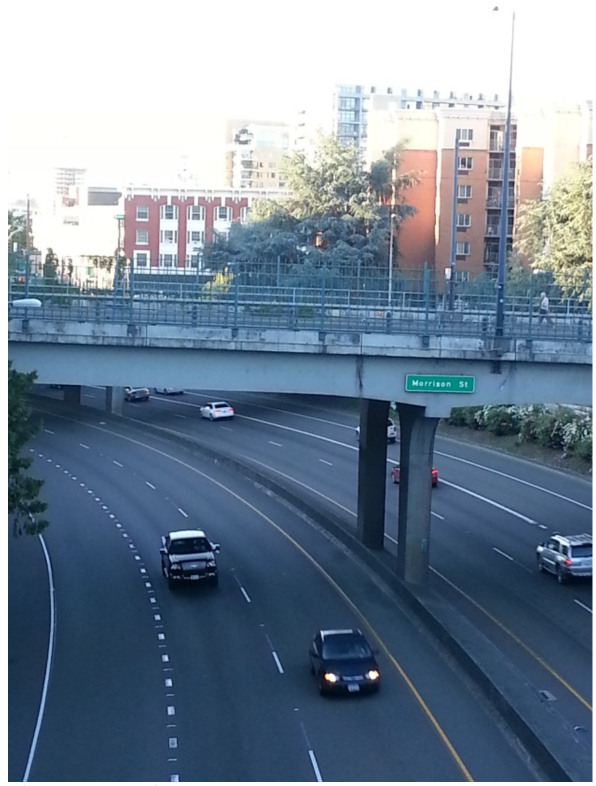
Using an LCP (Life Cycle Planning) Process to Support Transportation Asset Management: A Handbook on Putting the Federal Guidance into Practice

FHWA-HIF-19-006



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16. Abstract
The *Moving Ahead for Progress in the 21st Century (MAP-21)* and *Fixing America's Surface Transportation (FAST)* Acts promote the use of performance-based decisions for managing the nation's highway system. Under the legislation, State Departments of Transportation (DOTs) are required to develop and implement a risk-based Transportation Asset Management Plan (TAMP) that "shall include strategies leading to a program of projects that would make progress toward achievement of the State targets for asset condition and performance of the NHS in accordance with section 23 150(d) and supporting the progress toward the achievement of the national goals identified in section 23 U.S.C. 150(b)." 23 U.S.C. 119(e)(2). The minimum TAMP content includes the requirement to include life cycle planning and risk management analyses, the results of which are used to influence the State DOT's 10-year investment strategies.

A rulemaking process was conducted that established the following definition for life cycle planning (LCP): "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 515.5)." Specific requirements related to LCP are included in the Rule, but State DOTs are granted flexibility to tailor their LCP to their unique needs. Since LCP is a relatively new process for State DOTs, the Federal Highway Administration (FHWA) initiated a project to develop guidance documents related to LCP, risk management, and financial planning to assist State DOTs with the implementation of these activities. This specific initiative builds on the information provided in the LCP guidance by providing more detailed information on implementing an LCP process for both pavements and bridges.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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ACRONYMS AND ABBREVIATIONS

BMS	Bridge Management System
DOTs	Departments of Transportation
EEA	Engineering Economic Analysis
EUAC	Equivalent Uniform Annual Cost
FHWA	Federal Highway Administration
GCR	General Condition Rating
IBC	Incremental Benefit/Cost
ITS	Intelligent Traffic Systems
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LCP	Life Cycle Planning
NHS	National Highway System
NPV	Net Present Value
PMS	Pavement Management System
RCM	Reliability-Centered Maintenance
SOGR	State of Good Repair
STIP	Statewide Transportation Improvement Program
TAM	Transportation Asset Management
TAMP	Transportation Asset Management Plan
TIP	Transportation Improvement Program

CHAPTER 1: INTRODUCTION TO NETWORK-LEVEL LCP

Introduction

Life cycle planning (LCP) is an essential aspect of transportation asset management (TAM), and a required component of risk-based transportation asset management plans (TAMPs), under Federal regulation (23 CFR 515.5). This regulation defines life cycle planning as "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." However, Federal statutes and regulations do not address in detail how to conduct an LCP analysis or develop life cycle strategies for any of the vast array of assets State Departments of Transportation (DOTs) manage.

To address the need for guidance, the Federal Highway Administration (FHWA) published *Using a Life Cycle Planning Process to Support Asset Management*[1] in November 2017. A series of workshops were sponsored by FHWA during 2018 to help State DOTs apply the LCP guidance as well as other guidance documents developed in the areas of Risk Management and Financial Planning. The FHWA developed this handbook, *Using an LCP Process to Support TAM: A Handbook on Putting the Federal Guidance into Practice*, to provide additional practical guidance on using LCP to inform pavement and bridge investment decisions.

The focus of this handbook is on the use of pavement and bridge management systems to perform LCP analysis in support of risk-based TAMPs. Several aspects of TAMPs and transportation performance management (TPM), such as performance model development, target setting, and performance gap analysis, provide input to LCP and are impacted by LCP results. This handbook illustrates how these processes relate to LCP. Due to the technical nature of this document, directive language (e.g., "must", "will have to," "needs to") is used in some places to describe functional or technical characteristics necessary to successful analysis. However, this document is guidance and does not create any requirements or impose requirements other than those contained in statute or regulation.

What Is Life Cycle Planning?

Asset management is "a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair (SOGR) over the life cycle of the assets at minimum practicable cost (23 CFR 515.5)." What separates asset management from traditional transportation planning, maintenance, and operations practices is that asset management considers all stages of the asset's life cycle to determine the best investment strategy at any given time. This requires consideration of the many factors that impact asset performance, including changes in asset condition over time, traffic volumes, environmental conditions, unexpected weather-related events, material characteristics, construction practices, past expenditures, and anticipated revenue. It also requires a long-term focus that emphasizes investments in treatment strategies that address anticipated deterioration in a cost-effective manner.

An LCP analysis is central to asset management, as it establishes the asset owner's preferred sequence of actions for providing the designed function at the minimum practicable life cycle

[1] Available at https://www.fhwa.dot.gov/asset/pubs/life_cycle_planning.pdf

cost. It is important to note that life cycle cost uses engineering economic analysis concepts—explained further in Chapter 2—to consider the time-value of money. Engineering economic analysis is a means of determining the series of investments that will result in the greatest value from a system performance perspective, which may not be the same as the series of investments with the lowest life cycle cost.

LCP is a network-level analysis. This means it considers numerous assets within the same asset class[2] at the same time. It may be performed for an entire inventory, or any set of assets within the agency's inventory. LCP is separate and distinct from a life cycle cost analysis (LCCA), which is generally performed at the project, or asset level. Project-level LCCA is typically performed to select the preferred design alternative, as part of preliminary project engineering. To support this function, project-level LCCA not only considers asset condition, but also user benefits, safety benefits, traffic patterns, construction delay plans, environmental costs, and other project-specific considerations. The data for project-level LCCA is specific to the project site and the assets included within the project scope. At this level, the LCCA uses data related to the performance and operational expectations of a single asset and/or component to determine the best treatment to be applied to that asset at a specific time in the asset's life cycle. This level of detail is difficult to consider in a network analysis that is evaluating multiple treatment options for every asset section or component over a multi-year period.

Because of the differences in purpose and factors considered, the resulting network-level LCP recommendations often differ from the results from a project-level or asset-level LCCA. State DOTs can evaluate these differences to determine if a project still represents the best use of funds to achieve network-level goals, or if conversely, network-level strategies are not adequately considering project or asset-level needs. For example, the complete reconstruction of a major bridge may use all the funds available to a district in a given year, impacting the district's ability to address other preservation needs. In another situation, an agency's default strategy to routinely mill and overlay may ignore underlying pavement deterioration, leading to a treatment that fails much sooner than expected. To be effective, a network-level LCP should take both project and network factors into consideration.

LCP is one of several network-level analyses employed by asset owners to manage the performance of their networks. While the primary objective of an LCP analysis is to establish cost-effective strategies for managing network-level asset conditions, State DOTs should also consider how those conditions relate to other network-level objectives such as safety, mobility, or risk. The connection between different objectives is illustrated by an agency that determines an increase in bridge maintenance would lead to better conditions and lower costs for repairs and bridge replacements over the long term; however, at the same time, the agency realizes that there is a need to invest more heavily in replacing bridges that are susceptible to catastrophic failure from scour. The agency needs to balance the benefit of reduced long-term costs for the network with the risk to public safety at specific locations.

Federal LCP Requirements

State DOTs are required to use LCP in developing risk-based TAMPs. According to 23 CFR 515.7(b), "a State DOT shall establish a process for conducting LCP for an asset class or asset sub-group at the network level (network to be defined by the state DOT)." While this handbook

[2] An asset class is a type of asset. Assets may be further subdivided into asset sub-groups based on characteristics such as material or design type.

focuses on the technical aspects of the analyses performed in support of LCP processes, each State DOT must develop an LCP process that complies with 23 CFR 515.7(b), and explain in its TAMP how the results and recommendations from LCP analyses support the State DOT's investment decisions (23 CFR 515.9(g)).

Links to Other Sections of the TAMP

An LCP analysis supports the agency's selection of a strategy for managing asset conditions for long-term performance. This selected strategy, along with other aspects of risk and performance, are the primary inputs to the agency's process for establishing investment strategies in the risk-based TAMP. The investment strategies link to several elements of a performance-based management approach as described below.

2- and 4-Year Performance Targets

Establishing and achieving 2-year and 4-year performance targets for National Highway System (NHS) bridge and pavement condition, as established under 23 U.S.C. 150 and 23 CFR Part 490, should be part of a State DOT's overall approach to accomplishing its long-term objectives for a SOGR. The 2-year and 4-year targets serve as interim indicators of changes in condition levels and help the State DOT determine how well it is progressing toward its long-term SOGR objectives.

The results of an LCP analysis have a direct role in supporting the establishment of 2- and 4-year condition targets for NHS bridges and pavements. The 2- and 4-year condition targets established under 23 CFR 490.105 for Federal reporting are expected to be achievable given the forecasted funding level and selected TAMP investment strategies, which are influenced by the LCP results and the agency's desired SOGR.

Performance Gap Analysis.

LCP both informs performance gap analysis for asset conditions and is informed by the performance gap analyses for other performance areas. The TAMP performance gap analysis compares current and forecasted asset conditions to targets and the desired SOGR. The forecasted conditions are based on the selected investment strategies and anticipated budgets used in LCP. The TAMP performance gap analysis also considers the needs in other performance areas, such as travel time, reliability, and safety, that are best addressed through improving asset conditions. These needs are used to inform the selection of a preferred life cycle strategy.

Risk Management

Risk management considers the potential consequences (positive or negative) of unexpected events on system performance. Risks can impact the selected LCP strategies in many ways. For instance, investments to address seismic risks on significant bridges may lead to bridge investments on bridges that do not need condition-based improvements. Similarly, rock slides that lead to Interstate closures may need to be addressed to rectify system performance issues beyond Interstate conditions.

A strong LCP analysis should consider all risks that may impact system performance, including agency and financial risks. For example, an agency that selects a strategy that significantly increases the use of preservation treatments may have to address risks related to workforce development and/or contractor availability for the strategy to be implementable.

Links to Agency Planning Processes

An LCP process will typically include practices related to planning, program development, and program management, as described below.

Planning

LCP is a central aspect of a State DOT's TAMP, but it also is informed by, and feeds into, other planning products, such as the Long-Range Statewide Transportation Plans (LRSTP), Metropolitan Transportation Plans (MTP), and other plans developed in support of TPM (such as Highway Safety Improvement Plans or State Freight Plans). LCP provides the strategies that determine the resources needed to achieve long-term objectives for the TAMP that may also influence other planning documents. The LCP outputs may also be used to establish targets that are attainable with available resources. The various plans provide context to the LCP analysis, to help the State DOT better understand how achieving the objectives and targets established in those plans impact the agency's preferred life cycle strategy for each asset.

In 2013, FHWA published its *Performance-Based Planning and Programming Guidebook*[3] to help State DOTs better link planning and programming functions with desired performance outcomes for a multi-modal transportation system. It suggests strategies to help ensure that both long-term planning decisions and short-term project programming are aligned to achieve an agency's established goals. Since planning is conducted to help State DOTs decide their long-term strategic direction, it is imperative that performance trends and desired conditions are known, that funding constraints are understood, and that LCP strategies were used to evaluate and prioritize asset investment options.

Program Development

Primary program development products include the Statewide Transportation Improvement Program (STIP), Transportation Improvement Programs (TIPs) for metropolitan planning areas, and similar products that identify projects that have been selected for funding. The TIP and STIP cover at least 4 years, and are usually 6 years or less, in length. The LCP results and recommendations that are incorporated into a TAMP support the agency's project selection and prioritization processes to ensure that the investment decisions being made in the short term support longer-term asset management objectives and targets.

Traditionally, program development activities have considered each potential project as an individual activity, independent of any future strategies. LCP overcomes this limitation by developing treatment strategies that include activities over the life of an asset rather than optimizing the "next" treatment at the expense of other system needs.

Program Management

As State DOTs implement their programs, numerous decisions may be necessary as project schedules and scopes change, and as new needs come to light. Even annual programs can change dramatically as they are delivered. Network-level LCP can provide baseline strategies for comparison against the current program. The agency can use this comparison to determine if project-level decisions are likely to impact the accomplishment of network-level objectives.

[3] Available at https://www.fhwa.dot.gov/planning/performance_based_planning/pbpp_guidebook/page00.cfm#es

Benefits Realized From LCP

Establishing a robust LCP process supports asset management implementation in the following ways:

- State DOTs can show that decisions made today to address long-term needs are sustainable without sacrificing future budgets or system user expectations. Additionally, State DOTs can show that the series of treatments leads to better system performance than optimizing single projects in any given year.
- State DOTs can realize a reduction in the annual cost of system preservation without negatively impacting network conditions through an evaluation of the effectiveness of different treatment strategies.
- An LCP analysis can improve network conditions for a given level of funding by using optimal preservation strategies.
- State DOTs can demonstrate improved stewardship of public resources with the results of an LCP analysis.
- State DOTs can establish transparent, forward-looking highway infrastructure agendas that consider future needs. This improves the communication regarding infrastructure needs and agency priorities, both internally and with external stakeholders.

CHAPTER 2: ENGINEERING ECONOMIC ANALYSIS CONCEPTS USED IN LCP

Introduction

A network-level LCP analysis uses many of the engineering economic analysis (EEA) concepts used in other cost analyses, including the LCCA used by many State DOTs for making design decisions at the project level. This chapter introduces EEA concepts and presents their applicability to the LCP analysis described further in this document.

Engineering Economic Analysis Components

There are at least three central tenets to an EEA. First, there are multiple ways to address each option and each option has different cost and performance implications. Second, treatment options are analyzed over a chosen analysis period, such as an asset's typical life cycle. For long-life assets such as pavements and bridges, the analysis period typically covers many years and a range of treatment options. The third tenet is that the value of money changes with time, so the analysis must consider these differences. It is important to understand these and other key components to an EEA so that the concepts are applied appropriately in a network-level LCP.

Analysis Period

Assets can last for varying lengths of time; therefore, careful consideration must be given to the time period covered by a life cycle strategy. This time period is commonly known as the analysis period. For infrastructure assets such as pavements and bridges, the analysis period typically represents an asset's service life from cradle to grave. At the project level, current guidance recommends that the analysis period should be long enough to include at least one future major rehabilitation event (NCHRP 2011). However, a network-level LCP might use a longer analysis period to evaluate the differences between alternate treatment strategies. This longer analysis period is useful to consider life cycle strategies that include a series of treatments over an asset's whole life, which is especially important for long-life assets such as bridges where multiple rehabilitation treatments can occur before a bridge is reconstructed. Typical LCP analysis periods for pavements could range from 20 to 40 years while bridge analysis periods may range from 70 to 100 years. The most appropriate analysis period will depend the asset class being considered, and the functionality of the tools being used to conduct the analysis.

