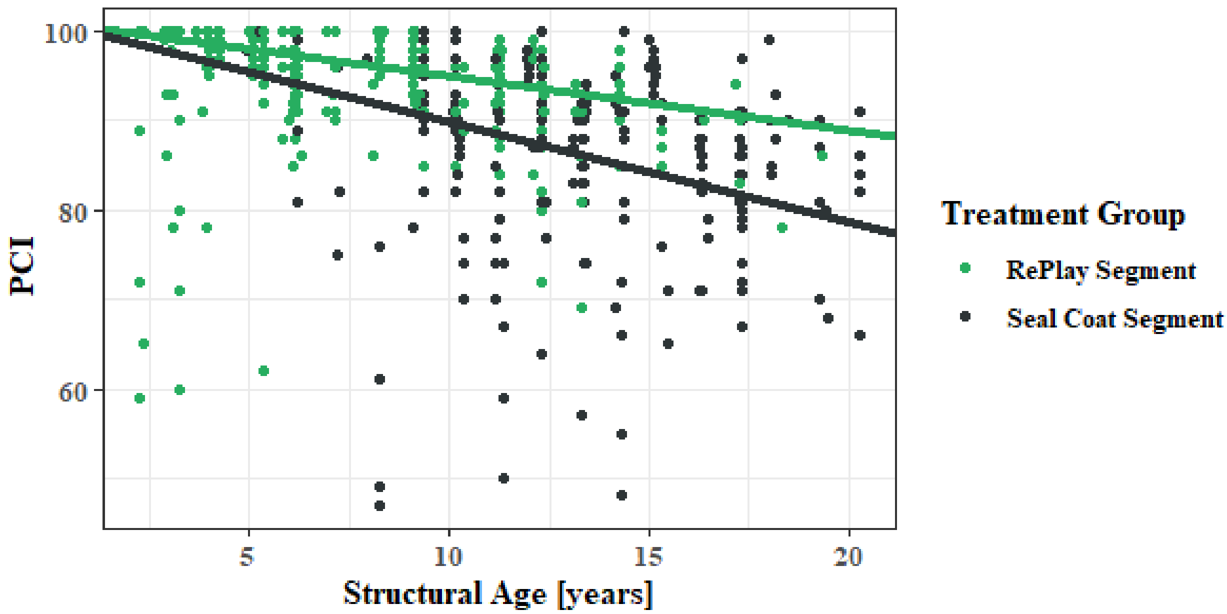


Figure 6. Comparison of seal coat-treated segment deterioration to RePlay-treated segment deterioration



Benefit of Additional Data

While no difference could be derived between segments with one RePlay treatment versus two, the additional data available following the most recent survey contains records for more than double the number of RePlay-treated segments which are at least ten years old. This additional data provides the opportunity to better understand RePlay's impact on aging pavements, regardless of number of treatments. Considering age alone instead of number of treatments allows for better understanding of the change in deterioration over time.

Table 2 shows deterioration rates by pavement age group and treatment. The upward variation in deterioration rate over time is likely the effect of uncontrollable elements of the study. For example, if a pavement is constructed with a poor subbase, it will deteriorate rather quickly and require more significant maintenance earlier. Segments with exceptional subbase will deteriorate more gradually and last longer. Further discussion of how these results are used to evaluate cost effectiveness can be found in the life-cycle cost analysis section.

Table 2. Deterioration rate of pavement by treatment group and age group

Treatment Group	0 to 5 years	5 to 10 years	More than 10 years
Untreated	-2.25	-1.76	-1.45
RePlay	-0.8	-0.45	-0.71
Reduction Rate (Untreated / RePlay)	2.8x	4.4x	2.0x
Chip Seal	-1.19	-1.44	-1.07

Additional data available in Phase 2 was also used to test whether the deterioration rates shown in Table 2 are statistically different and the level of confidence in that differentiation. Table 3 shows the 95 percent confidence intervals for each deterioration rate. There is a 95 percent chance that the actual deterioration rate falls within these ranges, on average.

