# Demonstrating the Application of Life Cycle Planning (LCP) on a Pavement Network

# Results From the Arizona DOT Pavement Pilot Project



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**16. Abstract**
Life Cycle Planning (LCP) is “a process to estimate the cost of managing an asset class, or asset sub-group, over its whole life with consideration for minimizing cost while preserving or improving the condition (23 CFR Part 515).” Since LCP is a relatively new process for State DOTs, the Federal Highway Administration (FHWA) developed a handbook on LCP to assist transportation agencies with the implementation process (FHWA-HIF-29-006).
To further assist agencies with the implementation of LCP, the FHWA initiated a pilot study to demonstrate and document the application of LCP principles on a pavement network using actual data from a State transportation agency. This report documents the findings from the pilot study and lays out a process for considering the many factors that impact long-term asset performance.


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# TABLE OF CONTENTS

# LIST OF FIGURES



# LIST OF TABLES

# CHAPTER 1: INTRODUCTION

## Background

In 2012, Federal regulations requiring the development of risk-based Transportation Asset Management Plans (TAMPs) introduced the concept of life cycle planning (LCP) as "**a process to estimate the cost of managing an asset class, or asset sub-group over its whole life with consideration for minimizing costs while preserving or improving the condition**" 23 CFR Part 515 (complete definition is in 23 CFR 515.5). The Federal Highway Administration (FHWA) published the nonbinding document "Using a Life Cycle Planning Process to Support Asset Management" in November 2017 (FHWA 2017) and a series of workshops were conducted to help transportation agency practitioners put the guidance into practice. In 2019, a nonbinding *LCP Handbook* ["Using an LCP (Life Cycle Planning) Process to Support Transportation Asset Management: A Handbook on Putting the Federal Guidance into Practice"; FHWA-HIF-19-006] was published by FHWA to provide additional information on using LCP to support pavement and bridge investment decisions (Zimmerman et al. 2019).

To further assist agencies with the implementation of LCP, the FHWA initiated a pilot study to demonstrate and document the application of LCP principles on a pavement network using actual data from a State transportation agency. This report documents the findings from the pilot study and lays out a process for evaluating different investment strategies in terms of their cost-effectiveness and their impact on long-term asset performance.

## The Importance of Life Cycle Planning

Asset managers are often asked questions such as "What is the impact of shifting some of our preservation funding from pavements to bridges over the next 5 years?" "Is there a way to reach our performance goals if capital funds are decreased for the next 3 years?" "Are we using our funds as cost-effectively as possible?"

LCP provides the foundation for addressing such questions. It considers treatment options at all phases of an asset's life cycle to determine the most cost-effective sequence of treatment strategies for an asset class or an asset sub-group using realistic funding levels. LCP utilizes asset condition data obtained from field surveys and inspections, deterioration models based on historical performance trends, and agency-developed treatment decision trees found in most pavement management systems (PMS) to predict the consequences of different combinations of treatments, budgets, and investment priorities.

## LCP Pilot Objectives

FHWA's *Using an LCP Process to Support Transportation Asset Management: A Handbook on Putting the Federal Guidance into Practice* (nonbinding guidance; FHWA-HIF-19-006) demonstrated the use of a PMS to conduct an LCP analysis. This document included a step-by-step process for conducting a network-level LCP analysis, but the examples were simulated to illustrate key points without providing details.

In 2019, FHWA initiated a study to pilot the *Handbook* and the implementation of the LCP process with actual data from a State Department of Transportation (DOT). The Arizona DOT (ADOT) agreed to use its PMS to provide outputs for different funding allocations and work type scenarios to illustrate the consequences of the changes on future pavement performance and network conditions. The results from the pilot study are documented in this report.

## Pilot Study Approach

### *Pilot Agency Selection*

The pilot study began with an assessment of State DOTs that had a PMS in place to implement the process presented in the document: *Using an LCP Process to Support Transportation Asset Management: A Handbook on Putting the Federal Guidance into Practice* (nonbinding guidance; FHWA-HIF-19-006). ADOT was identified as a strong candidate for several reasons. At the time the pilot started, ADOT had just completed the implementation of new pavement management software and was beginning the process to update its TAMP since its LCP processes had changed. ADOT expressed interest in participating in the pilot to structure its new LCP analysis approach and was selected.

### *The LCP Process*

FHWA introduced the 5-step process shown in figure 1-1. This process can be adapted to the needs and resources of any transportation agency.

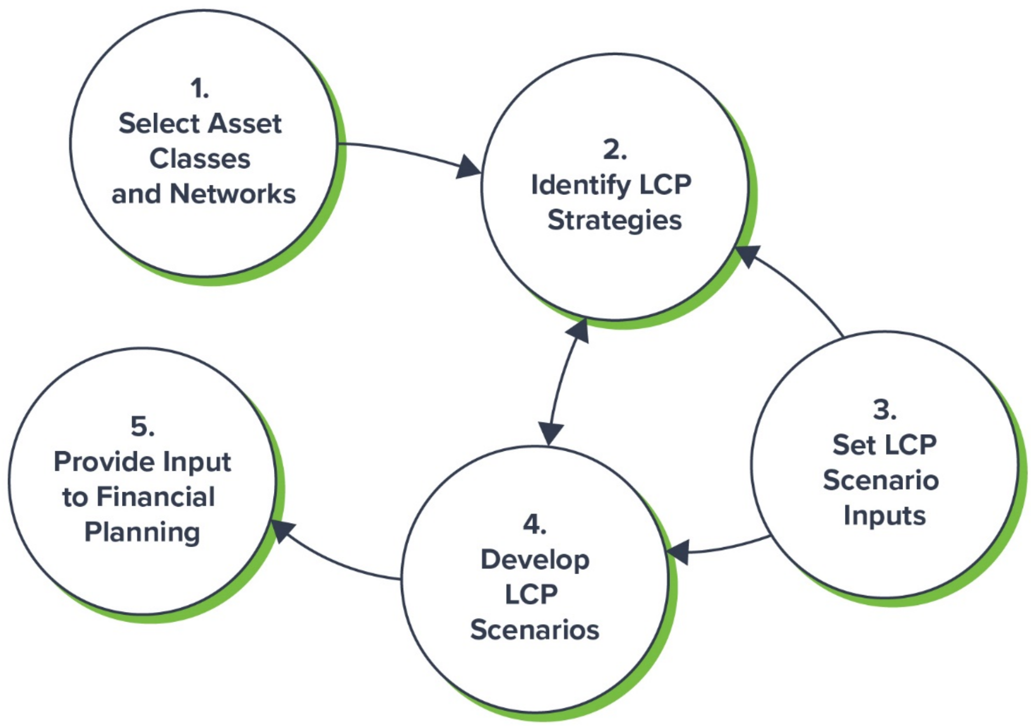


Figure 1-1. The 5-step LCP process introduced by FHWA (adapted from FHWA 2017).

During the pilot study, this process was followed to demonstrate its applicability using a PMS. The nonbinding process includes the steps described below.

#### *Step 1. Select Asset Classes and Networks*

The first step in the process is to establish the analysis parameters. This involves determining which asset classes, sub-groups, and portions of the network will be included (23 CFR 515.5). Those assets that represent the largest annual investment for the agency, or those that address strategic priorities like safety or risk reduction, are typically good candidates for LCP.

An LCP analysis can be conducted for an entire network or for subsets of the network. For instance, an agency might run an analysis on only its National Highway System (NHS) pavements. Other agencies that have included their entire network in their TAMP might choose to analyze subsets of the network separately if different LCP strategies will be used to preserve each subset. For instance, an agency might have one LCP strategy for its high-volume pavement network and a different strategy for its low-volume pavement network.

### *Step 2. Identify LCP Strategies*

The second step in the process is identifying LCP strategies for each asset class and network subset. These LCP strategies can be developed using the treatment decision trees and deterioration models in the PMS. It is beneficial to set up several different LCP strategies for each asset class, reflecting different approaches to manage the network. For example, an LCP strategy that relies extensively on rehabilitation and reconstruction treatments would generate different long-term performance results than another strategy that includes the more aggressive use of preservation treatments to defer major repairs. Risks may also drive an asset strategy, with a culvert replacement strategy established for areas with flooding issues and a preservation-based strategy for low-risk areas. The strategies represent a range of solutions that can be compared over a long analysis period in terms of their impact on reducing risks and performance gaps.

### *Step 3. Set LCP Scenario Inputs*

Management systems use certain parameters to define the funding levels, desired condition levels, strategy definition, analysis period, and other factors (such as minimum condition levels to be met or high-priority risks to be addressed) that will be considered in the analysis. As discussed in the body of the report, consideration of these parameters is important because of the significant impact they can have on the results.

### *Step 4. Develop LCP Scenarios*

The actual analysis is conducted during step 4. For pavements, these scenarios are typically generated using an agency's PMS.

As outputs from an analysis are evaluated, adjustments may be needed to the strategies and/or the inputs (as represented by the two-way arrows in figure 1-1). For example, if the desired performance cannot be achieved from a particular scenario, the agency may consider modifying the strategy to allocate more funds to preservation to see if that generates better results. Additional scenarios may also be generated to evaluate the impacts of increases or decreases to expected funding levels to help determine the sensitivity of the planned strategies to funding fluctuations. This iterative process demonstrates the value of having strong analysis tools in place to produce the results of many different "what-if" scenarios.

### *Step 5. Provide Input to Financial Planning*

The final step incorporates the results into the development of the 10-year TAMP financial plan. If the financial planning process results in changes to the expected funding levels or agency priorities, it is possible that additional iterations of the LCP process may be involved. In general, the stronger the coordination between the asset managers and the financial team during the early steps in the process, the lower the likelihood that the process will have to be repeated.