Although an analysis period may cover a long period of time, the results can be presented over a shorter planning period to evaluate performance outcomes. As shown in the examples presented in Chapters 4 and 5, the analysis results are presented over a 20-year window for pavements and a 40-year window for bridges. These windows were selected because they are considered long enough to begin to see some of the long-term trade-offs between LCP strategies. These long-term differences may not have been as obvious if a shorter window had been used.

Time Value of Money

The time value of money is a concept that explains why money available today is worth more than an identical sum of money made available in the future. Money's increase in value is due to its potential to grow in value over time because of dividend payments and capital appreciation. However, at the same time, material and labor costs often increase over time, which may more than offset the increase in value. In EEA, the concept of the time value of money is typically addressed using inflation rates and the discount rates, which are discussed below.

Inflation Rate and Purchasing Power

Inflation is the rate at which the prices for goods, products, and services increase over time. Because of inflation, the purchasing power of a unit of currency falls. The Federal Reserve moderates long-term price stability so that inflation rates stay relatively constant over time. This enables businesses to plan for the future with a better anticipation of what to expect. The opposite of inflation is deflation, which represents a general trend toward lower prices over time. Dollars that account for inflation (or deflation) are known as nominal, current, or data-year dollars. Dollars that do not account for inflation are known as constant or base-year dollars.

Discount Rate

To compare the costs or benefits (in constant dollars) occurring at different points in time (past, present, or future), the time value of money should be accounted for. This is the economic return that could be earned (e.g., interest) or the compensation to be paid to defer an amount to a later year. The adjustment to account for the time value of money is known as discounting.

The discount rate is key to determining the economic efficiency of a life cycle strategy and State DOT policy normally determines the appropriate discount rates to be used in the LCP analysis (FHWA 1998). The discount rate can have a significant impact on the results of an EEA and it is important to understand its effects, which are summarized below.

- Higher discount rates reduce the present value of a future amount more than lower discount rates.
- A discount rate of zero values future costs the same as current costs.

Applying Inflation and Discount Rates

Before beginning an LCP analysis, a State DOT should determine how it will handle the time value of money in the analysis. For a project level LCCA, the FHWA recommends the use of constant dollars (minus inflation) and real discount rates to avoid having to include and then remove inflation. For an LCP analysis, the decision as to how to apply inflation and discount rates may be driven, in part, by the functionality in the analysis tools that will be used. For example, some management systems apply inflation rates to future costs to represent the decreased purchasing power expected in the future. In these instances, where a discount rate is not applied, some State DOTs use an inflation rate that is the difference between a nominal inflation rate and the anticipated discount rate. Other systems may allow users to input both inflation and discount rates. Regardless of the approach used, it is important to understand the long-term implications of the decisions used since the time value of money can have a significant impact on the LCP strategy that is selected.

Treatment Options and Timing

Treatment options are actions that can be performed over the life of an asset to maintain it at a desired condition level, maximize overall network conditions, minimize life cycle costs, or achieve a desired average network-level condition. Treatment options differ in terms of their ability to address varying amounts of deterioration, cost, performance improvement, and expected life. Treatment type and timing may be triggered based on existing asset conditions, other performance factors (such as safety needs), or as a scheduled activity in a planned life cycle strategy. EEA practices support decision makers in determining what treatments and treatment timings are most suitable to achieve the minimum practicable life cycle cost for managing the asset.

Cost Effectiveness Analysis

Feasible LCP strategies are analyzed to determine the most cost-effective, or optimal, solution for a given asset class or asset sub-group. At the network level, this typically involves a cost-effectiveness analysis of some type to determine the long-term impacts of each option.

At a project level, projected strategy costs and benefits are converted into present dollars and aggregated to provide either a net present value (NPV) or an equivalent uniform annual cost (EUAC), each of which are discussed below.

Net Present Value (NPV)

Net present value (NPV) is a calculation that converts all future costs and benefits into present dollars for each life cycle strategy. For infrastructure assets, the NPV is often used to choose between various design or rehabilitation alternatives that are expected to provide the same level of performance to the asset users during normal operations over the same analysis period (FHWA 2002). NPV is calculated using the following equation:

$$NPV = Initial\ Cost + \sum Future\ Cost\ (or\ benefit) \times \left(\frac{1}{(1+r)^n}\right) \quad (1)$$

where:

r = discount rate

n = number of years in the future where the cost will be incurred

Equivalent Uniform Annual Cost (EUAC)

Equivalent uniform annual cost (EUAC) is a calculation that converts initial and future costs and benefits into annualized present value dollars over the life cycle of the asset. EUAC is more effective to use than NPV when the life cycle strategies under consideration have different analysis periods, however, EUAC assumes that the same strategies are repeated at the end of the analysis period (FHWA 2015). EUAC is calculated using the following equation:

$$EUAC = NPV\left[\frac{r(1+r)^N}{(1+r)^N - 1}\right] \quad (2)$$

where:

r = discount rate

N = analysis period

The life cycle strategy with the minimum practicable NPV and/or EUAC is the most cost effective.

As discussed in Chapter 3, pavement and bridge management tools use different approaches to determine the cost-effectiveness of various LCP strategies. Most pavement management systems use a form of benefit/cost analysis in which the benefits associated with each treatment in a strategy are represented by the additional performance gained. The ratio of benefits to cost represent the relative cost-effectiveness of each treatment, which allows funding to be allocated to a near-optimal solution. Bridge management systems often use integer programming, or other optimization approaches to evaluate life cycle strategies. Regardless of the approach used, the objective is to evaluate the relative merits of one strategy when compared to another.

Types of Costs Considered in an Analysis

An EEA may consider any of the following costs in the analysis to fairly evaluate and compare alternate strategies:

- **Agency costs**: These include direct and indirect costs incurred by the State DOT to construct or acquire the activities outlined in the strategy. Examples of agency costs include construction, administration, design, mobilization, work zone, and material costs.
- **User costs**: These include costs borne by road users and the general public as a result of construction activity. User costs are an aggregation of three separate cost components: user delay costs, vehicle operating costs, and crash costs (FHWA 1998).

Expenditure Stream Diagrams

Sometimes it is useful to graphically represent a strategy using an expenditure stream diagram. Traditionally used at the project level to compare alternate design strategies, expenditure stream diagrams may also be useful to represent LCP strategies considered for each asset class or asset subgroup.

Two examples of alternate pavement strategies are shown in Figures 1 and 2. Figure 1 depicts a strategy that relies primarily on rehabilitation activities while Figure 2 illustrates a strategy that uses low-cost preservation treatments over the pavement life cycle. In the expenditure stream diagram, the height of the arrows represents the cost of the treatment and their placement represents the timing. At the end of the analysis period, if the asset has a salvage value, a downward-arrow is used. When conducting a LCCA at the project level, the present value of the strategy is determined by converting all future costs to a present value in terms of base year costs. The strategy with the lowest present value is the strategy with the minimum practicable life cycle cost.

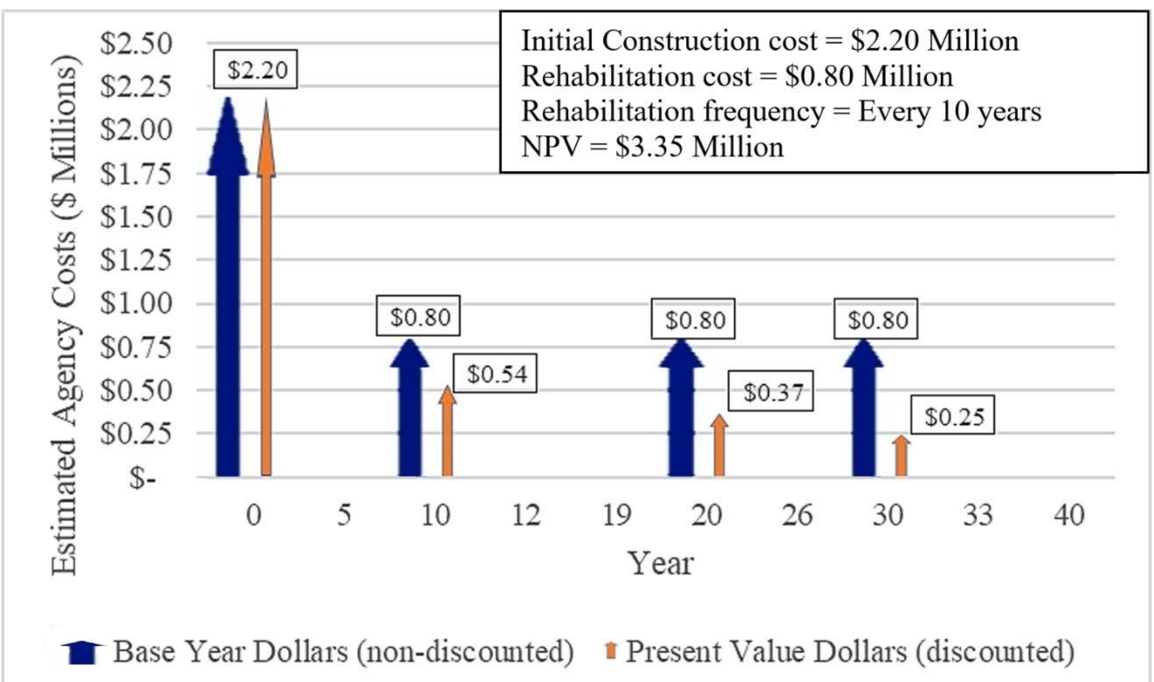


Figure 1. Expenditure stream diagram for a pavement rehabilitation strategy.

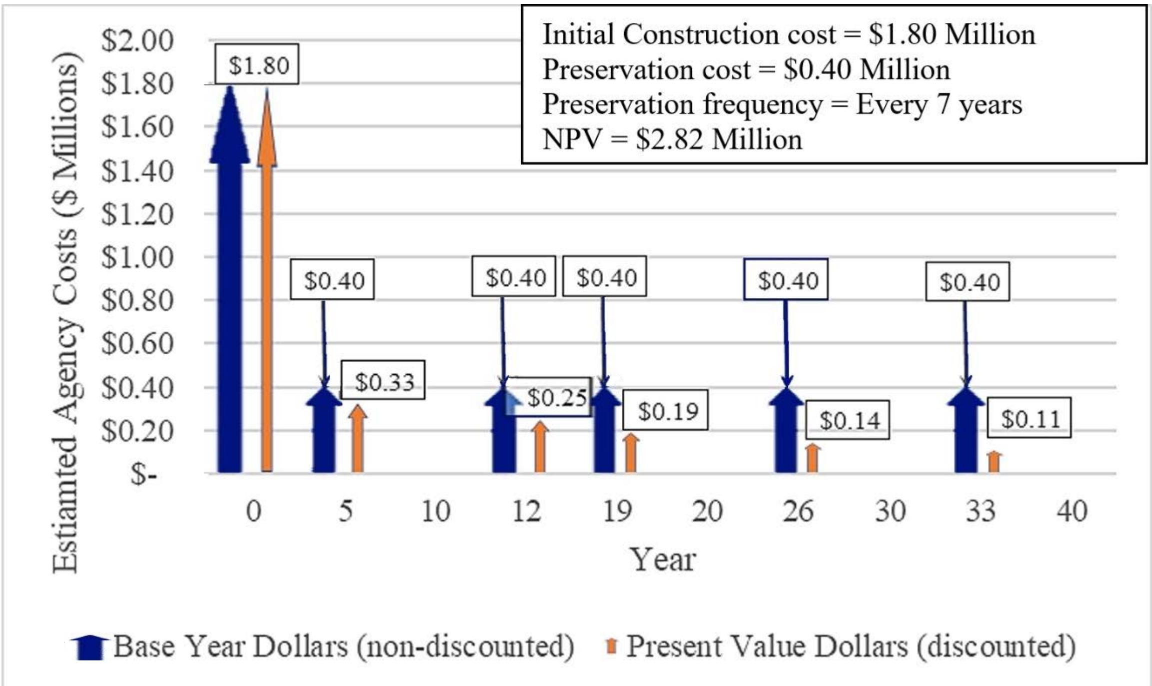


Figure 2. Expenditure stream diagram for a pavement preservation strategy.

In LCP, the lowest life cycle cost strategy may not always be the selected strategy because of several factors. For instance, there may not be sufficient funding at the network level to implement the lowest life cycle cost strategy across the entire system. There may also be other performance factors or agency priorities that impact the selected LCP strategy as in a situation where a State DOT may decide to retrofit select bridges to reduce risk even though the bridges weren't triggered based on conditions. For these reasons, the LCP process introduced in Chapter 3 is presented as an iterative process, meaning that a State DOT may have to repeat the analysis multiple times to find an implementable solution that balances the DOT's needs, priorities, and constraints.

Applying Engineering Economic Analysis to LCP

There are many similarities in the application of EEA concepts in a project-level LCCA and a network-level LCP. For instance, both analyses:

- Consider multiple treatment options over an analysis period.
- Recognize that different strategies vary in terms of cost and performance over time.
- May be constrained by costs, work zone issues, environmental constraints, or other factors.
- Consider the time value of money.

Although an LCP analysis uses many of the same EEA concepts used at the project design level, there are several significant differences in their use at the network level. To a large degree, these differences are influenced by the number of assets being considered in the analysis, the significant number of treatment options being evaluated over the analysis period, and the limitations of available analysis tools. Over time, as State DOTs mature in terms of their LCP capabilities, and as analysis tools evolve to support the analysis, there may be fewer differences between project- and network-level EEAs.

Magnitude of the Analysis

At the project level, a LCCA is traditionally used to compare one or more design approaches in terms of the present value. This type of analysis is very constrained in terms of the number of options considered (typically 2 or 3), the number of projects evaluated (typically 1), and the objective (minimum practicable life cycle cost). At the network level, the magnitude of the problem grows exponentially because of the number of assets in an asset class or asset sub-group, the number of bridge and pavement types included in the analysis, and the number of treatment options for each asset in each analysis year. Because of the magnitude of options that must be considered over a long analysis period, the use of pavement and bridge management systems as network analysis tools becomes important. 23 CFR 515.7(g) requires the use of pavement and bridge management systems to support TAMP development. The types of analyses typically conducted by pavement and bridge management systems to support LCP are described in more detail in Chapter 3.

These tools facilitate the analysis of three key elements to managing assets over their whole life at the minimum practicable cost: planning, costs, and life cycle. Planning accounts for changing demand, environmental conditions, and performance over time, which can be accounted for using models. Both direct and indirect costs are accounted for in the analysis using the EEA principles explained earlier in this chapter. These economic considerations provide critical feedback on how effectively the highway system is being managed with available funding. Finally, life cycle needs are accounted for by incorporating a range of treatments and work types that address the types of changes in performance that can be expected over the life of an asset.

Although there are known limitations to existing tools, efforts are underway to guide future enhancements to existing pavement and bridge management tools to better support LCP. For instance, pavement management systems traditionally rely on condition measures to drive improvements, although there are many other factors that should be accounted for in determining the most practicable LCP strategy. For both pavement and bridge management, research is being conducted that evaluates changes to the way a multi-year analysis is conducted using new performance measures (such as financial or life cycle measures in addition to condition) and compares a series of treatment trade-offs using a recursive analysis approach. While these changes may be years away, they are indicative of the value in performing LCP and the importance of enhancing existing tools as State DOTs mature in this area of asset management.

Selection of the Recommended Strategy

In a project-level LCCA, the project that will be constructed is known and the objective of the analysis is to determine the best design from an economic perspective. At the network level, the selection of the recommended LCP strategy for consideration in the financial plan is much more complicated since none of the projects are “known” and there are multiple factors that can influence the decision as to what is the “right” strategy.