In the 0-to-5-year range, there is overlap in the ranges for RePlay and chip seal, -1.09 to -0.87. This indicates there is a possibility that the real deterioration rates of these groups could be the same. In the 5-to-10-year group, untreated and chip seal overlap between -1.73 PCI/year and -1.49 PCI/year. None of the groups overlap in the older than 10 years group. Moreover, note that the ranges for RePlay and untreated never overlap, providing at least 95 percent confidence that the deterioration rates of these two groups are different across all assessed time periods, on average.

Table 3. Confidence intervals (95 percent) for each treatment and age group

Treatment Group	0 to 5 years	5 to 10 years	More than 10 years
Untreated	-2.52 to -1.98	-2.03 to -1.49	-1.69 to -1.21
RePlay	-1.09 to -0.51	-0.53 to -0.37	-0.81 to -0.61
Chip Seal	-1.51 to -0.87	-1.73 to -1.15	-1.17 to -0.97

Life-Cycle Cost Analysis

The approach used for economic analysis is equivalent uniform annual cost (EUAC) analysis, the same approach as Phase 1. EUAC analysis permits the elimination of many assumptions required when using the more common 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 are documented in the following sections. Assumptions regarding the service, construction cost, discount rate, etc. will also be discussed.

Input Values Determination

Service life, discount rate, and initial construction costs are required for conducting the economic analysis. Some of these values are equivalent to those used in Phase 1, while other input variables (including service life) have been investigated in further detail and understood with greater confidence with the additional available data. Table 4 below shows how variables have been reconsidered in relation to Phase 1. All other costs (e.g., pavement marking) associated with both treatment groups were assumed to be the same and were dropped from the analysis in accordance with FHWA guidelines.

Table 4. Input values changes from the Phase 1

Input variable	Changed from previous phase?	Description
Service life	Yes	According to the new deterioration rates proposed in Table 2, further analysis is needed.
Construction cost	No	The construction cost of pavement was estimated based on current industry practices using the SRF pavement cost estimator tool ($35 / SY). Cost estimation was conducted for the RePlay by using historical data. According to variation in the binder cost, three possible cost values were estimated for RePlay and incorporated to the sensitivity analysis ($1.70, $2.00, $2.50).
Discount rate	No	To capture the uncertainty associated with the discount rate, three discount rates (3%,5%, and 7%) were considered and included in the sensitivity analysis.