## Report Organization

This report is organized into three chapters, beginning with this introduction. Chapter 2 summarizes the data, software, and other resources used by ADOT to support the analysis, as well as the application of those resources to the nonbinding 5-step LCP process. Key takeaways, including challenges that were encountered and expected changes to business processes and system configuration, are also documented. Chapter 3 summarizes the findings and lessons learned.

# CHAPTER 2: PAVEMENT LCP PILOT PROJECT

## Introduction

This chapter documents the pavement LCP pilot study conducted with ADOT. Key findings and lessons learned are presented along with a discussion of how the LCP results differed from the agency's traditional activities. Challenges faced by ADOT during the implementation, and anticipated business process changes as a result of this pilot, are also documented.

## ADOT Resources for Conducting the LCP Analysis

The resources used by ADOT for conducting its LCP analysis are documented below:

- **Pavement LCP Team**. ADOT assembled a team for gathering and organizing pavement data for the LCP analyses. The team consisted of:
  - One pavement management section manager with overall responsibility for pavement management.
  - One pavement performance engineer who was familiar with the pavement condition information.
  - One surface treatment engineer who oversees ADOT's pavement preservation program.
  - Two senior pavement engineers involved in the PMS implementation.
  - One TAMP manager responsible for the updates to the TAMP.
- **Pavement Management System**. ADOT utilizes a pavement management system (PMS) that includes the components described in 23 CFR 515.17. ADOT worked with its PMS vendor to develop, program, and implement the system's algorithms, decision trees, and performance models. The software was being implemented as the pilot took place, which may have influenced some of the report findings.
- **Financial Management Office**. ADOT's Office of Financial Management Services (OFMS) provided information on the level of funding expected to be available for highway capital spending between 2020 and 2045.

## LCP Process

ADOT followed the nonbinding 5-step process (documented in chapter 1) to conduct the LCP analysis. Key items considered under each step are discussed the following sections.

### *Step 1: Select Asset Classes and Networks*

> To satisfy Federal regulations [23 CFR 515.5 and 515.7(f)], the LCP analysis included in a State DOT's TAMP is required to include the locally owned NHS pavement

Since this was a pilot study focused only on pavements, that was the only asset class considered in the analysis. For the network, ADOT analyzed all pavement segments on the NHS and State-owned non-NHS network to be consistent with the agency's TAMP development efforts. Although ADOT collects information on the entire NHS and included the locally owned NHS in its TAMP, the agency chose to focus only on the State-maintained system for this pilot study. ADOT divided the pavement network into four categories—interstate NHS, State-owned non-interstate NHS, high-volume non-NHS, and low-volume non-NHS. Table 2-1 provides the information on current pavement conditions for each subset of this network.

Table 2-1. ADOT pavement networks included in the LCP analysis.

| Pavement Network | Mileage (lane-miles) | Current Conditions (2020) |
|---|---|---|
| Interstate NHS | 5,195 | 47.9% Good and 0.4% Poor |
| State-owned non-interstate NHS | 7,253.8 | 28.0% Good and 0.5% Poor |
| High-volume non-NHS | 853.0 | 28.1% Good and 0.1% Poor |
| Low-volume non-NHS | 6076.1 | 14.7% Good and 2.5% Poor |

Notes:
- Current Conditions are based on national performance measures.
- High-volume non-NHS: > 5,000 Average Annual Daily Traffic (AADT).
- Low-volume non-NHS: ≤ 5,000 AADT.

### *Step 2: Identify LCP Strategies*

ADOT identified three LCP strategies for this pilot study, as described below:

- **Preservation Strategy**. In this strategy, the PMS uses the decision trees to select treatments that provide the highest cost-benefit ratio for managing the pavement network. Funding is almost evenly distributed between preservation and rehabilitation activities under this strategy.
- **Worst-First Strategy**. This strategy is very similar to ADOT's historical practices. Pavements in the worst conditions have the highest priority for funding. Most of the funding is used for funding major rehabilitation and reconstruction activities. A small fraction of the total funding (approximately 14 percent) is allocated to preservation treatments.
- **Hybrid Scenario**. The hybrid strategy represents the ADOT Pavement Section's recommendation to slowly phase in more preservation treatments. It is similar to the preservation scenario but tempered by special projects and professional judgment. Professional judgment might consider sites initiated by a call for projects, district visits and input, legislative mandates, exceptions to PMS recommendations, contracting and staffing issues, high profile projects, programming and financial challenges, and preliminary scoping. Under this strategy, approximately 30 percent of the total funding is allocated to preservation treatments and the remaining 70 percent to major rehabilitation treatments.

While ADOT configured its LCP strategies by controlling the amount of funding that was available for each treatment category, it could also be done by modifying the treatment decision trees in the PMS to trigger different types of treatments at different points in the pavement life cycle.

For example, in one decision tree, the International Roughness Index (IRI) trigger for a preservation treatment may be set to 110 inches per mile whereas in another decision tree focused on a more proactive application of preservation treatments, the IRI trigger could be set at 90 inches per mile. Another approach is to develop multiple decision trees that trigger different types of treatments for the same pavement condition value(s). These approaches for developing different LCP strategies require several trial analyses to verify the reasonableness of the outputs generated by the PMS.

ADOT conducted several preliminary analyses using different treatment trigger values in its PMS decision trees and decided to adopt the trigger values that resulted in the most practical treatment recommendations.

### *Step 3: Set LCP Scenario Inputs*

The primary inputs to each LCP strategy that ADOT developed are briefly described in the following sections.

#### *Analysis Period and Discount Rate*

ADOT conducted the LCP analysis using a 25-year analysis period to evaluate long-term impacts of each LCP strategy. Each analysis was conducted using a discount rate of 2.6 percent.

#### *Annual Funding*

The LCP analysis is influenced by the annual funding expected to be available for managing the asset class. During the first three years of the analysis (2020 to 2022), the average annual funding expected to be available is less than $200 million. The funding levels are expected to increase starting in 2023 and an average annual funding of $270 million is projected from 2023 to 2045. Figure 2-1 shows the funding levels used for each year over the analysis period. Although only one funding scenario was considered for the pilot, ADOT regularly considers alternate funding scenarios as part of its planning processes until the most realistic scenario is determined by the ADOT Office of Financial Management Services.

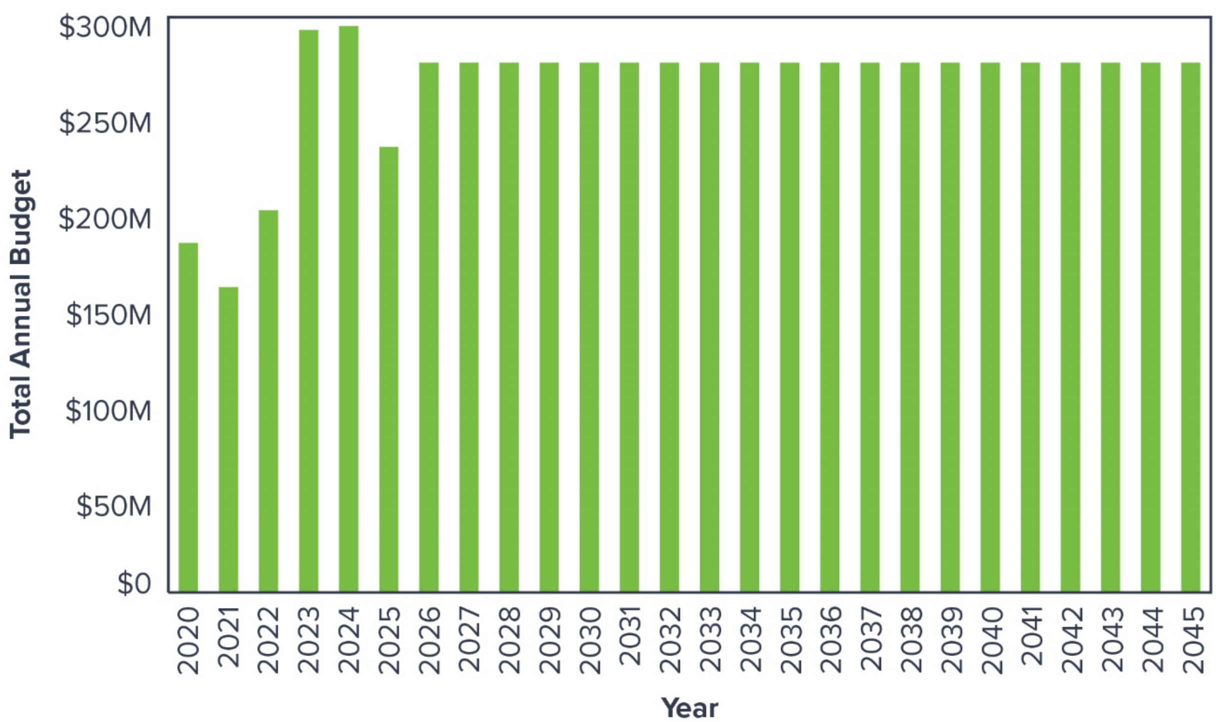


Figure 2-1. Total annual budget.

### *Treatment Definitions and Costs*

ADOT uses three broad treatment categories in its LCP analysis:

- **Preservation.** Treatments applied to pavements in *Good* or *Fair* condition (per 23 CFR 490.313) to slow the deterioration rates or address surface distresses that do not add structure to the existing pavement.
- **Major Rehabilitation.** Treatments applied to pavements in *Fair* or *Poor* conditions condition (per 23 CFR 490.313) to address surface distresses and add structure to existing pavement or provide significant structural improvements.
- **Reconstruction.** Applied to pavements that need complete removal and replacement to restore both structural and functional capacities.