This is another area where existing analysis tools could be improved to support LCP. For instance, a pavement management system traditionally evaluates treatment options based primarily on current and forecasted pavement conditions. A more holistic approach to LCP would allow the analysis of a broader range of performance considerations. For instance, if certain pavements are deteriorating at an accelerated rate due to underlying structure damage resulting from recurring flooding, an LCP strategy may consider enlarging drains in the area to reduce flooding. This also reduces the rate at which the pavements deteriorate, which would have a positive impact from a life cycle perspective. Across the network, addressing these types of broader issues can have a significant impact on a State DOT's long-term funding needs.

Another issue with existing pavement management systems is that the analysis identifies the next optimal treatment for each project section independent of future treatments as desired in LCP. Future pavement management systems would benefit from the ability to analyze a series of treatments for a given section rather than evaluate each treatment independently.

Implementation of Long-Term Strategies

In the traditional LCCA, treatment strategies are used to select the design approach, but there is typically little correlation between the strategy used in the analysis and the on-going maintenance and rehabilitation once the project is constructed. The TAMP is expected to establish a stronger connection between investment strategies analyzed in the financial plan included in the TAMP, and the projects that are incorporated into the STIP based on the results from LCP, financial planning, risk analysis, and performance gap analysis. To emphasize this link, the Asset Management regulations require an annual consistency determination (23 CFR 515.13) that evaluates the State DOT's implementation of the TAMP. This linkage strengthens the importance of the LCP strategies in the TAMP and helps to ensure that investment decisions are being made with a long-term perspective.

References

- Federal Highway Administration (FHWA). 1998. *Life Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin*. FHWA-SA-98-079. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2015. *Towards Sustainable Pavement Systems*. FHWA-HIF-15-002. Federal Highway Administration, Washington, DC.
- Newnan, D. G., T. Eschenbach, and J. Lavelle. 2004. Engineering Economic Analysis – Ninth Edition. Oxford University Press, Inc. New York, NY.
- National Cooperative Highway Research Program (NCHRP). 2011. *Guide for Pavement-Type Selection*. NCHRP Report 703. Transportation Research Board, Washington, DC
- Office of Management and Budget (OMB). 2012. *Memorandum for Chief Financial Officers and Agency Budget Directors: Interpretation of OMB Circular A-94*. Office of Management and Budget, Washington, DC.

CHAPTER 3: TOOLS TO SUPPORT LCP

Introduction

As discussed in the previous chapter, performing LCP at the network level requires the use of analysis tools that reflect both engineering and economic considerations when evaluating treatments over a large portion of a transportation network for an extended analysis period. Pavement and bridge management systems support network-level LCP, using current and projected asset conditions, along with rules that define when different treatment options are feasible, to determine the most cost-effective strategies for preserving or improving asset conditions over the long term. Although the analysis conducted using a management system may not be as robust as a project-level analysis, the results reasonably represent the minimum practicable life cycle cost strategies to achieve State DOT objectives. This chapter introduces pavement and bridge management systems and explains their use in conducting LCP.

Characteristics of a Comprehensive LCP Approach

There are several key characteristics that are important components to LCP, regardless of the asset that is being considered, as listed below.

- **Performance objectives** – In State DOTs, performance objectives are used to ensure that investments address strategic agency priorities. Asset conditions and/or minimum acceptable performance are two examples of the types of performance measures used in an LCP analysis to determine when improvements or other types of interventions are needed. They also provide a way to represent the impacts of different treatment strategies over an analysis period so progress toward agency objectives can be evaluated.
- **Applicable treatments over the life of an asset** – As shown in Figure 3, there are many different types of treatments that may be applied over the life of an asset. A comprehensive LCP analysis helps to determine the most cost-effective time to apply these treatments based on performance data. Therefore, pavement and bridge management programs normally are configured to consider a range of different treatment types and timing to fully represent an asset's life cycle.

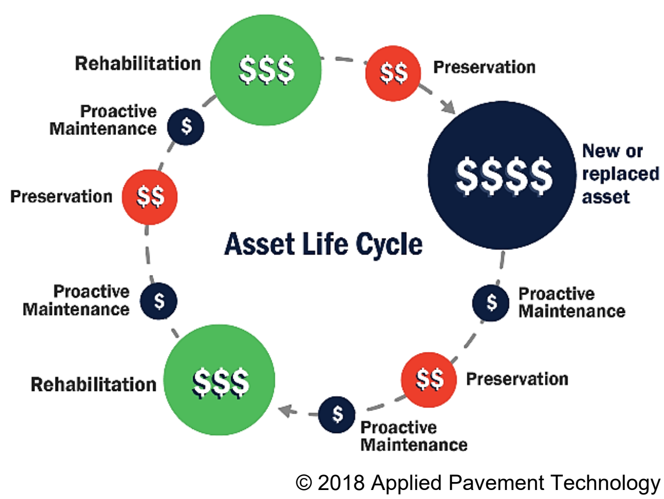


Figure 3. Example of an asset life cycle.

- **Deterioration models** – Since LCP considers treatment options over a long analysis period, the analysis tools are designed to predict changes in asset performance over time. Pavement and bridge management systems typically allow for very sophisticated performance models that reflect changes in asset conditions with and without treatments being applied. For other assets, or State DOTs with management systems not capable of this level of performance modeling, rates of deterioration may be based initially on expert opinions.

- **Desired conditions** – An important part of developing a long-term strategy for preserving transportation assets is establishing a desired network-level state of repair that represents the performance desired for each asset class (such as pavements and bridges). Ideally, the life cycle strategies that are developed in LCP will help the State DOT achieve its desired network-level conditions or narrow the gap between expected and desired conditions.
- **Targeted conditions** – One way of determining whether a State DOT is making progress toward achieving its desired network-level conditions is to set interim targets that reflect time-constrained achievements. For instance, if a State DOT defines its desired condition as 80 percent of the asset class in Good or Fair condition, interim targets might be set at 2- and 4-year intervals to help ensure that progress is being made toward the desired state.
- **Analysis tool to compare options** – In 23 CFR 515.17, minimum standards have been established for developing and operating pavement and bridge management systems. These standards require State DOTs to have analysis tools with the ability to evaluate alternate treatment actions through a benefit/cost analysis over an asset's life cycle. This cost-effectiveness analysis facilitates identification of program recommendations and implementation schedules as well as evaluation of the long-term impacts of various LCP options in terms of asset condition, system performance, and life cycle cost.

Introduction to Pavement and Bridge Management Systems

Pavement and bridge management systems are computerized software programs, or collections of integrated programs and analysis tools, that support the development of plans and programs by recommending optimized maintenance and repair strategies that make the best use of available funds. The analysis results in treatment recommendations that closely approximate an optimal life cycle strategy through a systematic approach to scheduling maintenance, preservation, rehabilitation, and reconstruction. However, as discussed in Chapter 2, there are some limitations to existing software tools that confine the current ability to fully evaluate LCP strategies at the network level. As State DOT practices in LCP mature, for example, a pavement management analysis would benefit from the ability to analyze a series of treatments as a strategy rather than analyze each treatment type independently.

Common components included in management systems are reflected in Figure 4. Information about the asset inventory (including asset type, dimensions, and location) and asset condition are accessible through a database that may be part of the management system software or may be linked to centralized agency files. The database also includes some type of referencing system that links the field location to data elements used in the management system. The development of the referencing system is commonly known as network definition.

Within the management system are deterioration models, treatment rules, treatment impact rules, and treatment costs that are used to represent the conditions under which different treatments are considered over the life of each asset. An optimization program generates multiple scenarios under given constraints to help develop an optimized set of projects and treatments over a multi-year period. The results of a management system are typically presented in several formats, including standard and customized reports, map displays, and charts.

Although both pavement and bridge management systems are comprised of similar components, each system analyzes asset conditions differently, as explained further in the following sections.

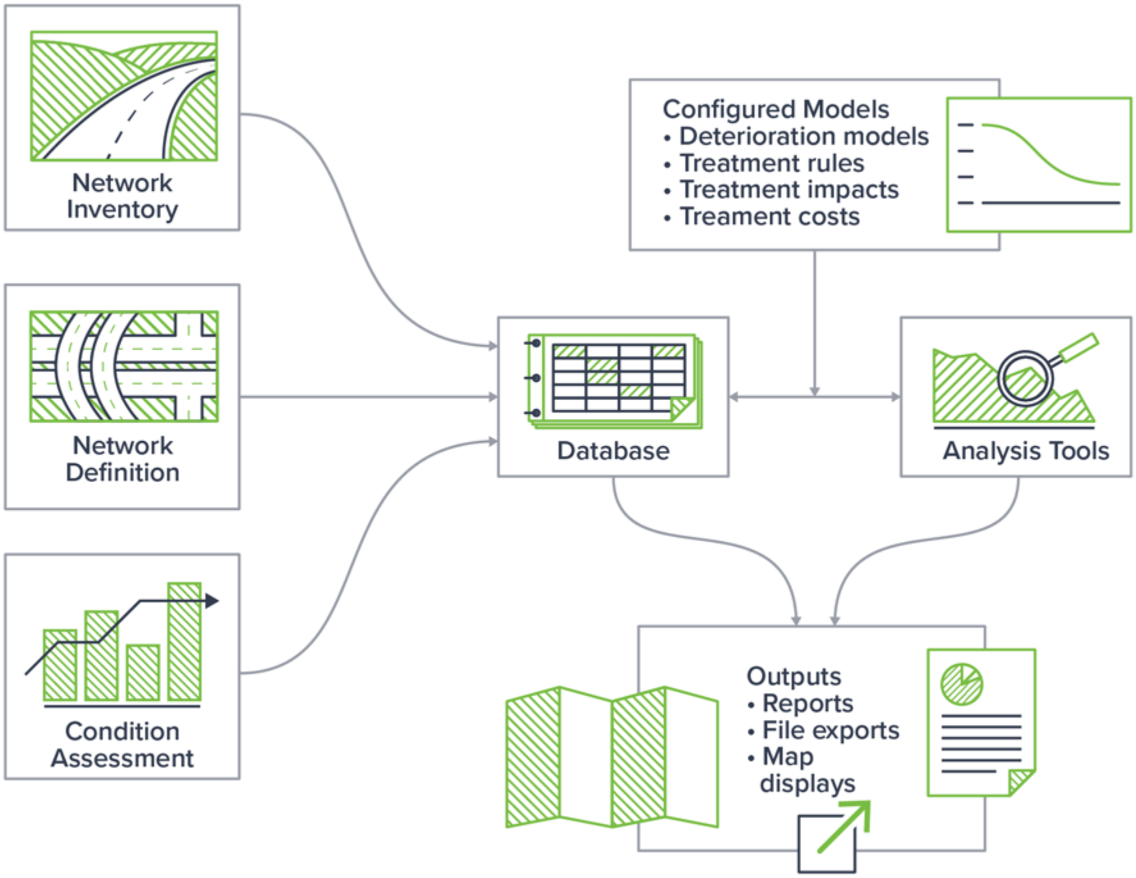


Figure 4. Management system components.

Pavement Management Systems

There are many different pavement management systems (PMS) available, representing different degrees of complexity, capability, and flexibility. Some systems are available through the public domain. These systems are generally designed for smaller agencies, such as small cities and counties. Their analysis capabilities are relatively simplistic, and users often have limited flexibility in terms of modifying the system to meet agency-specific needs. The PMS tools used by State DOTs are often much more sophisticated than the public domain programs and are usually licensed as a proprietary product distributed through a vendor. The proprietary systems typically offer more flexibility in terms of configuring the software to meet specific State DOT needs.

The more sophisticated systems include several features that make them especially useful for LCP, including those features described below.

- **Performance models** – Although there are many different approaches to developing performance models, most pavement management systems use deterministic models that predict a future condition based on current condition. To develop these models, historical deterioration trends are developed for pavement sections that are grouped into “families” with similar characteristics and similar performance trends. Some State DOTs use probabilistic models to predict future conditions. This approach uses transition probability matrices to predict the likelihood that a pavement section will transition from one condition state to another condition state representing a worse condition. If the section does not transition to another condition state, it remains in the same condition state for another year.

- **Decision trees or treatment rules** – A pavement management analysis uses current and projected pavement conditions to determine which sections are eligible for a treatment in each year of the analysis. Decision trees, or treatment rules, define the set of conditions that determine which treatments are viable. For example, a decision tree for preservation might require the pavement to be in relatively good condition (as defined by a range of condition index values) with little to no structural deterioration present. The rules might also define constraints related to surface type and/or traffic volumes for some treatments to be considered viable. A State DOT's decision trees can set different criteria for different highway systems and asset sub-groups, reflecting different life cycle strategies for different types of pavements serving different users. A comprehensive set of decision trees include the range of treatments that may be considered over the life cycle, including maintenance, preservation, rehabilitation, and reconstruction options.
- **Treatment costs** – For each treatment type incorporated into the decision trees, typical unit costs must be established so project costs can be considered in the analysis. Often, a PMS allows a user to input an inflation rate so that the time value of money is considered in the analysis.
- **Impact rules** – To determine the cost-effectiveness of various treatment options, impact rules are created and stored in the PMS. These rules identify how pavement conditions change with the application of a treatment (e.g., whether the conditions return to the condition of a new pavement) and how to model the performance of the treatment over time (e.g., whether a new performance model is followed).
- **Benefit/cost analysis** – A PMS explores all feasible treatment options over an analysis period for each pavement section in the database. For instance, the analysis might consider one option that applies a preservation treatment while the pavement is in good condition, followed by another application of the same treatment after 7 to 10 years when the conditions return to the same point. A second strategy might allow the pavement to deteriorate to a point where rehabilitation is a viable treatment option. A PMS evaluates the cost-effectiveness of each of these types of strategies across the network using a cost/benefit analysis. In a simplistic benefit/cost analysis, the expected life of a treatment (represented by area) is divided by the treatment cost. The treatment that has the highest benefit/cost ratio represents the most cost-effective option. Some State DOTs multiply the expected life of a treatment by a traffic factor, further inflating the benefit associated with treatments on high-volume facilities. This type of weighting factor is useful in prioritizing projects under constrained funding.

Bridge Management Systems

Several Bridge Management Systems (BMS) are available with varying approaches to modeling and different levels of complexity. The modules and analyses within BMS tools vary due to different approaches in modeling and further customization by State DOTs. The BMS tools used by State DOTs are sophisticated tools that typically reside on relational databases, which contain the modeling framework, inventory data, and agency-specific data. Because State DOTs have different approaches to managing their bridge networks, and different issues to address, the BMS tools available have some degree of flexibility for customization and future enhancements.

The BMS tools used by State DOTs have several features that can be used for LCP. The optimization framework impacts how these features can be used and interpreted for LCP. The program optimization problem may be modeled as a single-objective optimization problem (e.g., minimize life cycle costs or maximize condition) or a multi-objective optimization problem where multiple performance measures (e.g. condition, life cycle cost, risk of failure, mobility) are combined and presented by a utility function (maximize overall utility). The relevant features that are useful for LCP are described below.