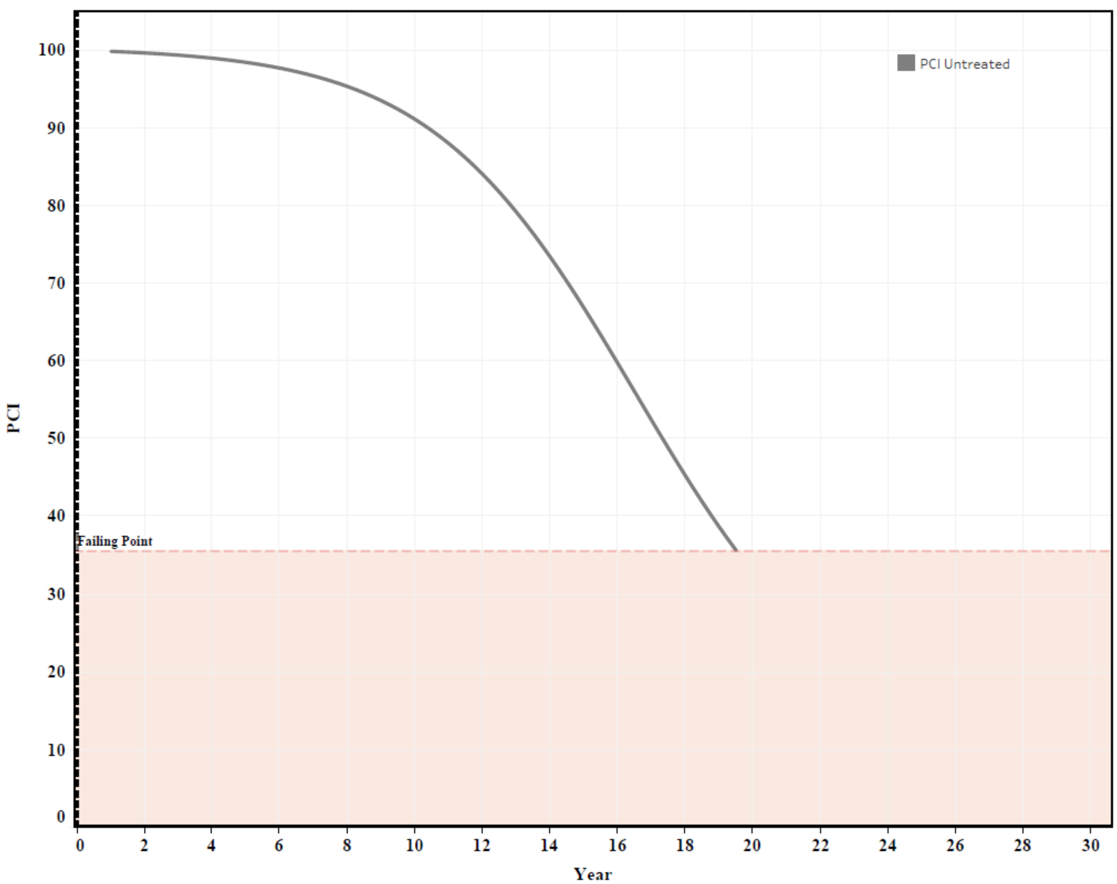
Service Life

The same research study on long-term performance of untreated asphalt concrete employed in Phase 1 was used as a baseline of service life estimation. 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 the Long-Term Pavement Performance (LTPP) program and Minnesota Road Research (Mn/ROAD) project (Wu, 2015). The model developed relating pavement condition to time (reduced time) is given by:

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

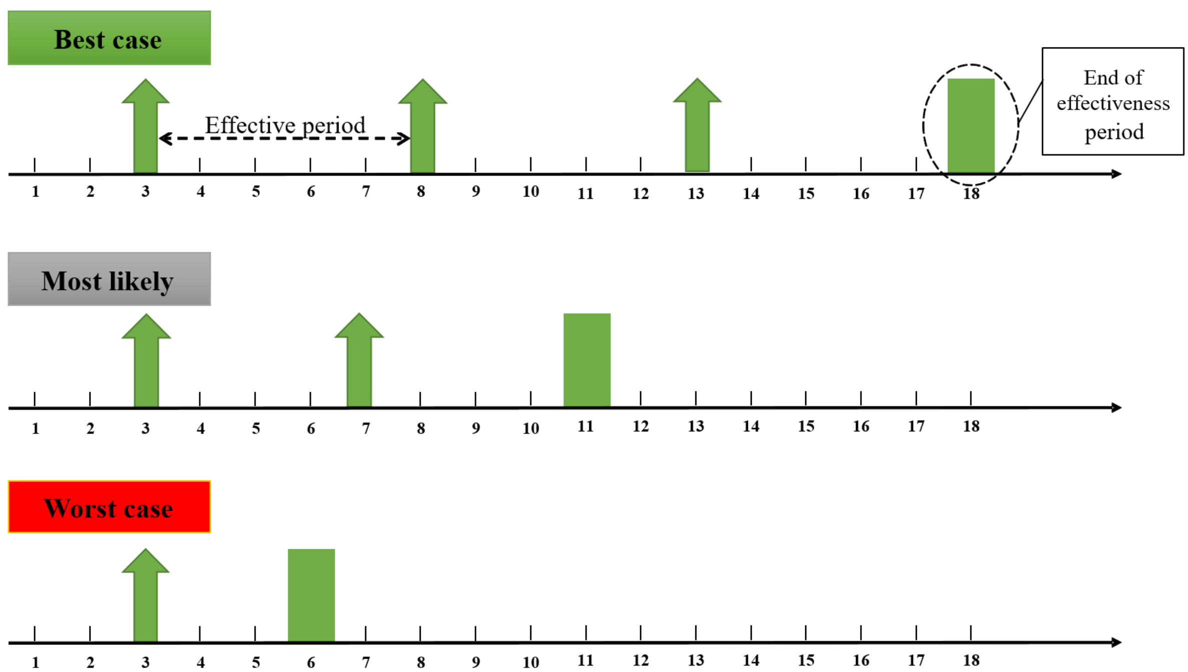
Figure 7 shows a schematic of the asphalt pavement performance master curve developed based on the adopted model. As it is shown in Figure 7, the failing criteria were defined as a PCI below 35 in the adopted study. This model will be used in the following section to estimate the service life of a surface that is treated with RePlay.