Table 2-2 presents some typical treatment unit costs provided by ADOT. The treatment unit costs include the cost for drainage and guardrail improvements.

Table 2-2. Summary of ADOT pavement treatments by treatment type.

| Treatment Type | Typical Treatments | Typical Cost per Lane-mile (per ADOT) |
|---|---|---|
| Preservation | Asphalt concrete (AC) grinding / milling | $20,000 to $80,500 |
| | Cape seal | |
| | Chip seal | |
| | Crack seal / fill | |
| | Fog seal / flush | |
| | Friction course (Asphalt rubber – asphalt concrete friction course [AR-ACFC / ACFC]) / mill & fill or overlay of friction course | |
| | Micro surface | |
| | Portland cement concrete pavement (PCCP) cross stitching | |
| | PCCP dowel-bar retrofit (DBR) | |
| | PCCP diamond grinding | |
| | Slurry seal | |
| | Spot repair | |
| | Thin bonded overlay | |
| Rehabilitation | Major AC overlays | $220,000 to $359,000 |
| | Mill & fill (existing AC) | |
| Reconstruction | Removal and replacement of existing roadway section | $636,000 to $1,062,000 |
| | Spot reconstruction | |

### *Deterioration Models*

ADOT's PMS uses a deterministic approach to model pavement performance. In 2017, ADOT began collecting automated pavement data on the State highway system (SHS) and locally owned NHS. However, the automated data technology did not correlate with ADOT's historical condition data. Therefore, ADOT only used the automated data points to develop empirical models of pavement deterioration for its PMS.

Since pavements in the network are composed of different materials and located in different climatic zones, ADOT's pavement deterioration models are subdivided into homogenous families based on pavement type, climate zone, traffic loads and foundation quality. As a result, ADOT has 28 pavement models for Highway Performance Monitoring System (HPMS) cracking, PMS cracking[1], faulting (rigid pavements only), international roughness index (IRI), and rutting (flexible pavements only). ADOT plans to update the deterioration models after acquiring five years of data and to periodically reevaluate the models every five years to improve reliability.

## ***Step 4: Develop LCP Scenarios***

The inputs were used to evaluate the LCP strategies. For purposes of the pilot, only the one funding scenario described in Step 3 was considered.

### *LCP Strategy Definition and Details*

ADOT's PMS uses a benefit-cost analysis to prioritize projects that are suggested using the treatment decision trees. Treatment decisions are based on a number of factors such as pavement condition (e.g., cracking, IRI, rutting, faulting), traffic, and preservation/rehabilitation cycles. ADOT's PMS project prioritization process first converts pavement distress and performance metrics (e.g., IRI, cracking, and rutting) to a 0- to 25-point scale, then weights each distress and each factor by its relative importance as summarized below:

- **Pavement Condition (75 percent).** Evaluated using the following criteria and weights:
  - *Asphalt*: IRI (25 percent), cracking (40 percent), and rutting (10 percent).
  - *Concrete*: IRI (25 percent), cracking (25 percent), and faulting (25 percent).
- **Risk (25 percent).** Calculated on a 1 to 25 scale (1 represents lowest risk and 25 represents highest risk), determined by multiplying the probability of failure and the consequence of failure (each rated on a 1 to 5 scale). Additional details on risk are provided in the following section.

Treatment benefit is calculated as the area between the "do nothing" curve and the shifted performance curve after treatment application (see figure 2-2). The treatment benefit area is then multiplied by a traffic factor ($AADT^{0.2}$) to compute the overall benefit obtained through the application of a treatment on each pavement segment.

[1] HPMS cracking considers only wheel path cracking as specified in the HPMS Field Manual; PMS cracking, as defined by ADOT, considers cracking over the entire pavement surface. PMS cracking is unique to ADOT and used for pavement treatment selection.

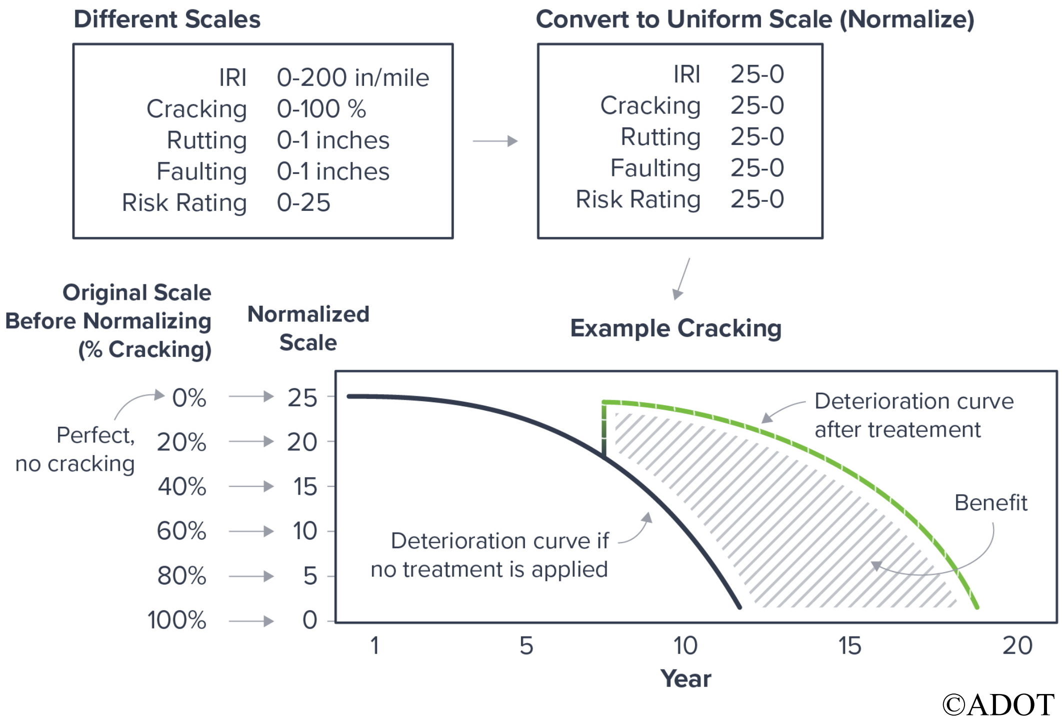


Figure 2-2. Illustration of benefit-calculation in ADOT's PMS.

The calculated benefit divided by the treatment cost represents the benefit-cost ratio, the parameter used in the treatment prioritization process.

### *Risks*

ADOT's pavement LCP pavement process considers the following risks related to geological and hydrological events:

- Earth cracking.
- Embankment failure due to rockfall.
- Expansive-contracting soils.
- Fault.
- Flooding.
- Landslide.
- Landslide due to embankment failure.
- Low water crossings.
- Slip-fault and erosion.
- Slope instability.
- Soil pumping.
- Unstable subgrade.
- Unstable subgrade and wash-out.

For each risk identified, the likelihood of the risk occurring (see table 2-3) and the consequence of the risk (see table 2-4) are determined.

Table 2-3. Risk likelihood ratings.

| Likelihood Rating | Description |
|---|---|
| 1 | Rare |
| 2 | Unlikely |
| 3 | Possible |
| 4 | Likely |
| 5 | Almost Certain |

Table 2-4. Risk consequence rating.

| Consequence Rating | Description |
|---|---|
| 1 | Negligible |
| 2 | Low |
| 3 | Medium |
| 4 | Very High |
| 5 | Extreme |

The probability of failure (POF) of the pavement segment due to the risk identified is then determined using the following equation:

$$POF\ Rating = (60\% \times Likelihood\ Rating) + (40\% \times Condition\ Rating) \qquad (1)$$

The overall risk score is then calculated using the following equation:

$$Risk\ Score = POF\ Rating \times Consequence\ Rating \qquad (2)$$

The calculated risk score is then used to determine a risk rating, as shown in in table 2-5.

Table 2-5. Risk score and risk rating.

| Risk Score | Risk Rating |
|---|---|
| 1 – 6 | Low |
| 7 – 13 | Medium |
| 14 – 19 | High |
| 20 – 25 | Very High |

ADOT assessed every pavement segment on the State-Maintained Highway System (SHS), identified the risk in each segment, and located them by milepost. As noted in the previous section, risk is included the benefit-cost calculation models included in the PMS. If the risk associated with a pavement segment is addressed by the treatment applied, the full benefit of applying that treatment is utilized. If the risk is not addressed by the treatment, only a partial benefit is applied. For example, if a pavement with a risk score of 25 is reconstructed to new condition and the risk is eliminated, the risk score would decrease from 25 to 1. However, if that same pavement is rehabilitated to new condition but the risk is not addressed, the risk score would decrease from 25 to 17.

The results of applying the three LCP strategies (discussed in Step 2) are presented in this section. For this pilot study, ADOT did not evaluate the impacts of applying different scenarios (such as reduced annual funding levels, increased annual funding levels, etc.) to each LCP strategy defined. Only one scenario was evaluated—annual funding levels expected over the next 25 years (presented earlier in figure 2-1). This scenario was considered a realistic representation of expected funding by ADOT's Office of Financial Management Services. Other agencies may find it beneficial to consider alternate funding scenarios to help evaluate the distribution of funding between assets, to estimate total needs, or to assist with target setting.

Figure 2-3 illustrates the distribution of funding between the two treatment categories considered in the analysis—Major Rehabilitation and Preservation—for each strategy outlined in step 2. The reconstruction category is not included since the PMS analysis determined that major rehabilitation treatments are capable of addressing the deficiencies in ADOT's pavement network.