- **Deterioration models** – Markovian models are probabilistic models used to predict bridge condition performance in most BMS tools and can be developed from historic condition data or can be assigned by expert elicitation. These models are presented as transition probability matrices for bridge components (deck, superstructure, and substructure) and elements (e.g. prestressed concrete girder, reinforced concrete deck). The transition probabilities in a matrix indicate the probabilities that one element unit will transition from one condition state to a worse state or stay in the same condition state. Traditional Markov models are memoryless and assume that the transition probabilities are the same regardless of the time a structure has already spent in a particular condition state. Newer enhancements to Markovian models incorporate time-dependent properties to address the variability in deterioration from past condition or age. Also, the effect of protective or preventive treatments that slow the rate of deterioration can be incorporated into deterioration models to represent the benefits of applying and maintaining these treatments (e.g. coatings, sealers, overlays, deck joints).
- **Decision trees or treatment rules** – Decision trees, treatment rules, or policy rules define a set of conditions that determine which treatments are viable for current or predicted bridge conditions. These rules may reflect State DOT policies for bridge work or may show decision trees that minimize life cycle costs (LCC) for bridge components or elements. For example, a State DOT rule might specify the minimum superstructure general condition rating (GCR) or health index for deck replacement projects so that such projects are not selected for structures with poor superstructure conditions that may require replacement or rehabilitation soon. The rules may also define constraints on material and treatment type for different volumes of traffic or road functional classification.
- **Treatment costs** – Bridge treatments can be assigned to bridge components or elements within a BMS tool. Each treatment type defined in the BMS must have an associated unit cost. Although most BMS tools come with a set of default costs, these should be reviewed and customized by State DOTs, if necessary. Like many PMS, BMS tools also include an inflation rate that can be changed to incorporate the time value of money into analyses.
- **Impact/benefit rules** – Each treatment should also be associated with suitable impacts or benefits that can be used to assess and compare different treatment options. These rules should indicate all relevant benefits that would be realized from a treatment such as condition improvement or reduced vulnerability. For example, a substructure rehabilitation project may improve both substructure GCR and scour condition rating. Both impacts should be mapped for the associated rule.
- **Integration of LCC into prioritization** – LCC calculations within a BMS consider sufficiently long analysis lengths (see Chapter 2) to properly account for the reductions in LCC from treatments over structure life cycles. Resource allocation to preservation treatments leads to higher short-term costs than "Do-Nothing" but eventually reduces

long-term costs by delaying or reducing future treatment needs. Similarly, all timely treatments increase short-term costs but ideally delay replacements and reduce long-term costs. This inherent trade-off between short-term and long-term costs is used in the LCC calculations to guide the treatment selection and program optimization in a BMS. Different BMS programs follow LCC methodologies that are based on the concepts explained in Chapter 2 with some nuances in calculation and in the way LCC is integrated into program optimization. For example, in a multi-objective optimization framework, the impact of treatments in short-term and long-term costs can be captured with a LCC utility. For each treatment alternative, LCC utility calculations are determined from both short-term project treatment costs and long-term treatment costs that may be needed over the analysis period. The higher the sum of short- and long-term costs for a treatment, the lower its LCC utility should be. Because the utility values are expressed as a value between zero and one, or a percentage, the LCC utility can be mathematically expressed as a ratio of LCC to a multiplier of structure replacement cost, subtracted from one. Figure 5 illustrates LCC utility values for five different treatments (T1 to T5) based on the explained methodology.

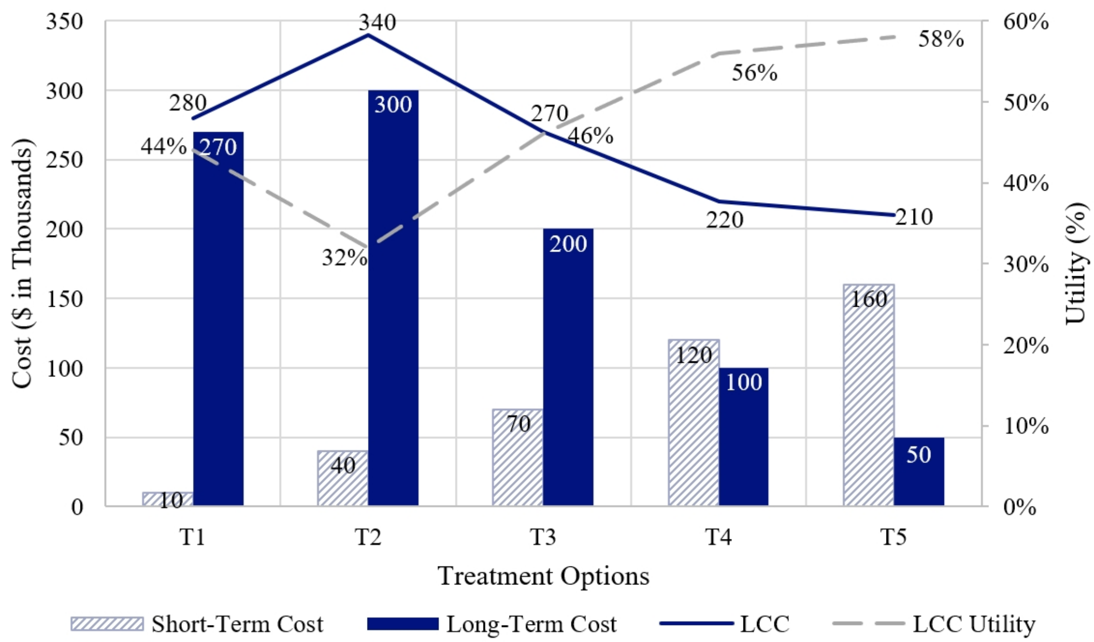


Figure 5. Example LCC utility calculation for treatments.

LCC utility values can then be used for comparing the LCC benefits of alternative treatments at the bridge-level. LCC utility can also be incorporated into the overall utility value, which is an aggregated value of all utilities for selected performance measures. In this example framework, the changes in the total utility value from a treatment alternative would constitute the incremental benefit from that treatment and would later be utilized within the incremental benefit cost ratio for bridge- and network-level prioritization.

- **Benefit/cost analysis** – Project-level and network-level benefit/cost analysis may be utilized in BMS tools. BMS tools have a bridge-level benefit/cost analysis that can be used to select optimal treatments at the bridge level. In most tools, network-level optimization is performed on an incremental benefit/cost (IBC) ratio to select the most cost-effective set of treatments that bring the highest benefits to the network. Like a PMS, a BMS also explores all feasible treatment options, which either are auto-generated based on decision trees or are manually assigned, over an analysis period for each structure in the database. For example, preserving a deck by overlays every 10-15 years, or doing a rehabilitation or replacement when it is in Fair or Poor condition are all viable options. However, these options have different benefits (e.g. improvement in condition, decelerated deterioration, increase in total utility, and reduction in life cycle costs). The IBC ratio is the ratio of the additional utility or benefit gained from a more expensive treatment over the difference in cost, as two treatment options are being compared. Among many treatment options, the one with the highest IBC ratio is the most cost-effective one.

Similarities and Differences in Pavement and Bridge Management System Approaches

A summary of the major similarities and differences in the approaches used by pavement and bridge management systems is presented in Table 1. While both a PMS and BMS can be used to represent the most cost-effective life cycle strategy, each approaches the analysis differently because of the variances in pavement and bridge preservation strategies, their service lives, the way they deteriorate, and other factors.

Table 1. Similarities and differences between pavement and bridge management systems.

Attribute	Similarities	Differences
Database Content	Asset inventory and condition information is used to support the analysis.	For bridges, data is stored by bridge, bridge component, and bridge element. The pavement network is divided into sections that vary in length, typically established from the length of past projects.
Performance Modeling	Both systems include a method for predicting changes in asset condition over time.	A PMS typically uses deterministic models to predict changes in condition by pavement family. Most BMS programs use probabilistic models at the component and element levels to predict future conditions.
Treatment and Impact Rules	Both systems include a method for evaluating the impacts of different treatment options.	A PMS uses decision trees and/or treatment rules to determine the feasibility of different treatment options. A BMS uses decision trees and/or treatment rules or benefit groups to present the impacts of treatments on element(s), component(s), or risk(s).
Analysis Approach	Both systems can be used to determine the most cost-effective set of projects and treatments for a particular asset class.	A PMS optimizes projects and treatments at the network level using a benefit/cost approach. A BMS uses an incremental utility-cost ratio to select the most-cost-effective projects and treatments for a specified budget.
Analysis Period	Both systems can analyze conditions over an extended analysis period.	A typical pavement management analysis considers conditions over a 20- to 40-year analysis period. Since bridges are designed to last much longer than pavements, a typical bridge analysis might evaluate impacts over a 70- to 100-year period.
Other	Minimum standards are required for both a PMS and a BMS in 23 CFR 515.17.	-

Using Pavement Management Systems for LCP

The use of a PMS for LCP represents an application that may differ from the typical type of analysis conducted to identify project and treatment recommendations for a given level of funding. This section describes how a PMS is used to support the LCP process described in Chapter 4.

Inventory and Condition Inventory

Before beginning the LCP analysis, each State DOT determines whether separate asset strategies will be developed for pavement sub-groups (such as asphalt or concrete pavements) or highway systems (such as Interstate, Non-Interstate NHS, and Non-NHS). In general, the complexity of the analysis increases as the number of sub-groups and systems increases because different performance models and treatment rules must be defined for each. However, since most State DOTs set different desired condition levels for different parts of the system, and since pavement deterioration rates and treatment strategies differ based on pavement type, most State DOTs have set up their PMS to consider these differences.

Performance Models

Performance models are needed for each of the treatments considered in the treatment rules. Most State DOTs have models established for rehabilitation and reconstruction treatments. Fewer State DOTs have models for maintenance and preservation treatments in place. If new models are needed, they can be developed using either historical pavement condition survey results or, in the absence of historical data, expert opinion.

Performance models for LCP may need to be more robust than those traditionally used. For example, to truly estimate the cost of managing an asset over its whole life, pavement conditions and deterioration patterns may need to be forecasted over a much longer analysis period than has been used in the past. Improvements in modeling may be necessary so State DOTs have as much confidence in 40-year predictions as they do in 5-year predictions.

Treatment and Impact Rules

An LCP analysis should include a range of treatments so that varying levels of deterioration that occur over the life cycle are represented. This implies that for each asset sub-group and highway system, rules for considering maintenance, preservation, rehabilitation, and reconstruction treatments have been developed. For some State DOTs, this means establishing new treatment rules that go beyond the types of treatments that are typically programmed. For instance, a State DOT that traditionally relies on rehabilitation and reconstruction strategies will need to add treatment rules for preservation treatments that are applied early in a pavement’s life cycle to extend the service life and postpone the need for rehabilitation. State DOTs that already consider preservation treatments might want to make changes to the treatment rules to explore different levels of preservation. For instance, a State DOT that uses preservation treatments occasionally might want to develop treatment rules that expand the conditions under which the treatments are considered viable – representing a more moderate or aggressive preservation strategy. Considering a range of treatment options allows an agency to consider whether there are alternate strategies that could be considered that would reduce the annual cost of preserving its pavement network.

As with performance models, impact rules are needed for each of the treatments included in the analysis.

Treatment rules may also need to be more robust for an LCP analysis than the traditional pavement management analysis, especially if treatment performance is influenced by treatment history or pre-treatment conditions. For instance, a State DOT may not expect to get the same life out of a third chip seal application as it did from the first. In this situation, a State DOT may need to refine its database to track the number of chip seal applications to model its future performance accurately.

Conducting the Analysis

When considering different LCP strategies, the first step in the analysis is to set a fixed level of funding for each asset sub-group and/or highway system to compare the long-term impacts of several different options. For example, a State DOT may compare the results of several different LCP strategies, including one that represents the typical treatment strategy and another that applies more preservation than is typically considered. State DOTs with funding constraints that do not allow them to address all system needs may evaluate strategies that rely on more frequent cycles of low-cost preservation treatments on low-volume roads to determine whether an alternate strategy reduces the overall cost of system preservation.

Implementation

It is important to remember that there should be a link between a State DOT's LCP strategies and the projects and treatments that are programmed through other business processes. Therefore, if the LCP analysis shows that an alternate approach to system preservation has merit, the State DOT should consider whether the implementation of the strategy requires changes to existing business processes. For instance, some State DOTs have updated the guidelines used by field personnel for project and treatment selection, other State DOTs have conducted workshops with district staff to build buy-in for the changes, and a few State DOTs have modified the pavement performance measures that they have been using to drive project selection. The implementation of LCP strategies should take a holistic approach to be successful.

Using Bridge Management Systems for LCP

The use of a BMS for developing an optimal program for a specified budget may differ from how a BMS can be utilized for LCP. Bridge programs are typically developed for shorter periods than LCP, which relies on longer term analyses and focuses on spending strategy. This section describes how a BMS can be used to support the LCP process described in Chapter 5.

Inventory and Condition Inventory

Before beginning the LCP analyses, each State DOT determines whether separate analyses will be necessary for different highway systems and bridge sub-groups. Ideally, separate models and decision rules are developed and assigned for different design and material types. Most BMS tools come with a framework to consider such differences in analyses. Predefined programs and budgets (e.g. painting program, scour retrofit program, deck overlay or rehab program) may necessitate breaking down the analyses depending on the BMS tool used. However, breaking down the network or the analyses should be kept to a minimum since keeping the networks and budgets as a whole leads to a better-informed analysis that could suggest an optimal mix of budgets or programs. The inventory classification with respect to bridge sub-groups and highway systems should be detailed enough to explore the impacts of relevant strategies. Because the analyses should support the State DOT practices and policies, the BMS analyses are set up to be aligned with the strategies being considered.

Performance Models

The first step for the LCP analysis is the development or customization of the deterioration models and the forecasting framework for the selected bridge sub-groups, components, and elements. The treatments associated with these groups should also be comprehensively defined in the BMS. Treatments may have multiple benefits (that should be linked to relevant performance measures) and may impact multiple component and elements. For example, a bridge replacement impacts all bridge components and elements. An overlay treatment improves the condition of the deck element, if the deck is also repaired, and adds a wearing surface element in the best condition. The models needed for maintenance, preservation, rehabilitation and replacement treatments along with their unit costs should be defined and linked to the relevant bridge sub-groups, components, elements, and performance measures.

Treatment and Impact Rules

An LCP analysis should include a range of treatments that includes all viable maintenance, preservation, rehabilitation, and reconstruction treatments over the life cycle. Decision trees that minimize LCC may be a great resource for LCP; however, the decision trees collectively should be comprehensive enough to consider all viable treatment options. The treatment rules included in the LCP analyses should represent a comprehensive preservation program that includes all components/elements and potential treatment types that significantly affect bridge service life and cost. Traditionally, rehabilitation and replacement projects formed the bulk of State DOT bridge programs, while some State DOTs also had preservation programs. State DOTs that would like to increase preservation treatments on their networks or would like to see the impacts of different levels of preservation within an LCP analysis must set up treatment rules accordingly to analyze prospective as well as existing strategies. The impact rules associated with each treatment rule should also be explicitly defined.

Conducting the Analysis

LCP strategies for bridge networks typically differ by the level of funding for each highway system and the proportion of replacement, rehabilitation, and preservation expenditures for each budget level. It is important that the analysis consider various alternatives to achieve performance targets and achieve system performance effectiveness at a minimum practicable cost. For many State DOTs, increased levels of preservation with alternative treatments that reduce long term LCC is a common strategy that can be compared to traditional strategies.

Implementation

The findings from an LCP analysis should ideally be used to improve a State DOT's overall asset management process. LCP findings might suggest increased use of alternative treatments or different funding levels for parts of the bridge network. These suggestions may need to be communicated with districts for successful implementation. The State DOT should reflect on the findings to identify which business processes or parts of the organization are impacted or which changes can make desired improvements. When properly conducted, LCP analysis can identify improvements that can be achieved in the short-term as well as a long-term vision for State DOTs to aspire to.

Steps Toward a More Sophisticated Analysis

The ability of State DOTs to conduct LCP is somewhat limited by the data available, the traditional performance measures that have been used, and the capabilities of pavement and bridge management software. However, as State DOTs become more familiar with network-level LCP and the reductions in annual preservation costs are realized, it is likely that the industry will mature, leading to improved investment strategies with time. Some of the developments that would improve LCP capabilities for pavements and bridges are described below.

Pavement Enhancements

The three enhancements described below would significantly improve the management of pavements from an LCP perspective.