Figure 7. 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))



In Phase 1, to cover a wide range of RePlay implementation practices, three possible scenarios were developed for RePlay implementation as shown in Figure 8. Figure 8 shows a five-year effective period with three RePlay applications as the best-cast scenario, a four-year effective period with two RePlay applications for most likely scenario, and a three-year effective period with one RePlay application for the worst-case scenario.

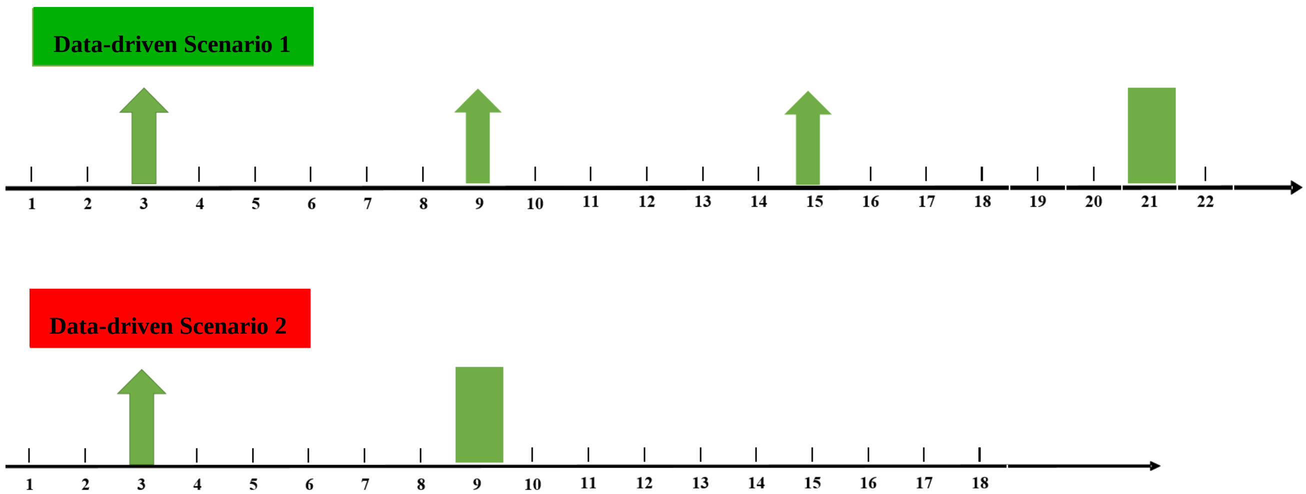
Figure 8. Three theoretical RePlay implementation scenarios used in Phase 1



In addition to the three scenarios developed for Phase 1, two additional scenarios were identified based on the statistical analysis using newly available data, a single treatment scenario and a multi-treatment scenario. As shown in Table 2, RePlay-treated segments exhibit a considerable reduction in the deterioration rate of asphalt concrete. Additionally,

Figure 3 shows greater pavement longevity than previously assumed. Based on these findings, treatment period effectiveness adjustments were made. In the new set of scenarios, the effectiveness period of RePlay was increased by one year, resulting in an assumed six-year effectiveness period. The new scenarios are shown in Figure 9.