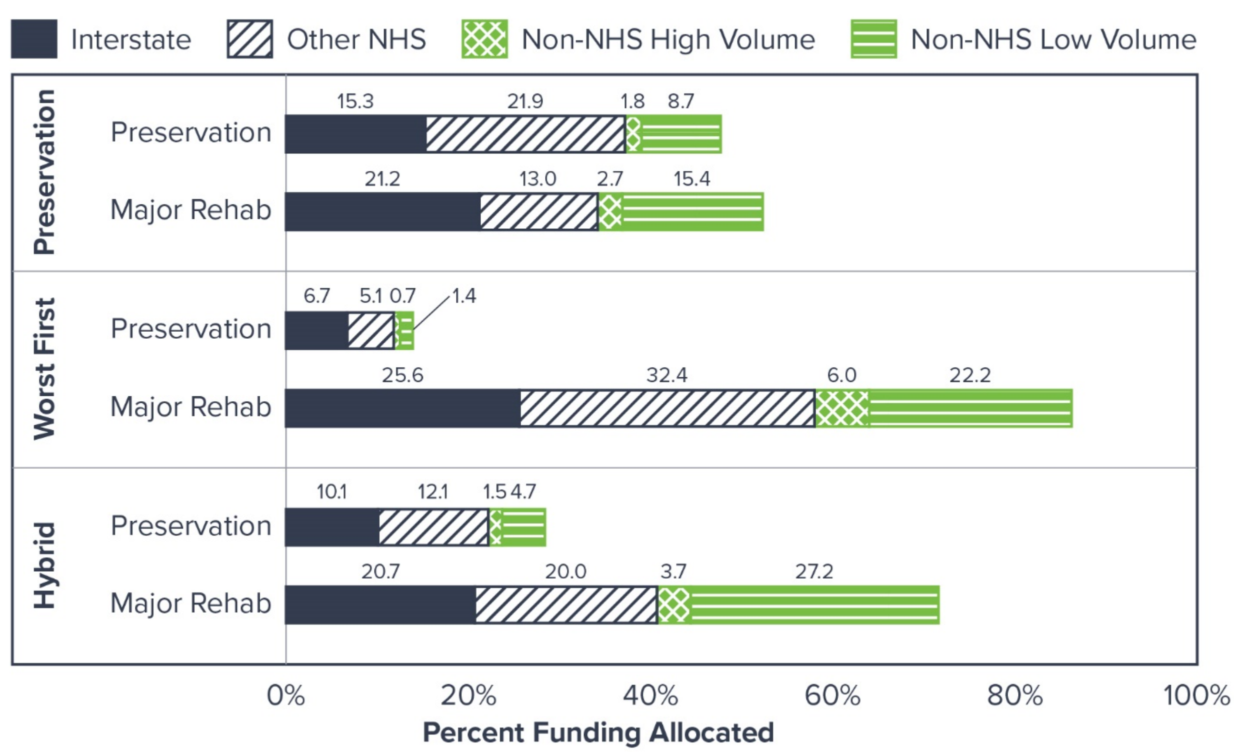


Figure 2-3. Percent funding allocations by repair type for the three LCP strategies.

The distribution of funding between the major rehabilitation and preservation categories for each LCP strategy are summarized below:

- Preservation Strategy:
  - Preservation treatments: 48 percent.
  - Major rehabilitation treatments: 52 percent.
- Worst-First Strategy:
  - Preservation treatments: 14 percent.
  - Major rehabilitation treatments: 86 percent.
- Hybrid Strategy:
  - Preservation treatments: 28 percent.
  - Major rehabilitation treatments: 72 percent.

To determine the optimum level of preservation funding applied in the hybrid strategy, ADOT reviewed its PMS output to determine the total amount of preservation funding that was unspent at the end of the analysis period. This review was repeated for varying levels of preservation funding. As shown in figure 2-4, preservation funding levels between 27 and 30 percent of the total program funding resulted in the maximum use of preservation funds (> 99 percent). Based on this analysis, ADOT allocated approximately 28 percent of the total funding toward preservation treatments for the hybrid strategy.

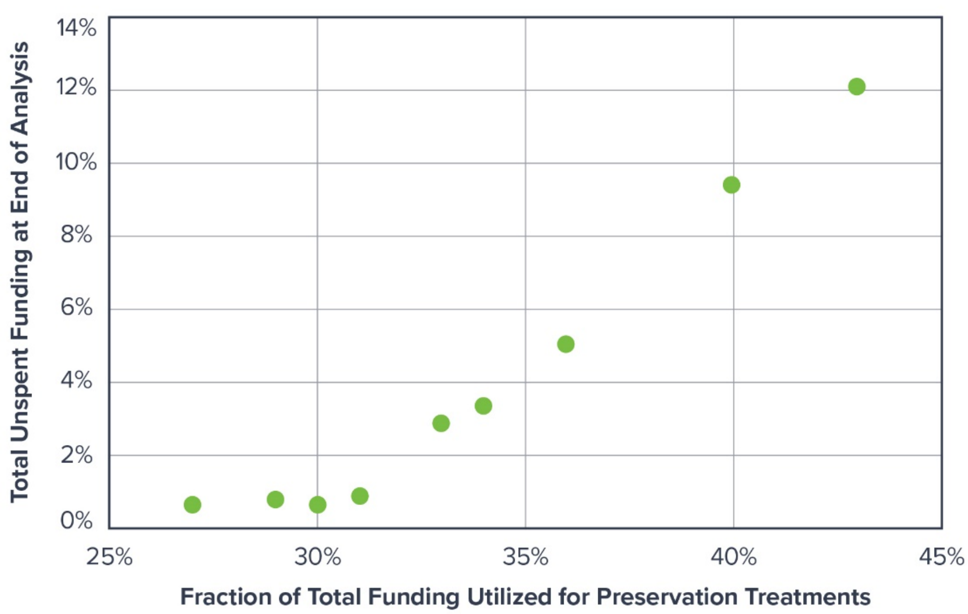




Figure 2-4. Illustration of the approach used to determine the optimum funding allocation for preservation treatments.

The funding distribution between the four pavement networks for each LCP strategy is shown in figure 2-5.

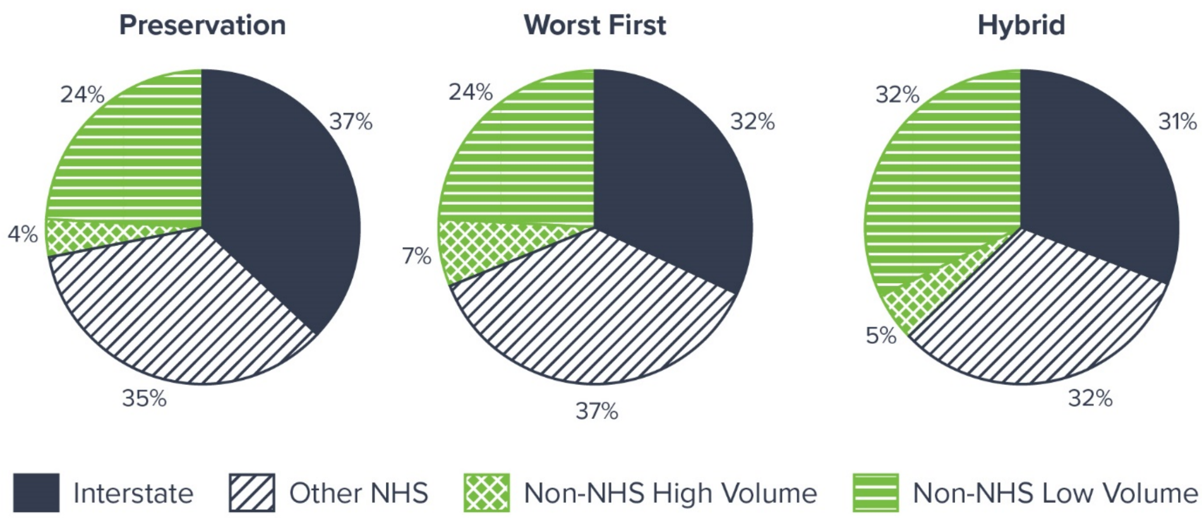


Figure 2-5. Percent total funding spent on each pavement network for hybrid, worst first, and preservation scenarios, respectively.

### *Pavement Condition Analysis*

Figure 2-6 shows the initial condition of ADOT's pavement network (in 2019) and the pavement conditions projected at the end of the analysis period (in 2045) for each LCP strategy evaluated. The worst-first strategy results in the maximum percentage of pavements in *Poor* condition and the hybrid strategy results in the minimum percentage of pavements in *Poor* condition. The highest improvement in the percentage of pavements in *Good* condition is realized through the preservation strategy although ADOT had practical concerns with being able to spend 48 percent of its budget on preservation treatments as defined for this strategy.