- New types of performance measures – Today's PMS use pavement condition measures to illustrate the long-term impact of one LCP strategy over another. Although condition is an important measure, it represents a "lagging" measure that indicates the outcome of a past decision. Ideally, future pavement performance measures will include "leading" indicators that drive the resulting outcome, potentially allowing State DOTs to be more proactive in achieving improved conditions.
- Consideration of multi-treatment strategies – At the present time, most PMS evaluate each project and treatment combination in isolation, rather than as one step in a series of treatments for a given pavement section. In the future, the ability to consider a series of treatment strategies for each pavement section in the database could lead to the identification of more cost-effective LCP strategies.
- Better consideration of maintenance in the analysis – According to a synthesis of practice (Zimmerman 2017), only 42 percent of the State DOTs that responded to a survey have any information about routine maintenance activities in their PMS. Since routine maintenance applications can have a significant impact on extending pavement service life, and thereby reducing life cycle costs, the analysis would benefit from improved consideration of maintenance impacts in the benefit/cost analysis.

Bridge Enhancements

The five enhancements described below would improve the life cycle analysis capabilities within BMS tools and improve the LCP guidance that can be developed using BMS.

- New types of performance measures – Similar to PMS, BMS also use condition measures to show long-term impacts of LCP strategies. Identifying and including "leading" indicators as future performance measures in LCP analysis would also lead to more proactive strategies and bridge programs.
- Consideration of multi-treatment strategies –At the present time, BMS tools provide limited capabilities to group multi-treatment strategies. The capability to do so would simplify the State DOT preparation and let analysts more easily and accurately model bridge treatments.
- Data-driven performance models – Because the definition and inspection of bridge elements have changed with time (AASHTO, 2013), the historic element condition data for developing models for the newly defined elements or the elements with changed definitions compared to Commonly Recognized Elements (AASHTO, 1997) are not

available. As the data become available, State DOTs should update models based on originally developed models by expert elicitations.

- Improved presentation of preservation treatments – Because the inclusion of preservation treatments in BMS is more recent than inclusion of traditional replacement and rehabilitation treatments, the performance models and treatment rules for preservation treatments have more potential to be improved and refined in future.
- Improved analysis tools – Current BMS tools limit viable treatments to decision trees or treatments assigned by the State DOT based on inspector recommendations. The ability to perform recursive life cycle analyses that can dynamically evaluate all combinations of treatments in each year of the analysis period would help select optimal treatment combinations with optimal timing.

Application of LCP Concepts to Other Assets

Pavements and bridges are examples of assets that benefit from on-going maintenance and preservation activities to extend service life as much as possible, thereby postponing the need for more expensive repairs. There are other assets managed by State DOTs, including culverts, that are best managed using a life cycle approach. Some assets, such as ITS assets and signals, may be better managed using an interval basis for maintenance. Additional assets, including guardrails, may be managed on a reactive basis, to address damage caused by vehicular impacts. A relatively new concept in transportation, Reliability Centered Maintenance (RCM), was originally developed for the airline industry to determine the best maintenance approach based on how the asset is used and how it fails (SAE International 2009). The selection of the most appropriate maintenance approach then drives the type of data needed to manage the asset effectively. For instance, assets that are best managed on a life cycle (or condition-based) approach need condition data from inspections that are scheduled and performed on a regular basis. Assets managed on a reactive basis do not rely on processes to monitor changes in condition with time, but rely on processes to alert maintenace staff to damage requiring repairs.

Any assets that are best managed using a condition-based approach would benefit from LCP to determine the optimal type and timing of treatments recommended over the life cycle. Several State DOTs have conducted LCP for ancillary assets using spreadsheet tools designed specifically for this purpose, as illustrated by the example from the Nevada DOT that is provided in figure 6 (Nevada DOT 2018).

The Nevada DOT adopted an interval-based approach to maintain and manage its ITS devices. The conditions of the ITS assets are estimated based on the device manufacturers' recommended service life as described below:

- GOOD – Device age is less than 80 percent of the manufacturers' recommended service life.
- LOW RISK – Device age is between 80 to 100 percent of the manufacturers' recommended service life.
- MEDIUM RISK – Device age is between 100 to 125 percent of the manufacturers' recommended service life.
- HIGH RISK – Device age is greater than 125 percent of the manufacturers' recommended service life.

A simple condition transition probability matrix was developed for each ITS device to model deterioration based on expert opinion. The matrices describe the time required for a device to deteriorate from one condition state to another (e.g., "Good" to "Low Risk") with an inherent assumption that there is a 50 percent probability that devices will deteriorate to the lower condition categories at the end of the time period represented in the transition matrix. Maintenance actions were programmed based on estimated conditions and a separate transition matrix was developed to reflect the "impact" of each treatment on a device. For example, minor repairs moved a device from Low Risk to Good but did not change the condition of a device at Medium or High Risk. Major repairs improved the condition by one category (e.g., a Medium Risk device moved to a Low Risk category) and replacement brought any device back to Good condition.

Over a 20-year period, the Nevada DOT's preservation strategy is expected to save approximately $1.1 million over the "worst first" strategy that had been used in the past. The worst first strategy did not include minor repairs and relied heavily on replacing ITS devices as they stopped working.

As part of its TAMP development, the Nevada DOT developed a simple spreadsheet to help estimate maintenance needs for ITS assets over a 10-year period. The spreadsheet has helped the Nevada DOT adopt a performance-based approach for managing its ITS assets.

Figure 6. Nevada DOT's Analysis of ITS Funding Needs (Nevada DOT 2018).

References

- AASHTO. 1997. *AASHTO Guide for Commonly Recognized (CORE) Structural Elements*. American Association of State Highway and Transportation Officials, Washington, DC.
- AASHTO. 2013. *Manual for Bridge Element Inspection*. American Association of State Highway and Transportation Officials, Washington, DC.
- Nevada DOT. 2018. *Initial TAMP*. Nevada DOT, Carson City, NV.
- SAE International. 2009. *Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes*. JA1011_200909. SAE International, Warrendale, PA.
- Zimmerman, K.A. (2017). *Pavement Management Systems: Putting Data to Work*. National Cooperative Highway Research Board (NCHRP) Synthesis 501. National Academies of Science, Washington DC.

CHAPTER 4: HOW TO CONDUCT NETWORK-LEVEL LCP FOR PAVEMENTS

Introduction

A network-level LCP analysis applies the deterioration models, treatment rules, treatment costs, and treatment impacts that were discussed in Chapter 3 to the pavement inventory and condition information available in the PMS. The LCP analysis also benefits from the use of the following information:

- System hierarchies (e.g., high-priority routes vs. low-priority routes).
- Changes in system demand that may impact deterioration rates or treatment options.
- Analysis period, inflation rate, and discount rate.
- Expected budget levels for the pavement program.
- Other constraints that influence investment decisions, such as meeting a minimum required condition levels.
- Information on desired state of good repair (SOGR) and/or existing performance gaps to be addressed.

When conducting an LCP analysis that is focused on achieving the minimum practicable life cycle cost of managing a pavement network, consideration should be given for proactive treatment application, such as applying treatments before the pavement section reaches the condition trigger values programmed in the PMS decision trees. In some cases, the treatments may also be delayed to future years due several reasons to reduce short-term costs.

This chapter introduces a suggested 5-step process for conducting a network-level LCP analysis. It describes the conduct of a comprehensive analysis that follows each of the five steps and provides an example showing how each step in the process can be applied.

Step-By-Step Process for Conducting a Network-Level LCP Analysis

The descriptions and figures provided in this section illustrate the use of a process for conducting a network-level LCP analysis. State DOTs may use other processes that are customized to best suit their specific needs.

Figure 7 illustrates the 5-step process that was presented in the LCP guidance document issued by FHWA (FHWA 2017a). This process can be adapted to fit the particular needs and resources of any State DOT. It is intended to enable State DOTs to develop TAMP investment strategies that consider the results of the LCP analysis as well as the results of financial planning, risk analysis, and performance gap analysis. Background information on using a life cycle process to support asset management has been documented elsewhere (FHWA 2017a).

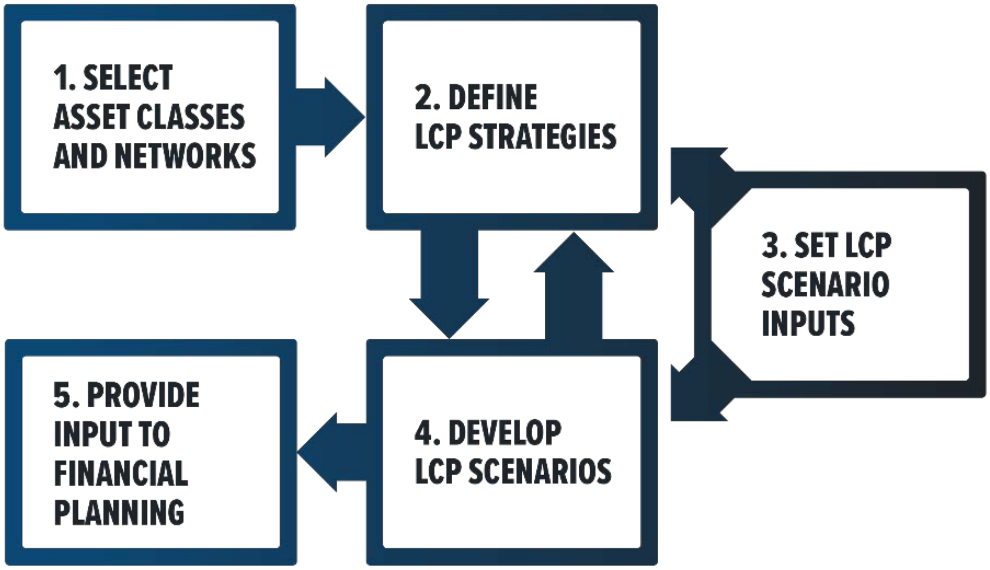


Figure 7. A 5-step LCP process for transportation assets (adapted from FHWA 2017a).

Step 1. Select Asset Classes and Networks

The first step in a network-level LCP analysis is the selection of pavement networks to be included in the analysis.

A network is generally defined based on attributes such as functional class, jurisdiction, ownership, and traffic. A network could include all NHS routes within a State or both NHS and non-NHS routes, for example. State DOTs have flexibility in how they define the network for LCP purposes. State DOTs also have flexibility in selecting the portions of the pavement network that will be analyzed using LCP at the network level, in addition to the required Interstates and other NHS pavements. The pavement network may be further divided into subgroups with the same characteristics and functions, to better reflect differences in performance and treatment strategies. The overarching objective of this step is to define networks that match how the pavement system is managed. If the desired state of good repair varies for different parts of the system, separate networks should be created in the PMS. A number of other factors (such as monetary value, risk, and environmental considerations) may also be considered in the network selection process. An example prioritization approach to consider when selecting the pavement networks to be included in the LCP analysis is shown below.

1. Divide network into the following categories:
    a) Interstate pavements.
    b) Non-Interstate NHS pavements.
    c) Other categories defined by the State DOT or by functional classes such as arterials, collectors, local roads etc.
2. Select networks (defined in step 1) to be included in the analysis and subdivide the network based on other characteristics (such as pavement type and traffic) that are used by the State DOT to manage the network.

3. Further divide the network into subdivisions that consider risk (such as pavement segments that are vulnerable to flash floods or pavement segments in accident prone areas where safety needs to be prioritized).

Example

Table 2 summarizes the basic pavement inventory information that will be used to illustrate the step-by-step procedure to conduct a network-level LCP for pavements in the following sections. The pavement network has been divided into three categories for analysis purposes: (a) Interstates, (b) Non-Interstate NHS pavements, and (c) non-NHS pavements. The current condition and the desired state of good repair for the three pavement categories are shown in Table 2.

Table 2. Pavement inventory information used to illustrate pavement LCP analysis.

Pavement Network	Mileage (lane-miles)	Current Conditions (2018)	Desired State of Good Repair
Interstate	2,000	90% Good and Fair	97% Good and Fair
Non-Interstate NHS	5,000	80% Good and Fair	85% Good and Fair
Non-NHS	12,000	70% Good and Fair	75% Good and Fair

Step 2. Define LCP Strategies

The second step in the process involves the definition of LCP strategies for the pavement network, which involves the establishment of treatment rules, treatment cycles, and treatment intervals. If the pavement network has been divided into subgroups, LCP strategies should be established for each of the subgroups. The LCP strategies should consider deterioration rates, treatment costs, and condition improvement benefits, as well as the factors that influence treatment type, timing, and priority. When available, treatment histories can be useful in determining treatment intervals for developing treatment rules. If histories are not available, expert judgement or industry standards may be used.

Example

For the example introduced in *Step 1*, the following three LCP strategies have been defined, as summarized in Table 3:

- **Current Strategy**: This reflects the State DOT's current strategies for pavement life cycle management. This strategy prioritizes treatments that address structural defects in pavements in *Poor* condition using thick mill and overlay treatments.
- **Moderate Preservation**: Provides equal priority between less expensive preservation treatments (such as thin mill and overlay) that extend the time assets are in *Good* or *Fair* condition, and more expensive rehabilitation treatments (such as medium mill and overlay) for pavements in *Poor* condition.
- **Aggressive Preservation:** Prioritizes treatments that extend the service lives of pavements by applying preservation treatments to keep pavements in *Good* or *Fair* condition as long as possible.

Table 3. Example LCP strategies.

Pavement Network	Pavement Condition	Current Strategy	Moderate Preservation	Aggressive Preservation
Interstate and Non-Interstate NHS	Good	• Routine Maintenance	• Routine Maintenance	• Routine Maintenance
	Fair	• Routine Maintenance	• Thin Mill and Overlay	• Microsurfacing • Thin Mill and Overlay
	Poor	• Thick Mill and Overlay with pre-overlay repairs	• Medium Mill and Overlay	• Medium Mill and Overlay
Non-NHS (Moderate Traffic)	Good	• Do Nothing	• Routine Maintenance	• Routine Maintenance
	Fair	• Routine Maintenance	• Routine Maintenance	• Single Chip Seal • Microsurfacing
	Poor	• Thick Mill and Overlay with pre-overlay repairs	• Double Chip Seal	• Double Chip Seal
Non-NHS (Low Traffic)	Good	• Do Nothing	• Do Nothing	• Routine Maintenance
	Fair	• Do Nothing	• Routine Maintenance	• Routine Maintenance
	Poor	• Thick Mill and Overlay with pre-overlay repairs	• Single Chip Seal	• Single Chip Seal

Treatment Costs: Thick Mill and Overlay: $800,000 per lane-mile, Medium Mill and Overlay: $400,000 per lane mile, Thin Mill and Overlay: $120,000 per lane mile, Double Chip Seal: $70,000 per-lane-mile, Single Chip Seal: $35,000 per lane mile, Routine Maintenance: $10,000 per lane mile

These strategies are programmed into the PMS using treatment rules/decision trees that are used to determine the appropriate treatment type based on the existing condition of the pavement. Once the treatment types are determined, the PMS also determines the resulting improvements in the pavement condition and the deterioration model to use.

In order to illustrate the general process for developing LCP strategies, a simplified approach is demonstrated in this example. State DOTs typically make use of more complex treatment rules/decision trees based on several pavement performance/distress indicators (such as fatigue cracking, IRI, rutting, and faulting) in order to determine the most appropriate treatment.