Figure 9. Data-driven scenarios developed for Phase 2

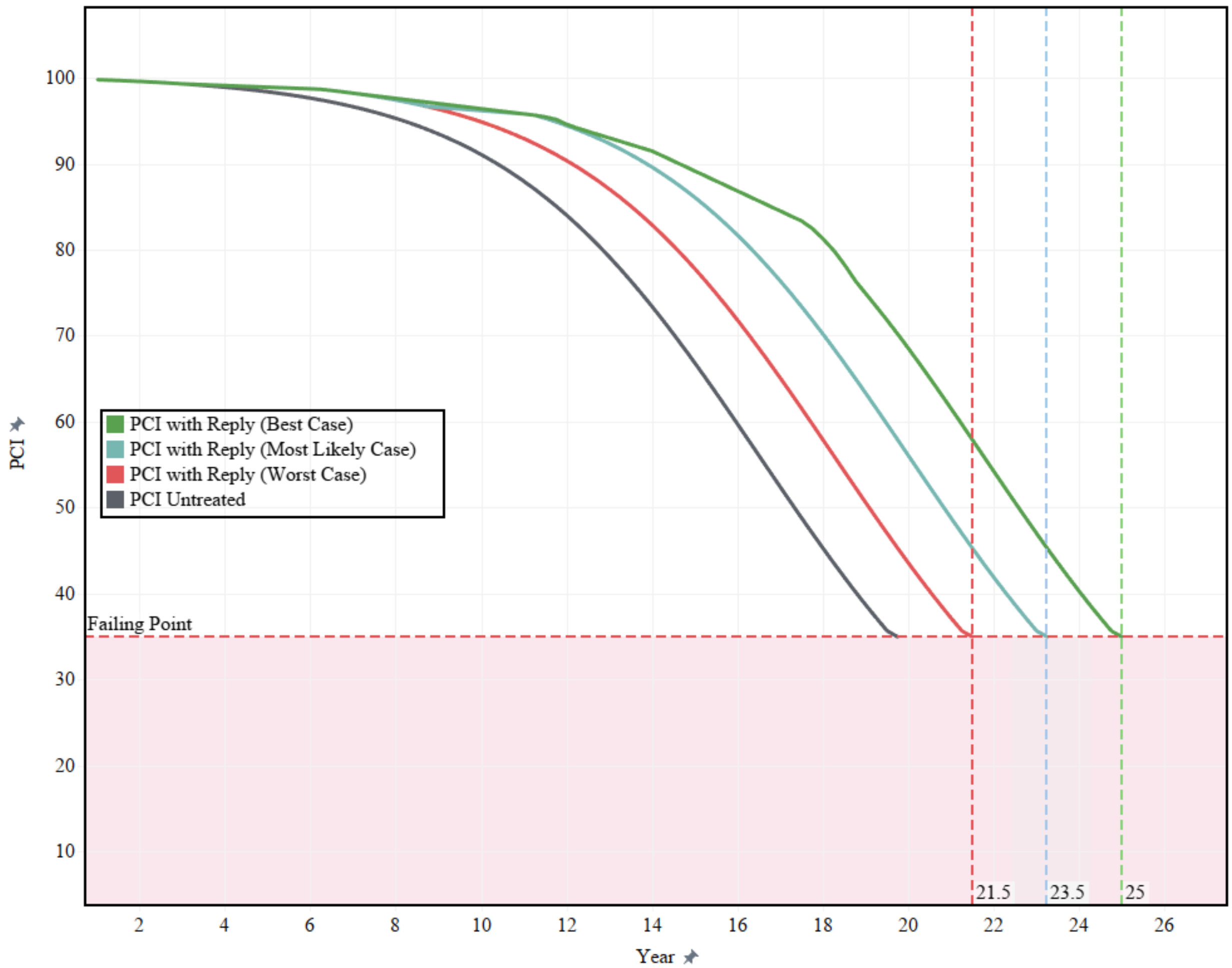


To estimate the longevity of the asphalt surface under each of the scenarios, modifications were made to the untreated asphalt service life model. During RePlay's effective periods, the deterioration rate of the surface is assumed to be the untreated deterioration rate of the base model modified by the results in Table 2. This means that for the first treatment period the deterioration rate for the RePlay-treated surfaces is 2.8 times less than an