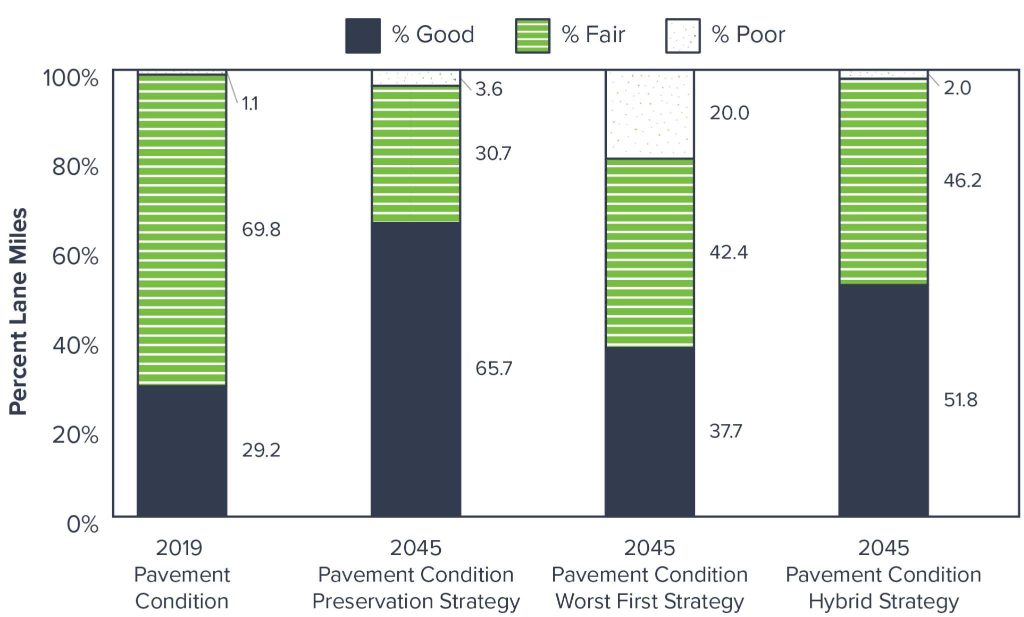


Figure 2-6. Initial and predicted lane miles for different scenarios.

Figures 2-7 through 2-11 present the pavement condition trends from 2019 through 2045 for each pavement network and LCP strategy evaluated.

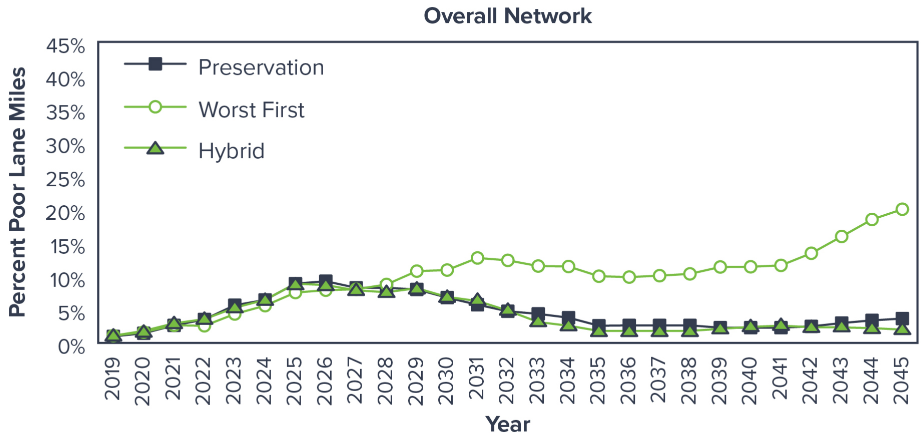


Figure 2-7. Pavements in *Poor* condition—Overall network.

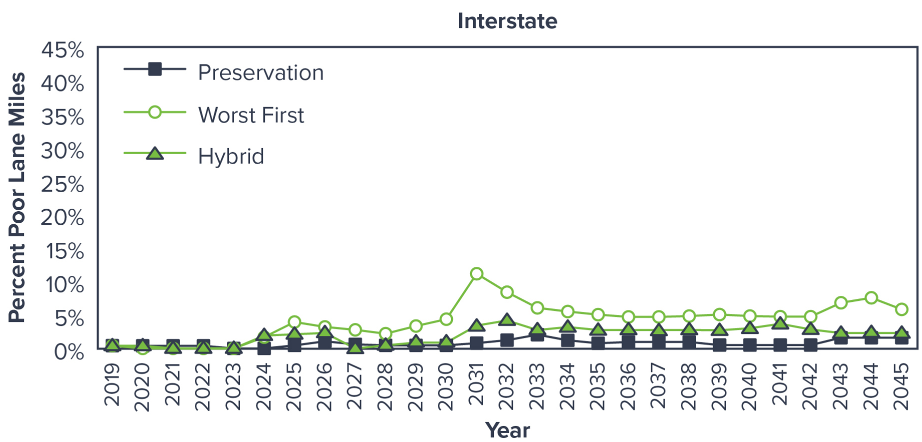


Figure 2-8. Pavements in *Poor* condition—Interstate network.

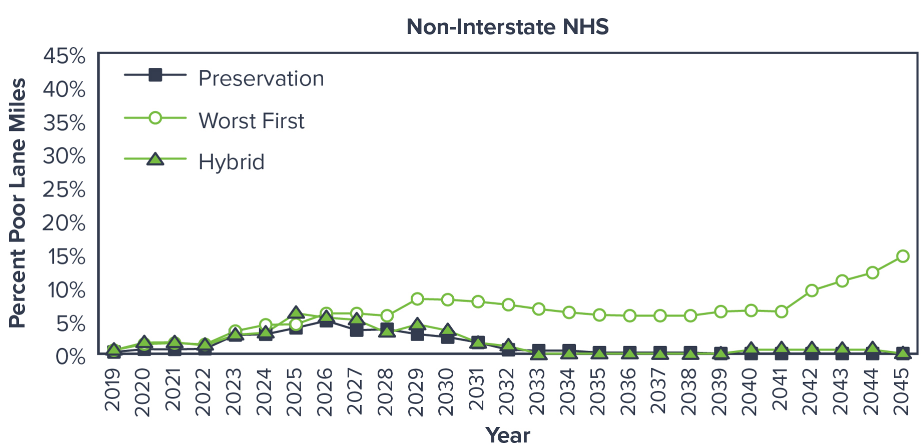


Figure 2-9. Pavements in *Poor* condition—Non-interstate NHS network.

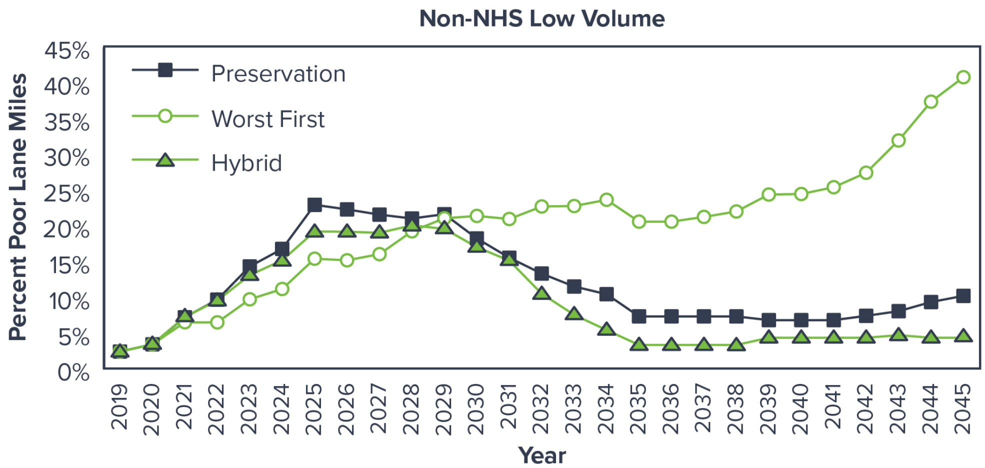


Figure 2-10. Pavements in *Poor* condition—Non-NHS low volume network.

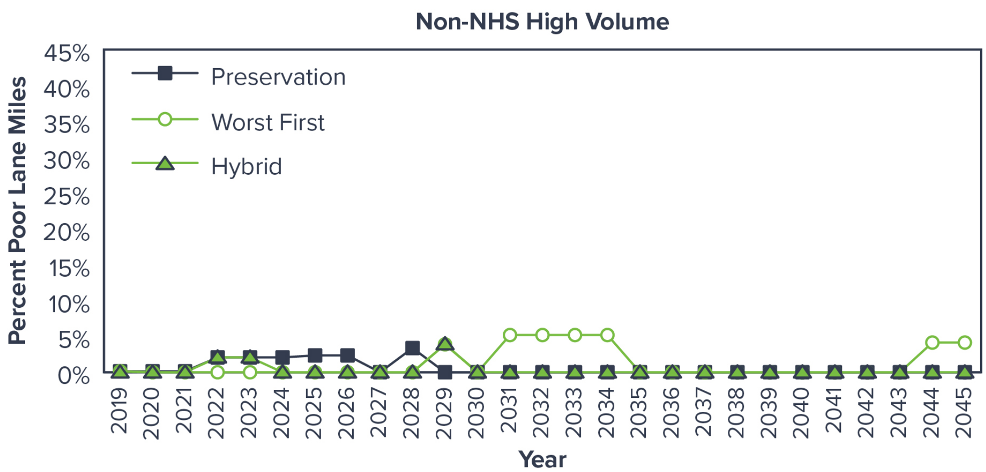


Figure 2-11. Pavements in *Poor* condition—Non-NHS high volume network.

The key takeaways from figures 2-7 through 2-11 are summarized below:

Consideration of longer analysis periods (≥25 years) is important in understanding the true impact of different LCP strategies and scenarios evaluated.

- The worst-first strategy results in the highest overall percentage of pavements in *Poor* condition at the end of the analysis period.
- The percentage of pavements in *Poor* condition over the first 10 years of the analysis is fairly similar for each of the three LCP strategies evaluated. However, after the first 10 years, the percentage of pavements in *Poor* condition steadily increases for the worst-first strategy. This highlights the importance of considering a longer analysis period for LCP.
- The condition of the non-NHS high volume network is expected to improve throughout the analysis period, irrespective of the LCP strategy considered. However, it should be noted that the non-NHS high volume network only makes up about 4 percent of the overall pavement network.

### Benefit-Cost Analysis

The preservation and hybrid strategies provide a better long-term return on investment compared to the worst-first strategy.