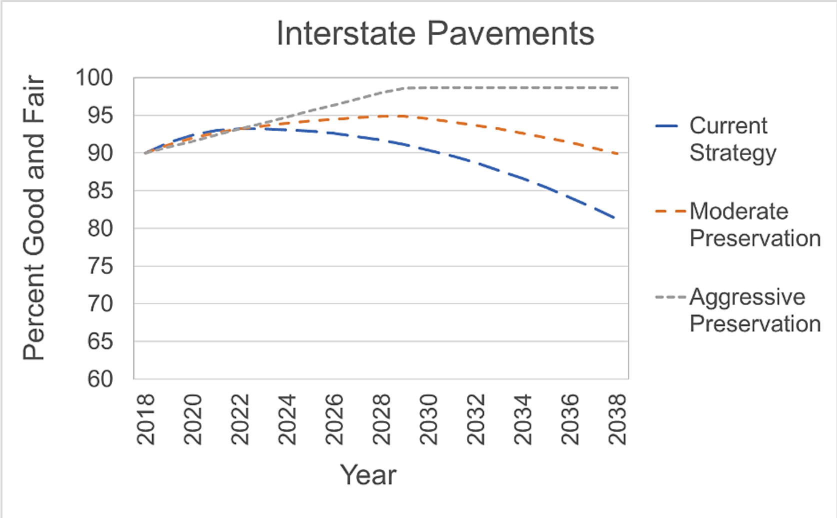
In the example shown in Table 3, the non-NHS network has been split into two sub-categories (moderate traffic and low traffic) and different LCP strategies have been established for each of these categories. State DOTs may also consider developing separate LCP strategies for pavement subgroups that exhibit different performance trends or if they are managed using strategies that are considerably different from other portions of the pavement network.

Once the LCP strategies have been defined, the impact of these strategies over the long-term (≥40 years) using an average annual budget based on historical annual investment in pavements is investigated. The results of the three LCP strategies analyzed are shown in Figures 8, 9, and 10 (only the results of the first 20 years of the analysis are shown in the figure for simplicity). The first of the three graphs for each system presents overall condition, the second graph shows the number of miles of pavement that received major rehabilitation or reconstruction treatments, and the third graph shows the number of miles that received maintenance or preservation work. The performance of both the moderate- and low-traffic-volume non-NHS pavements has been aggregated into a single category for presenting the results in Figure 10.

The following observations can be made from Figures 8, 9, and 10:

- The *Current Strategy* will result in steeply declining pavement conditions over the next 20 years. This strategy prioritizes funding on pavements in *Poor* condition, resulting in more investments in major rehabilitation and reconstruction projects. It can also be seen that there is quite a bit of fluctuation in the number of lane-miles addressed annually.
- The *Moderate Preservation* strategy will result in modest improvements in the pavement conditions between 2018 and 2028, however, this strategy is not adequate to maintain the pavement conditions over the long-term and a steady decline will result after 2028. This strategy provides a better balance between major rehabilitation/reconstruction projects and maintenance/preservation since a pro-active preservation approach is adopted. As the network approaches a steady-state condition, the number of lane-miles of pavements treated each year also plateaus.
- Implementation of the *Aggressive Preservation* strategy will drastically improve pavement conditions between 2018 and 2028 after which steady-state conditions will be achieved. The impact on the number of lane-miles addressed each year is very similar to the *Moderate Preservation* strategy, the only difference is the increased emphasis placed on preservation treatments.

a)



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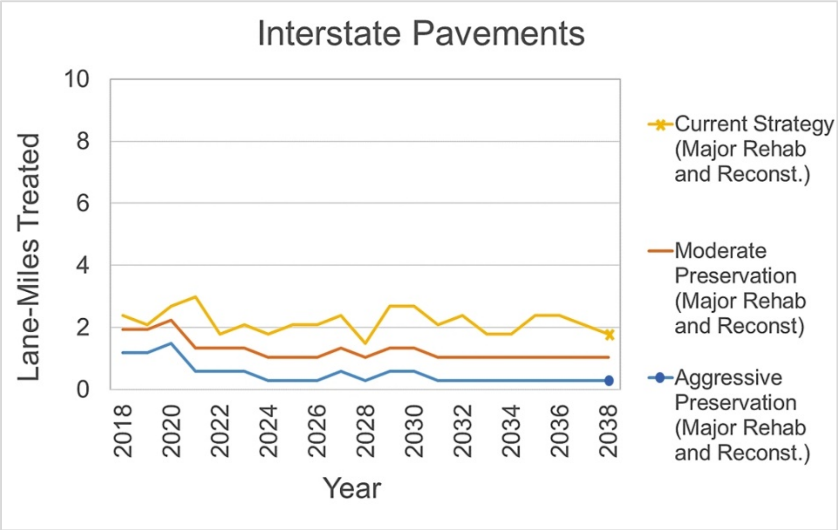

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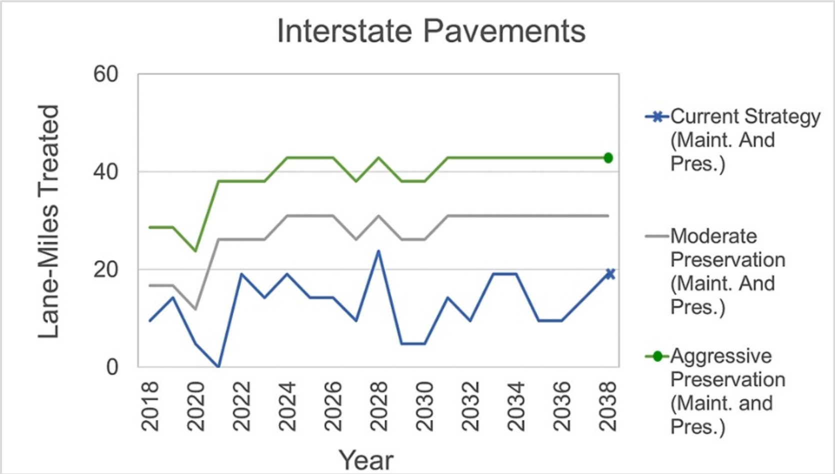


Figure 8. Impact of the three LCP strategies for Interstate Pavements (based on average historical budgets).

a)

b)

c)

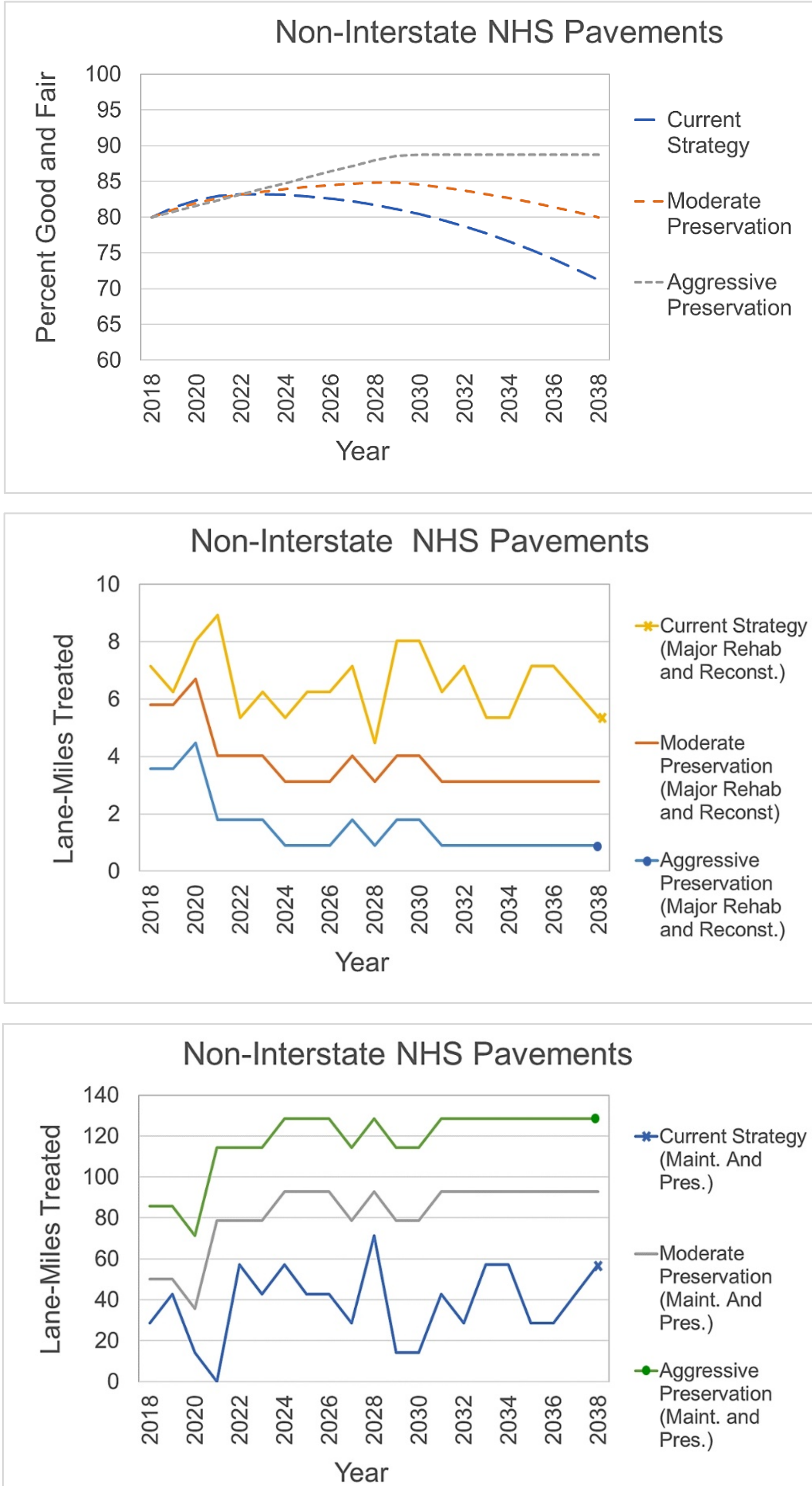


Figure 9. Impact of the three LCP strategies for non-Interstate NHS pavements (based on average historical budgets).

a)
b)
c)

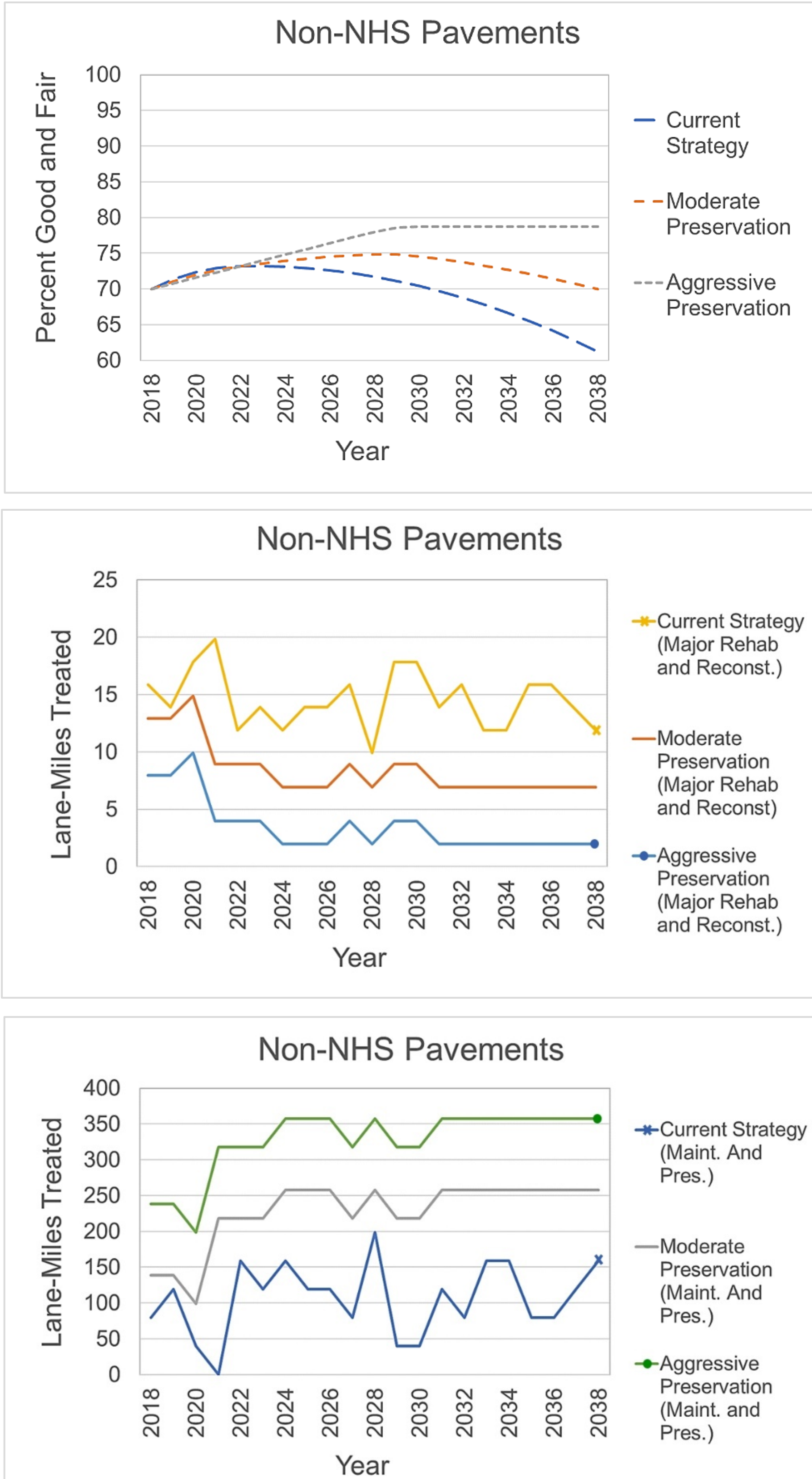


Figure 10. Impact of the three LCP strategies for non-NHS pavements (based on average historical budgets).

Step 3. Set LCP Scenario Inputs

In this step, the LCP scenario inputs that will be used in Step 4 are set by the State DOT. These include establishing the analysis period to be used, SOGR, risks, performance gaps, anticipated funding levels (which may come from financial planning), and any constraints or requirements, such as minimum pavement conditions.

The primary inputs to an LCP scenario are summarized below:

- **Current Conditions**: Provides a starting point for the analysis and serves as a primary input for identifying appropriate treatments according to the selected LCP strategy.
- **Analysis Period**: Establishes the timeframe that will be considered for the LCP analysis. For pavement LCP analysis, the chosen analysis period should be at least long enough to span the life of the next major rehabilitation activity and preferably extend through the lives of several rehabilitation treatments or the first reconstruction event. Care should be exercised to not unnecessarily increase the analysis period and raise the difficulty and uncertainly of predicting future events. State DOTs should continually monitor and update the performance models used in the PMS in order to improve the reliability of the outputs. For network level LCP, a typical analysis period would range between 20 and 40 years.
- **Discount and Inflation Rates**: Establishes the discount and inflation rates used in the LCP analysis to consider the time value of money.
- **Annual Funding**: Determines various budget constraints being analyzed for each year of the analysis, impacting which treatments can be applied to each segment in the pavement network for each analysis year and how the pavement network will change over the analysis period chosen.
- **Treatment Definitions**: Describes the type of treatments that will be considered in the LCP analysis. Similar treatments are often grouped into a single category to simplify the analysis.
- **Treatment Costs**: Determines the cost of defined treatments.
- **Strategy Rules and Details**: Establishes the conditions under which treatments are appropriate to apply and the basis for prioritization between treatments when funding is insufficient to address for all appropriate treatments.
- **Risks**: Recognizes the high-priority risks identified as a part of the risk management analysis efforts during the development of the TAMP. For pavements, some key considerations include:
  - Changes to future maintenance and rehabilitation cycles that may result from variations in climatic conditions (such as extreme temperatures and an increased frequency of 100-year events).
  - Anticipated increases in heavy truck traffic loads after a certain number of years due to planned development in certain areas.
  - Pavement segments where drainage issues have been historically observed, especially for segments located in high-precipitation areas and those vulnerable to flooding.
  - Corridors with increased crash rates.