untreated asphalt and for the second and third treatment period this number would be 4.4 and 2.0, respectively.

During the effective periods, linear approximation was used for deterioration rate adjustments (with a slope of 4.3). The results of the modified service life model for the theoretical Phase 1 scenarios are presented inFigure 10a. The service life model modified for the new, data-driven Phase 2 scenarios is shown in Figure 10b.

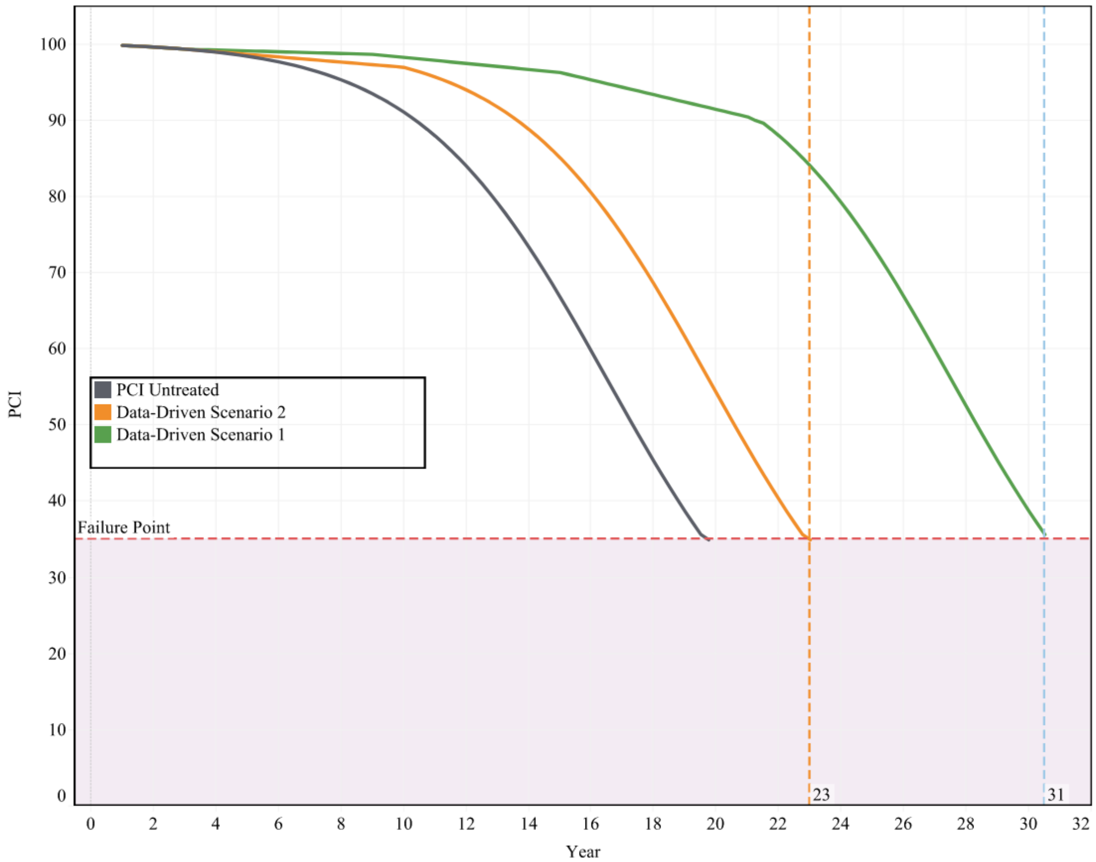
Figure 10. Service life prediction model for RePlay scenarios:

(a) Service life estimate for the scenarios developed in Phase 1 (updated with new data)



(a)

(b) Service life estimate for the new, data-driven scenarios developed in Phase 2



(b)

Figure 10a shows that there are slight reductions in the service life estimates developed based on the new data (a year or less for all the scenarios). The estimate for the new, data-driven scenario with multiple treatments shown in green in Figure 10b shows an increase in service life estimate over Phase 1's best case scenario.

Economic Analysis Results

A life-cycle cost analysis using an EUAC approach was developed in Excel. The sensitivity analysis was conducted on the variables that consist of high-level uncertainty including discount rate, RePlay cost, number of RePlay treatments, and RePlay effectiveness 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. Potential RePlay costs include $1.70 per square yard, $2 per square yard, and $2.50 per square yard. Number of treatments and effectiveness period of RePlay are captured in the five service life scenarios detailed in the Service Life section of this report. For this analysis, the untreated life-cycle cost was taken as an economic criterion.

Figure 11 shows the results of economic analysis. Each box within the figure corresponds to a service life scenario and discount rate. Each of the three potential RePlay cost scenarios is highlighted at individual points along the green line within each box. Each point is labeled with the life-cycle cost of replay within each scenario. The red line represents the untreated scenario for comparison. Figure 11 indicates that in all the combinations of the possible scenarios using RePlay incurred a lower cost rather than the base case scenario (untreated).