Figure 2-12 shows the relative benefit-cost ratios over the 25-year analysis period for each LCP strategy. These values represent the sum of the ratios for all treatments applied over the analysis period. The values were then normalized with respect to the total benefit-cost ratio for the worst-first strategy. The overall benefit-cost ratios for the preservation and hybrid strategies are fairly close to each other, both of which are approximately 10 percent higher than the worst-first strategy. This analysis indicates that the preservation and hybrid strategies provide a better return-on-investment over the 25-year analysis period than the worst-first strategy.

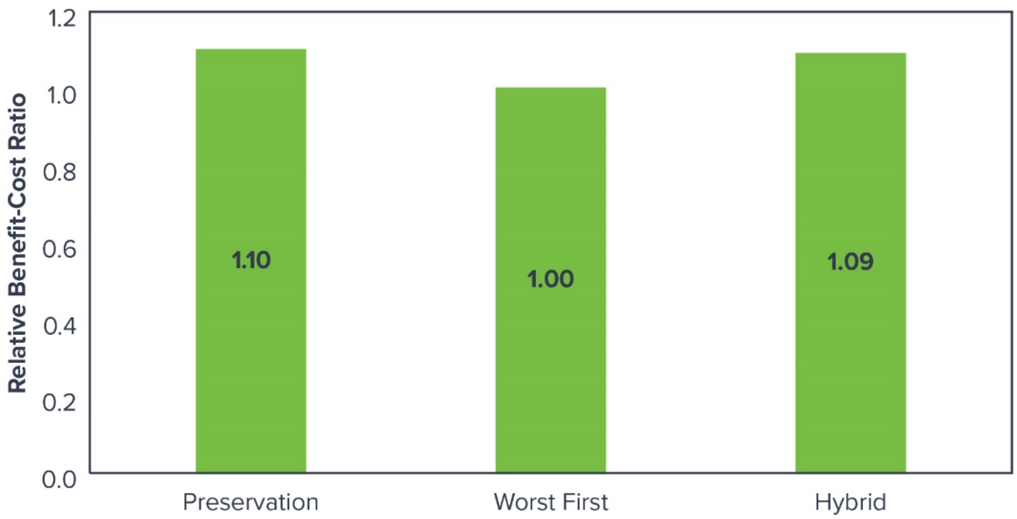


Figure 2-12. Total benefit-cost ratio for different scenarios.

### Risk Analysis

The impact of each LCP strategy in addressing pavement risk is illustrated in figure 2-13. The preservation and hybrid strategies result in a reduction of approximately 68 percent of the pavements in high risk and very high risk to a risk category of medium or lower, whereas the worst-first strategy is able to address only about 53 percent of the pavements in high and very high-risk categories. This is primarily related to the total number of lane-miles addressed over the 25-year analysis period by each LCP strategy evaluated, as shown in figure 2-14.

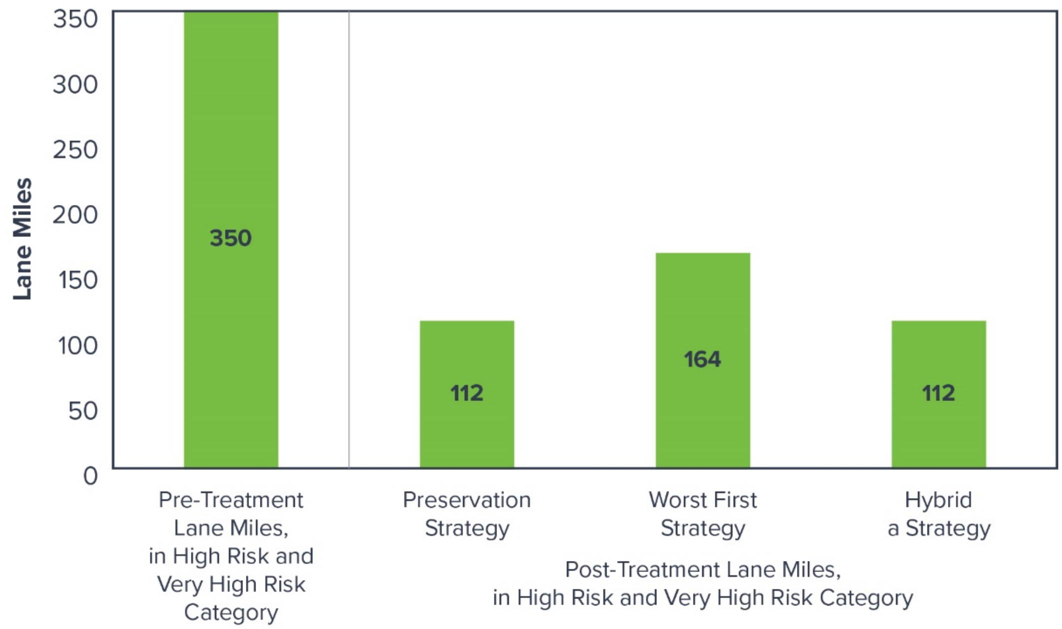


Figure 2-13. Impact of LCP strategies in addressing pavement risk.

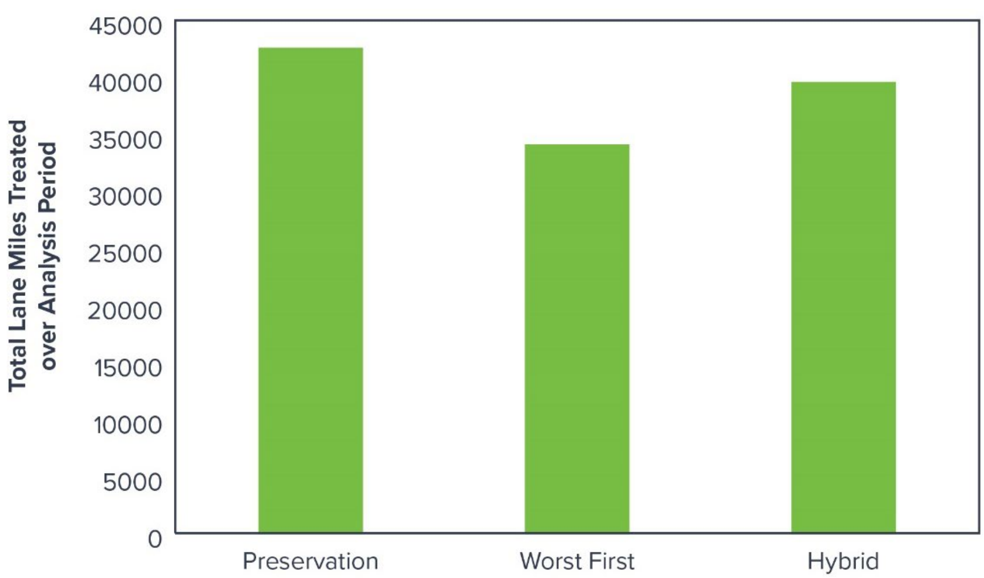


Figure 2-14. Total lane-miles address by each LCP strategy.

While the worst-first strategy results in the application of a greater amount of major rehabilitation treatments that are more effective in reducing the risk ratings, the higher cost associated with the major rehabilitation treatments results in a lower percentage of the network being addressed over the analysis period (as shown in figure 2-14). The preservation and hybrid strategies are able to treat approximately 24 and 16 percent more lane-miles, respectively, over the 25-year analysis period when compared to the worst-first strategy.

The preservation and hybrid strategies are more effective in addressing pavements with high and very-high risk scores when compared to the worst-first strategy primarily because these strategies treat more lane-miles.

### Step 5: Provide Input to Financial Planning

Figure 2-15 illustrates the impact of each LCP strategy on pavement condition for the entire network. The percentage of pavements in *Poor* condition increases from about 2 percent to approximately 8 percent during the first five years (2020 to 2025) for all the LCP strategies. However, after the first five years, the percentage of pavements in *Poor* condition steadily decreases for the preservation and hybrid strategies and the pavement conditions remain fairly uniform from 2035 to 2045. The hybrid strategy results in a slightly lower percentage of the pavements in *Poor* condition (2 percent) when compared to the preservation strategy (3.6 percent). In contrast, the percentage of pavements in *Poor* condition steadily increases from around 10 percent in 2030 to about 20 percent in 2045 for the worst-first strategy.

While the total expenditures are comparable among the LCP strategies evaluated, the preservation and hybrid strategies result in better pavement conditions at the end of the analysis period when compared to the worst-first strategy.

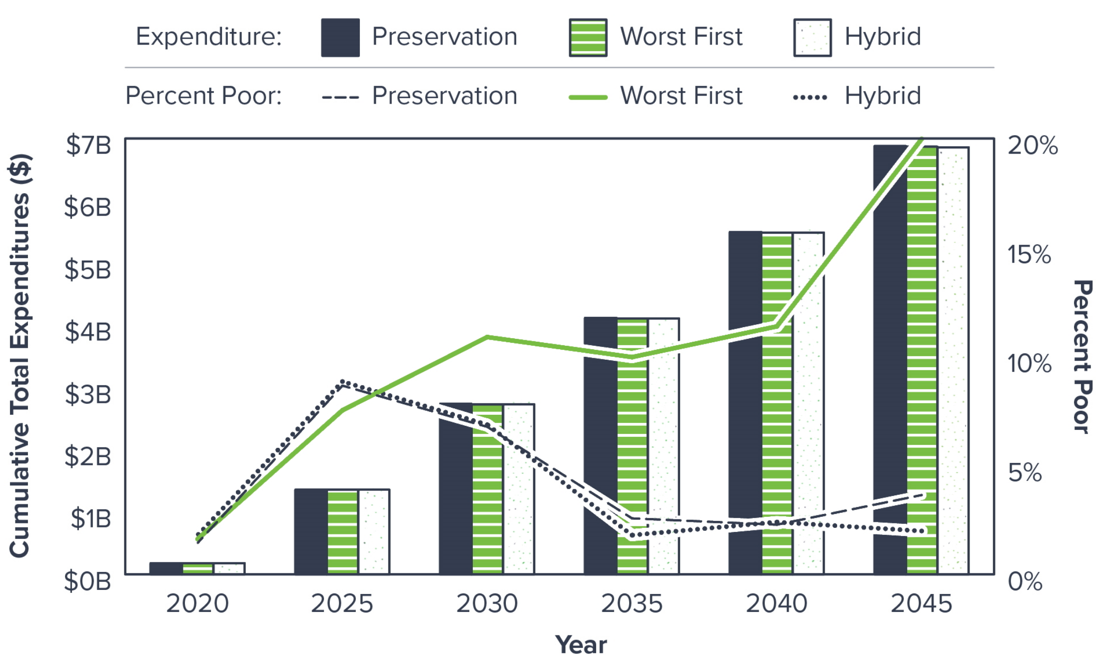


Figure 2-15. Comparison between LCP strategies evaluated by ADOT (entire network).