As discussed earlier, one approach for incorporating risks into an LCP analysis is to define a pavement network (or a number of networks) that includes all pavement segments that have a higher degree of risk associated with them. Most PMS provide the users with an option to define customized fields to flag and track specific pavement segments. This feature can be used to flag the "high risk" pavement segments. A State DOT may also choose to have a dedicated pot of funding to manage the "high risk" pavement network.

- **Deterioration Models**: Provides details on how the application of one or more strategies impacts pavement conditions, and how those performance curves vary between the LCP strategies analyzed.

Example

For the example LCP analysis introduced in steps 1 and 2, Table 4 summarizes the LCP scenario inputs.

Table 4. LCP Scenario inputs for example LCP analysis.

Item	LCP Scenario Inputs
Current Conditions	• Interstate pavements: 90% Fair and Good • Non-Interstate NHS pavements: 90% Fair and Good • Non-NHS Pavements: 70% Fair and Good
Desired State of Good Repair[1]	• Interstate pavements: 97% Fair and Good • Non-Interstate NHS pavements: 85% Fair and Good • Non-NHS Pavements: 75% Fair and Good
Analysis Period	• 40 years
LCP Strategies	• See Table 3
Performance Curves for LCP Strategies	• See Figure 8
Annual Funding (for entire pavement network)	• 75 million per year (pessimistic scenario) • $150 million per year (reduced funding levels) • $200 million per year (expected annual funding) • $250 million per year (optimistic scenario)

[1]Assuming the state of good repair is defined solely in terms of long term targets.

Step 4. Develop LCP Scenario

Step 4 involves the development of LCP scenarios using the strategies defined in Step 2 and the inputs from Step 3. Due to the iterative nature of the analysis, the development of LCP scenarios may lead back to Step 2 and the development of the new strategies. The development of LCP scenarios will help the agency address the following key questions:

- Has the agency met or exceeded minimum performance requirements?
- What level of funding is needed to achieve the desired SOGR?
- What condition levels can be achieved at different funding levels?
- Is there a more cost-effective strategy to preserve the pavement network conditions?
- Does the scenario address risks and other constraints the agency is currently experiencing or expected to experience in the future?
- If funding is not adequate to meet the desired SOGR, what condition level can be achieved for the available funding?

Incorporating Risks

The FHWA's guidance on risk management provides a discussion on identifying and managing high-priority risks, including those associated with extreme weather and geologic events (FHWA 2017b). These risks can potentially influence the LCP strategies (Step 2) and LCP scenario inputs (Step 3). The impacts of these risks should be considered while developing the LCP scenarios in Step 4.

For example, if structural inadequacies have been identified on a few high-priority Interstate routes, they may require significant investments in major rehabilitation activities in order to restore their structural integrity before complete reconstruction becomes the only viable option (if the condition has deteriorated to an extent where major rehabilitation actions are no longer effective). Such situations may require the re-allocation of a significant portion of the pavement program's funding to address imminent risks, impacting the definition of LCP scenarios in Step 4.

Other Considerations

A State DOT may also decide to investigate other LCP Scenarios (such as funding needs to meet minimum performance requirements, prioritizing Interstate pavements, impact of performing only minimum maintenance, or maintaining current conditions or asset value) before putting forth recommendations for the development of the financial plan and investment strategies. As presented earlier, the development of LCP scenarios is an iterative process that can account for considerations beyond just fiscal implications.

Consideration of risks and performance gaps are key factors in developing a well-rounded LCP strategy. State DOTs should also consider other situations that are relevant to them, such as:

- Exclusion of a particular portion of the pavement network if it is managed through a separate source of funding or if a special LCP strategy is required for that portion of the network.
- Network expansion as a result of a new freight plan proposed by the State DOT.

- Radically changing the life cycle management strategy for a certain portion of a network to reduce the overall life cycle cost of managing the pavement network as a whole. For example, a State DOT may choose to convert a certain fraction of its very low-volume roads to a chip-seal pavement or a gravel pavement, depending on expected traffic levels, significance of the route, and other site-specific issues. By doing this, additional funding may be available to maintain the remainder of the network.

While routine maintenance costs may not be explicitly considered when conducting an LCP analysis using a PMS, the financial planning process could consider historical trends in maintenance expenditures so that routine maintenance investment needs can be adjusted accordingly.

Example

Figures 11 through 13 illustrate the results of applying the three LCP strategies (defined in Step 2) to the four LCP scenarios summarized below.

- **Expected Annual Funding Levels**: This scenario represents the annual funding levels expected over the next 20 years ($200 million per year).
- **Reduced Annual Funding**: This scenario represents a 25 percent reduction in the expected funding levels ($150 million per year).
- **Optimistic Scenario**: This scenario represents a 25 percent increase in the expected funding levels ($250 million per year).
- **Pessimistic Scenario**: This scenario represents a significant reduction in expected annual funding ($75 million per year).

Based on the LCP Scenario outputs (shown in Figures 11, 12, and 13), the State DOT would likely adopt the *Aggressive Preservation Strategy* to meet its desired state of good repair by year 2038 at the expected funding level of $200 million per year.

a)
b)
c)

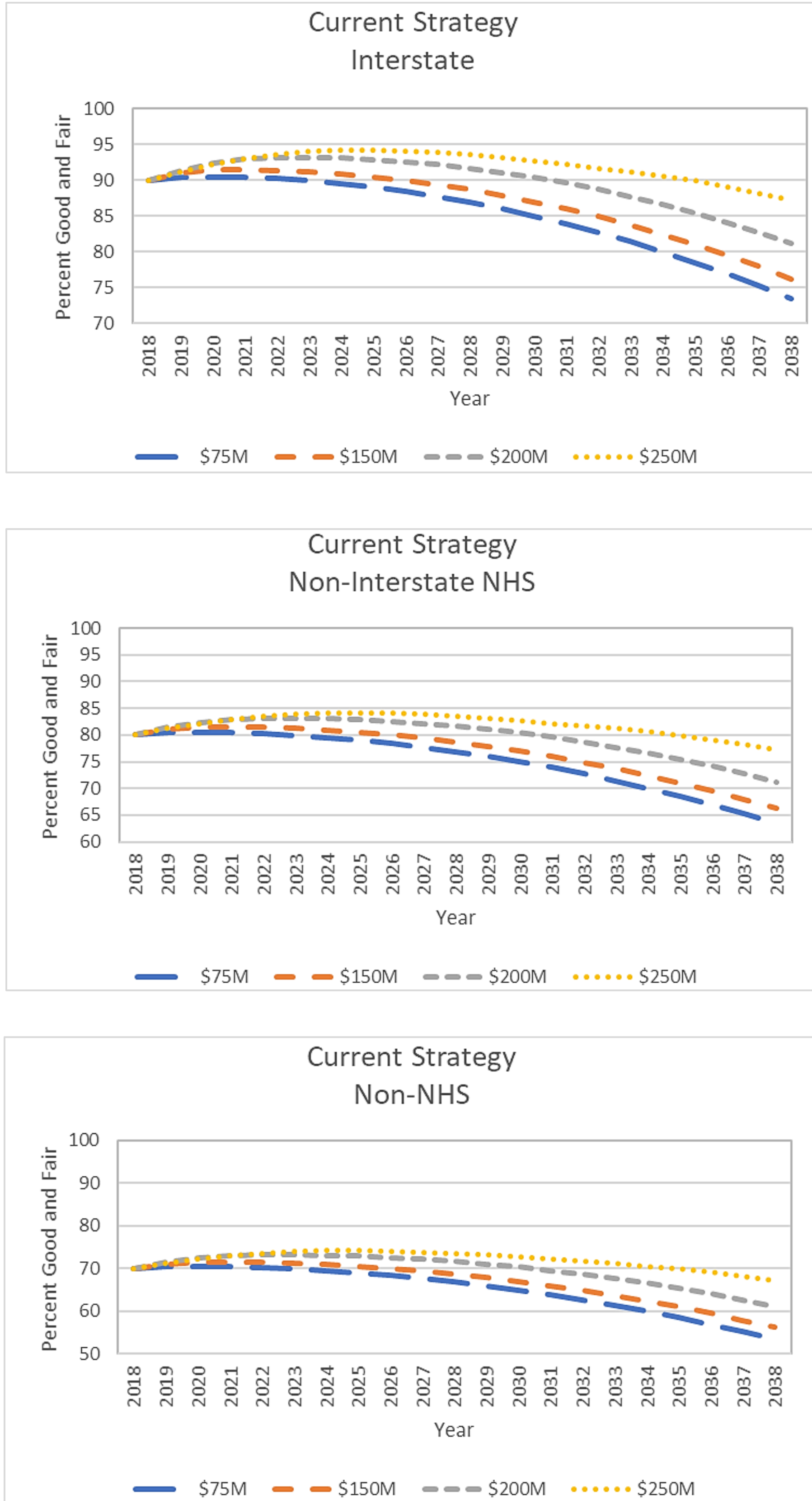


Figure 11. Results of applying the *Current Strategy* to the four LCP scenarios.

a)

b)

c)

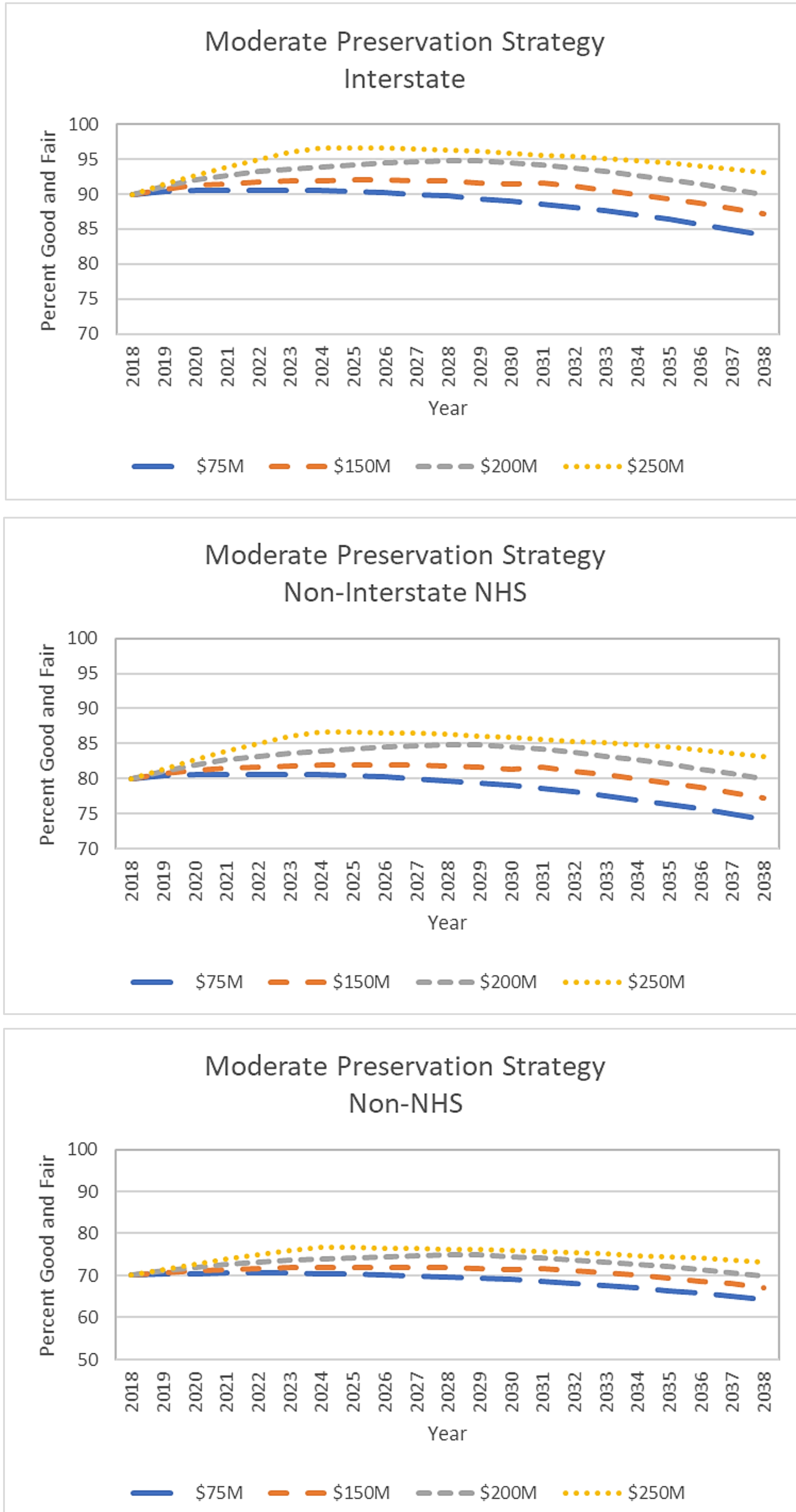


Figure 12. Results of applying the *Moderate Preservation Strategy* to the four LCP scenarios.

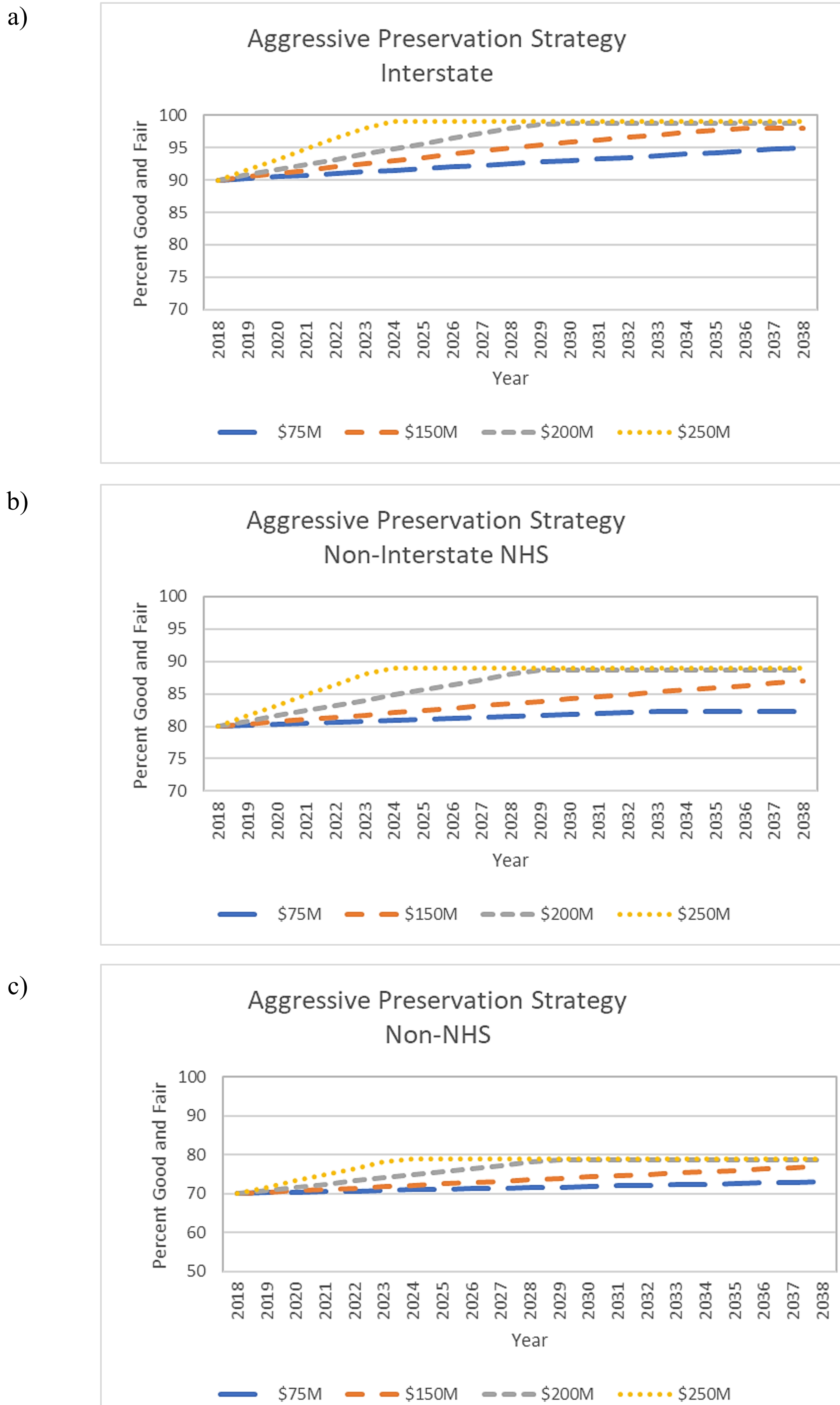


Figure 13. Results of applying the *Aggressive Preservation Strategy* to the four LCP scenarios.