Figure 11. Economic analysis results for Phase 2

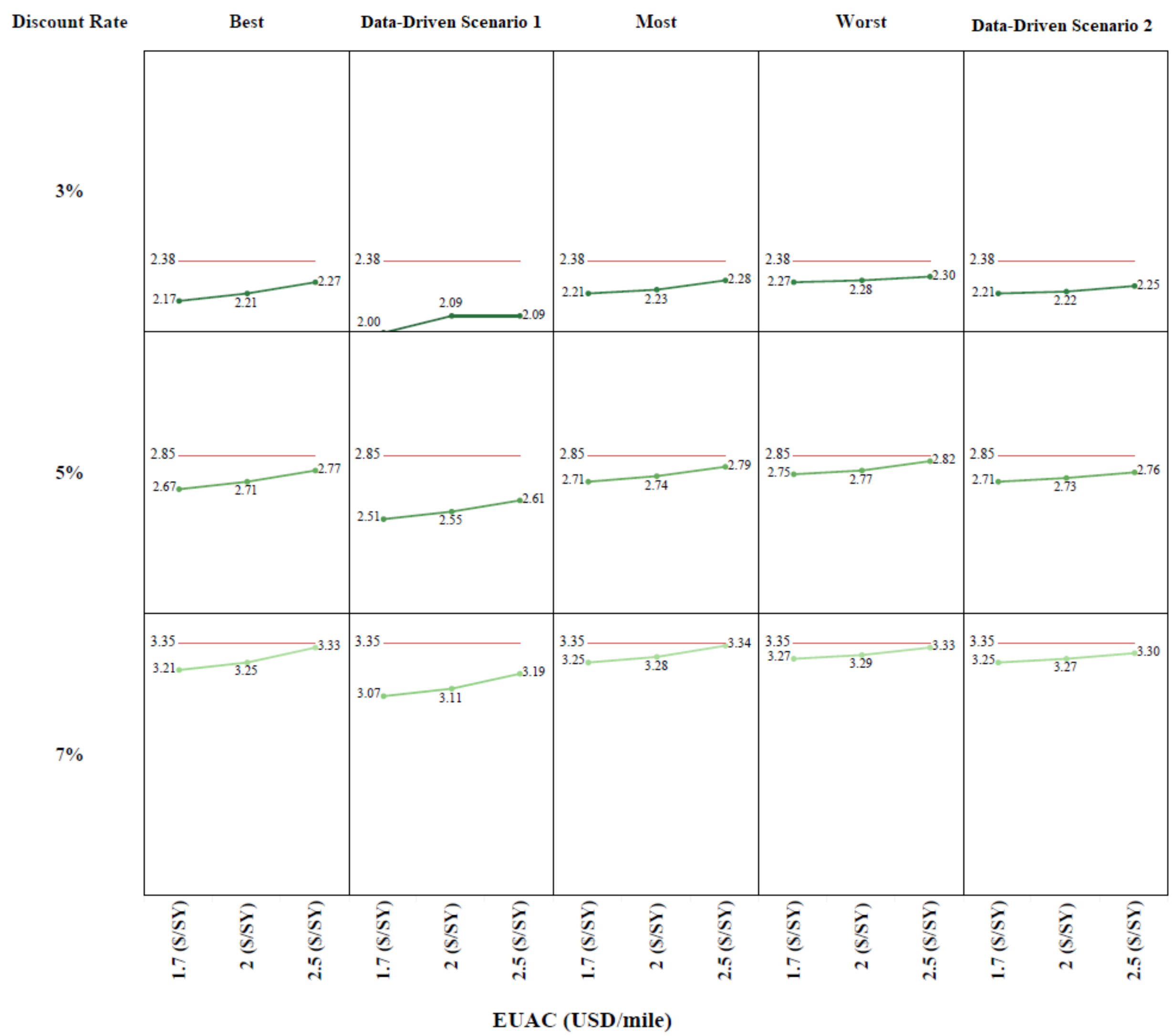


Figure 11 also shows that the life-cycle cost of RePlay is highly sensitive to discount rate and implementation cost of RePlay. While the construction cost of RePlay is inexpensive compared to other treatment methods, it is expected that advancements in bituminous material technology and construction practices could reduce the RePlay implementation cost. This would further reduce RePlay life-cycle cost.

Conclusions and Recommendations

This report builds on an initial study documenting assumptions, methods, and results of statistical analysis and subsequent life-cycle cost analysis of RePlay Agricultural Oil and Preservation Agent®, a biobased asphalt pavement preservation agent. The report adds additional data, statistical analysis, and sensitivity tests. The overall study design for Phase 2 mimicked that of Phase 1. Data from the City of Hutchinson, MN was cleaned and used to establish rates of pavement deterioration for RePlay-treated segments relative to untreated pavement segments (for three time periods in Phase 2). A stochastic life-cycle cost analysis was conducted for different scenarios to determine the cost effectiveness of using RePlay relative to no treatment for regularly managed segments.

Statistical analysis revealed that segments treated with RePlay have a statistically significant lower rate of pavement degradation compared to untreated segments. This relationship was found to continue over time. Combining the rates of degradation from the statistical analysis with an existing model for untreated asphalt pavement degradation, estimates of RePlay service life were developed (two new scenarios in addition to three scenarios developed in Phase 1). The service life analysis demonstrated that RePlay could increase the longevity of road surfaces by 1.5 to 11 years. The development of deterioration rates is influenced by uncontrolled factors including routine crack treatments and pavement subbase condition.

Using the State of Minnesota as a case study, the results of 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.

The methodology followed in this study provides agencies with a sensitivity analysis which has shown RePlay use produces the lowest life-cycle cost. Recommendations that may result from this research are established in fundamental LCCA theory which provide public transportation agencies with an added level of confidence in predicting the financial benefit for this pavement preservation treatment.

References

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Wu, K., 2015. Development of PCI-based pavement performance model for management of road infrastructure system. Arizona State Univ. https://repository.asu.edu/attachments/163996/content/Wu_asu_0010N_15506.pdf