The results of the LCP analysis demonstrate that timely application of pavement preservation treatments can help improve and sustain pavement conditions over longer time periods.

## Arizona DOT Pavement LCP Pilot Study Key Takeaways

The LCP pilot study demonstrated the feasibility of using a PMS for conducting an LCP analysis that compares the long-term network-level impacts of different treatment strategies. The following sections summarize the key takeaways from the LCP pavement pilot study efforts with ADOT.

### *An LCP Analysis Supports Departure from ADOT's Traditional Approach*

ADOT has traditionally followed a reactive, worst-first strategy for managing its pavement network. In the past, most of the funding was spent on pavements that had deteriorated to the point that only major rehabilitation or reconstruction activities could restore the structural and functional capacities. This strategy was not considered to be a financially sustainable approach as the pavement network ages.

> The LCP analysis conducted by ADOT demonstrated that the hybrid strategy was the most appropriate choice based on the funding constraints and existing condition of its pavement network. However, the same approach may not be suitable for other agencies due to a number of factors such as funding constraints, performance goals, climatic conditions, traffic volumes, risk factors, etc. A PMS analysis can help agencies determine the best LCP strategy to adopt based on agency-specific considerations.

ADOT recognized that the timely application of relatively low-cost preservation treatments, such as chip seals and thin asphalt overlays, could reduce the rate of pavement deterioration and delay the need for major interventions that cost more to the agency and have negative impacts on road users. Using a data-driven approach, ADOT determined that allocating approximately 30 percent of the available funding towards preservation treatments would result in the best return of investment both in the short-term (10 years) and the long-term (25 years). Based on the results of the analysis conducted, ADOT is in the process of shifting to the hybrid LCP approach that slowly phases in more preservation projects over time.

ADOT has also incorporated pavement risks into the PMS analysis process for the first time. Since risk scores are built into the benefit-cost calculation models, the PMS prioritization process does not solely focus on maximizing pavement conditions for a given budget level but also looks to minimize pavement risks. The agency is continuing to explore the benefits of considering risk in the analysis.

### *Challenges With the PMS Configuration May Impact the LCP Analysis*

Some of the main challenges that ADOT faced during the LCP analysis are summarized below:

- **Performance Models.** Starting in 2017, ADOT began collecting pavement condition data using an automated data collection vehicle on SHS and locally owned NHS routes. However, the data from the automated system did not correlate with ADOT's historical condition data, which had been collected using manual methods. Due to this issue, ADOT elected to use only recently collected data for developing its pavement performance models. This may have had an impact on the analysis results, but the magnitude of the impact is unclear. As more data becomes available in the future, ADOT plans to review and refine the performance models.

> *"What you establish for treatment decision trees and benefit have a big impact on results. Every State will do this differently."*
>
> — Thor Anderson, Asset and Performance Manager, ADOT

- **Decision Trees and Benefit Models**. During the initial stages of the PMS implementation efforts, ADOT realized the impact the decision trees and benefit calculation models can have on LCP results. The process of refining the decision trees and benefit calculation models used an iterative process with the PMS vendor. This effort consumed a significant amount of time. It demonstrates the importance of reviewing the PMS configuration to ensure that reasonable results are being generated.
- **Routine Maintenance Costs.** While routine and reactive maintenance activities (such as spot patching, pothole repairs etc.) do not have a discernable impact on the overall condition of the pavement network, maintenance needs are directly related to the amount spent on system preservation and rehabilitation. As capital budgets decrease, as ADOT is projecting over the next two years, it can expect to see an increase in reactive maintenance needs to keep the system operating safely. ADOT manages maintenance data in a separate maintenance management system and the data housed in that system does not directly align with the PMS inventory. Due to this disconnect, ADOT was not able to factor in the routine maintenance costs in the LCP analysis using its PMS. ADOT plans to consider maintenance costs separately during the investment planning process.

### *A PMS Is a Valuable Tool for Life Cycle Planning Analysis*

The pilot study demonstrated the value of using a PMS to evaluate the long-term impacts of different treatment strategies as part of an LCP analysis. However, the process demonstrated the importance of carefully reviewing the reasonableness of the outputs over a long analysis period. Some of the lessons that ADOT learned from conducting the LCP analysis are summarized below:

- **Verify the Reasonableness of the PMS Configuration**. The timing for the LCP pilot closely followed the implementation of ADOT's new PMS software. As a result, the system had been configured with initial decision trees, benefit calculations, and performance models, but none of them had been extensively tested by the time the pilot started. During the analysis, ADOT recognized some of the initial analysis results did not match what one would expect based on common engineering judgment. This prompted ADOT to conduct several analysis test runs and model adjustments to ensure that the PMS generated realistic outputs. It also emphasized the importance of having pavement management staff who understood the PMS configuration and the impact these models had on analysis results.
- **The Length of the Analysis Period Matters**. All three treatment strategies showed similar impacts during the first five years of the analysis. However, over the next 20 years, a significant difference in performance became obvious with the worst-first strategy. As a result, ADOT recognized the importance of using an analysis period for life cycle planning that is sufficiently long enough to demonstrate these differences. Although ADOT's TAMP focuses on a 10-year period, ADOT concluded longer time periods were appropriate for its LCP analysis. The length of the analysis period will vary depending on the asset class and asset sub-group being considered.

- **Treatment Strategies are more than Just Different Funding Levels**. As ADOT was able to demonstrate, a mature LCP analysis considers different combinations of preservation and rehabilitation treatments over the life of a pavement. ADOT configured these different treatment strategies by controlling the amount of funding that was available for each category of repair over the analysis period, but it could also be done by modifying the treatment decision trees to trigger different types of treatments at different points in the pavement life cycle.
- **Benefits Associated with some Treatments are not Captured.** As noted earlier in the chapter, ADOT is modifying its practices to increase the amount of pavement preservation being applied each year. The increase in preservation is being implemented over several years. ADOT noted during the LCP pilot that some preservation treatments, such as fog seals, were not receiving credit in the PMS for the long-term benefits to prevent oxidation in Arizona's arid climate. This was likely due to the fact that ADOT's reported condition ratings include only cracking, rutting, and roughness on asphalt-surface pavements. Since fog seals do not eliminate cracking and have little to no impact on rutting and roughness, the PMS models were not giving credit to this important preservation strategy. Over time, ADOT may consider developing separate performance models for pavements with and without fog seals as a possible solution to this issue.

> *"Some treatments have a benefit, but don't translate into a condition improvement (e.g., fog seal). The software doesn't give credit for all preservation treatments."*
>
> — Thor Anderson, Asset and Performance Manager,

### *Business Processes Needed to Support the LCP Results*

The new PMS software is introducing changes to the planning and programming processes at ADOT. During the pilot study, strategies were considered to make better use of the LCP analysis results and the planned TAMP investments in ADOT's planning processes. In particular, ADOT is considering efforts to update its "Planning to Programming" (P2P) process that is used to prioritize projects on the SHS. The results of the PMS analysis are likely to replace some of the subjective scores used to prioritize pavement preservation projects in the existing P2P process. The revisions to this process are expected to continue into the next planning cycle.

Other action items included:

- **Integration of Maintenance Management Data with Pavement Management Data**. ADOT is evaluating potential options that can align maintenance management data with pavement management data to help the agency effectively consider maintenance costs in the LCP analyses.
- **Evaluation of Treatment Costs**. ADOT recognized that project costs can potentially double after they are scoped and is proactively trying to account for this issue by using treatment unit costs in the PMS that match closely with programmed project costs.
- **Understanding Treatment Service Life**. ADOT is evaluating treatment service life data captured through construction history records to understand the performance of major rehabilitation treatments. ADOT is particularly interested in understanding the performance of subsequent rehabilitation treatments placed after the first major rehabilitation activity. The goal is to determine whether any updates are required to the performance model families and the decision trees used in the PMS.

# CHAPTER 3: SUMMARY OF FINDINGS AND LESSONS LEARNED

## Summary

Since the concept of an LCP was introduced as a key TAMP development component, the FHWA has issued nonregulatory guidance and conducted workshops and training to assist transportation agencies with LCP implementation. To further support the implementation of an LCP, the FHWA initiated a pilot study to demonstrate how pavement management software could be used effectively to conduct an LCP analysis.

The Arizona DOT was selected as the pilot agency following its implementation of new PMS software. Its participation served as a test of its new software and guided several pavement management system revisions to better support an LCP analysis.

The pilot study demonstrates the feasibility of using a PMS to conduct an LCP analysis. It describes the efforts undertaken by ADOT to configure its pavement management tools to support the analysis. The lessons learned from the pilot implementation, and suggestions for future enhancements, are summarized in this chapter.

## Lessons Learned from the Pavement LCP Study

ADOT had recently completed the implementation of new pavement management software at the time the pilot began. Agency staff were eager to use the pilot study as a way to "test drive" the system configuration to evaluate how it could be used to update ADOT's TAMP and demonstrate the effectiveness of the agency's plans to increase its pavement preservation budget over time.

Two aspects to the ADOT pavement pilot should be noted. First, the pilot study documents the consideration of risk in the selection of pavement improvements. As noted earlier, a risk score is used to weight the benefit of a particular treatment and to document the resulting reduction in agency risk. This approach established a direct link between pavement management and risk that allows ADOT to explore strategies that reduce the likelihood and consequence of unexpected events in the future. As shown in the pilot study results, ADOT found that because of the number of miles that could be improved with either the Preservation or Hybrid strategies, risks could be reduced even if risks weren't eliminated by a major rehabilitation action.

Second, ADOT used its PMS to conduct a separate analysis that enabled staff to approximate the level of funding for pavement preservation that most effectively used available funding. The analysis explored the amount of funding required to address all preservation needs over the analysis period. It found that increasing the amount of preservation funding beyond approximately 30 percent exceeded the network's preservation needs. As a result, ADOT is gradually building up to a level in which approximately 30 percent of the available funding is used for proactive, pavement preservation treatments.

ADOT's experiences during the pilot provided important lessons learned for other agencies interested in using their PMS to conduct an LCP analysis. Each of the lessons learned is summarized below.

### *LCP Is More Than Modeling Different Funding Scenarios*

LCP strategies establish a structured sequence of treatments that might be applied to a pavement section over its life, the appropriate time for the treatments to be applied, and the cost of the strategy. One strategy in an LCP analysis might include an aggressive program of rehabilitation and reconstruction to reduce the number of pavements in *Poor* condition once they have deteriorated. Another strategy may include some rehabilitation and reconstruction, while a focused investment in preventive maintenance treatments can keep roads in *Good* and *Fair* condition from dropping into the *Poor* category. For the most part, treatment decision trees in the PMS influence the type and timing of improvements suggested.

There are at least two ways to simulate different treatment strategies in a PMS. One approach involves establishing different sets of decision trees that vary the range of values in which different treatments are feasible. For example, changing the limits for using preventive maintenance treatments earlier in the pavement life cycle would allow a comparison to a separate strategy in which preventive maintenance treatments are only considered on pavements in *Fair* condition. The outputs from the PMS will enable an agency to evaluate which strategy results in better long-term performance.

A second approach, which was used by ADOT, is to modify the available funding for different levels of repair while keeping the overall funding level constant. For example, an annual budget of $40M could be evaluated with half of the money ($20M) allocated to preservation and the other half ($20M) allocated to rehabilitation and reconstruction. A second scenario might consider 37.5 percent ($15M) to preservation and 62.5 percent ($35M) to rehabilitation and reconstruction. This approach constrains the amount of money being used for different levels of improvement, which in turn impacts the life cycle strategy that is being considered. However, as ADOT discovered, if the PMS cannot find pavement sections that satisfy the criteria for a category of repair, it is possible that not all funding is being used in the analysis. For example, if 50 percent of the funding had been allocated to preservation in ADOT's analysis, approximately 20 percent of that funding would not be used because the system could not find pavement sections that satisfy the preservation decision trees. This situation occurs when an agency specifies the budget to be spent on different types of treatments. If the system is allowed to allocate funding according to its benefit/cost analysis, this issue should not occur.

Regardless of the strategy selected, the pilot illustrates the importance of evaluating different LCP strategies, in addition to the consideration of different funding scenarios, which vary the overall level of funding available for the network. In the previous example, the funding was separated on a 50/50 and a 37.5/62.5 split between preservation and rehabilitation/reconstruction. A different LCP funding scenario would vary the funding available for system improvements, perhaps from $40 million annually to $38 million. The same 50/50 and 37.5/62.5 splits would be applied to the new LCP funding scenario to determine the long-term impact of the two different LCP strategies.

### *Consideration of Longer Analysis Periods is Important*

As demonstrated by the figures provided in chapter 2, there is a significant difference in the resulting condition under each LCP strategy over the long term. In the ADOT example, the Preservation, Hybrid, and Worst First strategies all resulted in similar network conditions over the first 5 to 9 years. However, as demonstrated in figure 2-7, there is a significant difference in system conditions that takes place after year 9. An analysis that considered only the first 10 years, for example, would not recognize the impact each strategy has on long-term performance and cost.

### *Importance of Reviewing System Configuration and Business Processes*

The ADOT pilot study was conducted as the agency was completing the implementation of its PMS software. For that reason, ADOT was able to easily incorporate changes into the system configuration to better support the LCP analysis. Based on the types of adjustments that ADOT made to the models, it is likely other agencies that have had their PMS software in place for years might also benefit from an objective assessment of the system outputs to determine whether the current configuration produces realistic results. At ADOT, the agency found that several iterations were needed before the outputs were considered reasonable. The benefit calculation models needed some adjustments to determine appropriate weighting factors for each parameter that impacted the overall benefit rating (pavement condition, risk, and traffic). The decision trees also needed to be adjusted to ensure that the treatments recommended by the PMS closely matched with the decisions that are expected to be implemented in the field. Funding levels for Preservation were also adjusted to ensure that the planned funding for this category of repair was realistic and implementable.

ADOT also recognized that it was important to determine the impact that the new PMS and the resulting LCP strategies would have on existing business processes. For ADOT, this meant revisiting their P2P process, which is used to prioritize projects. For other agencies, this may involve reviewing planned projects over time to determine whether the selected LCP strategies are, in fact, being implemented.

### *Potentially Underestimating Costs*

At ADOT, pavement maintenance activities are documented in a maintenance management system (MMS) that is separate from the PMS. Since the information in the MMS is not reported by pavement management sections, there are limited opportunities for the two systems to interface. As a result, maintenance costs were not directly considered in the LCP analysis and ADOT is missing the opportunity to estimate future increases in maintenance budget needs that may result from strategies that underfund capital improvements over time. Similarly, if highway system expansion projects are funded regularly, the omission of those projects in the LCP analysis may also be underestimating future costs.

## Future Enhancements to LCP

Based on the results of the pilot study, several suggestions for future developments that have the potential for enhancing LCP capabilities were noted. These include the following:

- Over time, repeated applications of pavement improvements tend to result in shorter performance periods. For example, an initial overlay may provide 15 years of service while a second overlay may only provide 12 years of service. The difference in performance periods can be expected to have a significant impact on LCP analysis results. However, differences in overlay performance are not typically reflected in pavement performance models. By incorporating a count into the PMS, agencies could have the ability to better estimate when future treatments might be needed.
- As discussed in chapter 2, ADOT has explored the consideration of risk in optimizing its planned expenditures. Their current approach is embedded in the benefit/cost functions of the PMS and are not provided as an output for consideration in planning a work program. For purposes of this report, that information was extracted manually. However, with minor changes to pavement management output, the impact of a planned program on

reducing risk could be generated as easily as the benefit/cost information that is typically provided.

- The LCP analysis is limited by the treatment decision trees that have been established. When decision trees are used, a treatment is triggered based on predetermined thresholds for one or more parameters, such as ride quality (e.g., International Roughness Index [IRI]), overall pavement condition (e.g., Pavement Condition Index), individual pavement distresses (e.g., rutting, fatigue cracking, weathering etc.), and traffic volume. This approach results in a recommended set of treatments that are applied to each pavement segment in the network that exceeds one or more thresholds over the chosen analysis period. Additionally, if the chosen analysis period is not long enough (≤20 years), several pavement segments might not receive any treatment recommendations. The outputs of the decision trees are assumed to be the "optimal" or "near optimal" solutions. However, this assumption may not be true, particularly in the context of longer analysis periods (>20 years). By limiting the analysis to identify treatments based on predetermined thresholds, the approach might not account for the economic benefit of investing early or choosing a more substantial treatment in lieu of less expensive preservation treatments.

  To address the limitations of using decision trees, the Remaining Service Interval (RSI) approach may be considered as an alternative approach for conducting an LCP analysis. This approach uses a longer analysis period and evaluates all feasible treatment strategies that help in achieving the desired performance goal without using decision trees. The RSI framework helps in identifying a structured sequence of different types of strategically timed repair and replacement measures required to provide the desired level of performance to users over the lifecycle, at minimum practicable costs. The RSI framework is flexible; it allows agencies to use any performance measure to establish level-of-service criteria and inform other performance constraints used in the analysis. More information on the RSI approach is available in the following nonbinding resources.

  - **RSI: A White Paper** (Ram et al. 2020). This white paper outlines, in simple terms, the fundamental concepts associated with the RSI framework. The document leads the reader through the basic process of RSI application and uses simple examples to illustrate how the RSI framework can be used to support investment decisions.
  - **Pavement Remaining Service Interval Implementation Guidelines** (Elkins et al. 2013). This report discusses relevant terminology and provides a step-by-step process for implementing the RSI framework.
  - **Application and Validation of Remaining Service Interval Framework for Pavements** (Rada et al. 2016). This FHWA report demonstrates and further develops applying the RSI framework. The study used real data from two States' PMS to develop case study examples at both the project and network levels.

- As noted earlier, maintenance costs are frequently tracked separately from a PMS, which limits the consideration of all life cycle costs. Taking steps to align the PMS with the MMS would strengthen an agency's ability to fully evaluate cost implications over the entire analysis period.

Several of these enhancements are being investigated by FHWA and other organizations to enhance future LCP practices. The initial results from these efforts show promise for enhancing current LCP analysis capabilities and informing investment decisions.

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