Step 5. Provide Input to Financial Planning

The results of the LCP scenarios developed in Step 4 serve as inputs to the financial planning process, along with the results of the risk and performance gap analyses. The resulting impact of each LCP scenario in terms of conditions achieved at the end of the analysis period can be summarized for the decision makers to evaluate trade-offs as they consider the investments needed for other asset classes. It is suggested that results are presented for both short (≤ 10 years) and long (≥10) timeframes so the decision makers can evaluate both short- and long-term implications and adjust the performance targets and the desired state of good repair as needed. Guidance on developing financial plans for a TAMP is provided elsewhere (FHWA 2017c).

Example

For the example discussed in Steps 1 through 4, illustrations like Figures 14 and 15 may be developed to guide the financial planning process. Figures 14 and 15 show the resulting pavement conditions in 2028 and 2038 for the various annual budgets discussed earlier if the *Aggressive Preservation Strategy* is adopted.

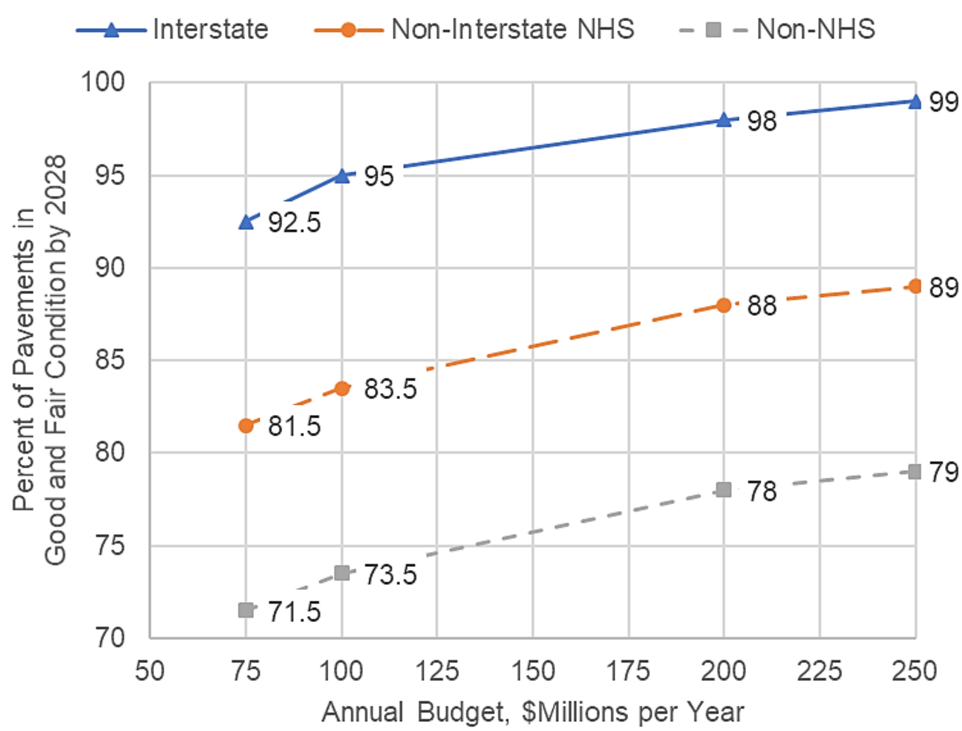


Figure 14. Pavement condition in 2028 vs. annual budget level (for the *Aggressive Preservation Strategy*).

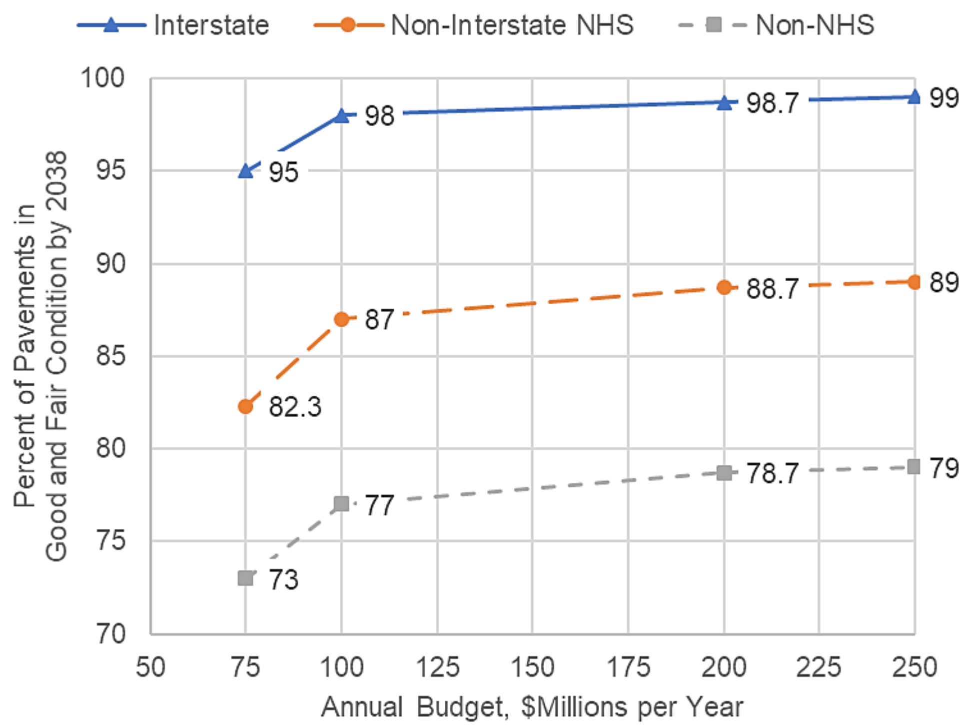


Figure 15. Pavement condition in 2038 vs. annual budget level (for the *Aggressive Preservation Strategy*).

In the example shown, the LCP scenario based on a $200 million annual budget (which represents the expected annual funding level) yields the following results if the *Aggressive Preservation Strategy* is adopted:

- By Year 2028
  - 98 percent of Interstate pavements in *Good* and *Fair* condition.
  - 88 percent of the Non-Interstate NHS pavements in *Good* and *Fair* condition.
  - 78 percent of the Non-NHS pavements in *Good* and *Fair* condition.
- By Year 2038
  - 98.7 percent of Interstate pavements in *Good* and *Fair* condition.
  - 88.7 percent of the Non-Interstate NHS pavements in *Good* and *Fair* condition.
  - 78.7 percent of the Non-NHS pavements in *Good* and *Fair* condition.

During the financial planning process, the decision makers can make use of graphics like those presented in Figures 14 and 15 to estimate the impact of other funding scenarios and develop a desired state of good repair based on the level of funding expected to be available for the pavement program. These graphs are also very useful in conducting trade-off analyses, particularly when the State DOT must allocate the available funding between several asset classes. Based on the budget decisions made during the financial planning process, any revisions to the available funding would be used to re-run the analysis as discussed in Step 4.

Addressing Realities

Conducting an LCP analysis should be fairly straightforward if an agency has a relatively mature PMS and a well-established pavement management division. However, implementing an LCP strategy has more challenges associated with it since decision makers often have to consider a number of issues that cannot be explicitly accounted for in an LCP analysis. A cross-asset trade-off analysis and optimization tool can help State DOTs allocate resources effectively among the various assets being managed so they can provide the best possible level-of-service to the public at the minimum practicable life cycle cost. However, most State DOTs do not have the tools to conduct a true cross-asset trade-off analysis today. Even without these capabilities, State DOTs can monitor and track the performance of the pavement network and adjust the life cycle management strategies to account for the realities that they face.

Many of the issues that State DOTs face revolve around a common theme—the lack of adequate funding to address the needs identified and meet the established performance targets. In reality, funding is never likely to be adequate to address all the needs identified. An effective life cycle plan is resilient enough to adapt to the consequences of uncertainties associated with the availability of funding. The alternate strategies that State DOTs adopt can take a number of forms such as:

- Reducing the performance target for a specific portion of the network to be able to meet the needs on high-priority routes.
- Using low-cost preservation treatments in lieu of high-cost rehabilitation treatments, where applicable.
- Considering the conversion of a fraction of a State DOT-maintained network to a toll-based system to increase revenue.

As an example, consider a State DOT that was hit by a significant funding shortfall for maintaining the pavement network in one particular year due to the need to divert funds to other higher priorities (such as hurricane-damaged areas in the State). The State DOT cannot simply continue implementing the investment plan established at the start of the investment period without adjusting it to consider the impacts of postponing or cancelling several projects due to the funding shortfall. Some of the deferred pavement segments may have been candidates for preservation treatments and could have deteriorated to a worse condition where preservation treatments will no longer be effective by the time funding is available. In such situations, the State DOT would re-run the PMS analysis to determine the most suitable treatment options. In some cases, a revision to the fundamental strategy adopted may also be necessary. For instance, in the first few years, the State DOT may adopt an aggressive preservation approach and after the funding shortfall, the State DOT may have to settle for a moderate preservation strategy for a few years. Regularly monitoring the progress and performance of a State DOT's life cycle plans is important so adjustments can be made to account for on-the-ground realities. Some strategies that State DOTs can use to improve the robustness of their LCP plan include:

- Re-run the PMS analysis each year there is a significant deviation from the planned strategy.
- Consider the use of leading performance indicators to monitor and track the adherence to the recommended strategies. An example of one such performance indicator is the Asset Sustainability Index. It is a very simple network-level performance measure expressed as the ratio of the amount budgeted to the total needs determined by the PMS (FHWA

2012). The performance measure is particularly useful when used to monitor specific investment categories (such as maintenance, preservation, rehabilitation, or reconstruction).

- Develop several LCP strategies that are suitable for a wide-range of fiscal situations that a State DOT may face in the future.

Many of the situations that arise happen outside the pavement management environment and it is important to recognize these situations and develop a plan for addressing them. Irrespective of the situations that arise (e.g., change in leadership resulting in significantly different investment priorities, inclement economic conditions, lack of qualified contractors, or material price volatility), one of the most important parameters that impacts the long-term sustainability of a State DOT's pavement network is the development of a sound life cycle plan, continually monitoring it to determine adjustments required, and adhering to the plan established.

Presenting LCP Results

The results of the LCP analysis can be presented in a simple manner that communicates the message effectively to decision makers and drives the need for business process changes (if warranted). Example approaches that have been used by State DOTs are presented in this section.

During the development of its TAMP, the Nevada DOT compared a worst-first strategy to its current strategy (preservation approach) for managing the pavement network over a 60-year analysis period and demonstrated the benefits in terms of the dollars saved in maintaining each lane-mile of the pavement network (see Figure 16). The analysis showed that the preservation approach resulted in an annual savings of approximately $145 million when compared to the worst-first approach.

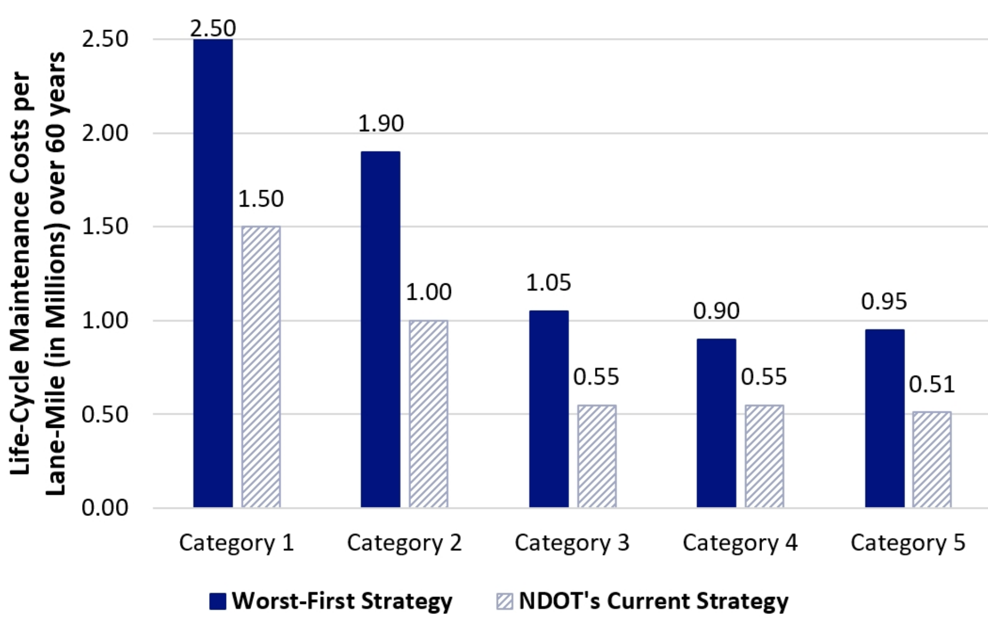


Figure 16. Comparison of the LCP analysis results from the Nevada DOT Initial TAMP (Nevada DOT 2018).

Another State DOT determined that if it persisted with its existing pavement strategies, it would be difficult to continue achieving the established performance targets with the anticipated levels of funding. Hence, an alternate strategy was considered that focused on increasing the use of chip seals on low-traffic-volume pavements. The analysis found that approximately 48 percent of the low-volume pavements were eligible for chip seals using the PMS treatment rules (based on pavement conditions, truck traffic levels, and average daily traffic levels). If 50 percent of the pavements in this category, which were traditionally overlaid, were chip sealed instead, the analysis showed that the annual cost of preserving the network could be reduced by $75M to $121M once a steady state condition had been achieved. These results were sufficient to incentivize the State DOT to develop and implement new business processes that help to ensure the timely and appropriate use of chip seals on eligible pavements. A series of workshops were conducted to help the various districts within the state adopt and implement the new life cycle strategy. Four years after implementing the new LCP strategy, the State DOT has seen pavement performance improve to levels higher than the conditions originally projected by the analysis and cost reductions more than the predicted values.

References

- Federal Highway Administration (FHWA). 1998. *Life Cycle Cost Analysis in Pavement Design. Interim Technical Bulletin*. FHWA-SA-98-079. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2012. *Asset Sustainability Index: A Proposed Measure for Long-Term Performance*. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2017a. *Using a Life Cycle Planning Process to Support Asset Management*. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2017b. *Incorporating Risk Management into Transportation Asset Management Plans*. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2017c. *Developing TAMP Financial Plans*. Federal Highway Administration, Washington, DC.
- Nevada DOT. 2018. *Initial TAMP*. Nevada Department of Transportation, Carson City, NV.

CHAPTER 5: HOW TO CONDUCT NETWORK-LEVEL LCP FOR BRIDGES

Introduction

A network-level LCP for bridges applies the deterioration models, treatment rules, treatment costs and benefits that were discussed in Chapter 3 to the bridge inventory and condition information available in the BMS. The LCP analysis also benefits from the use of the following information:

- System hierarchies (e.g., high-priority routes vs. low-priority routes).
- Changes in system demand that may impact deterioration rates or treatment options.
- Analysis period, inflation rate, and discount rate.
- Expected budget levels for the bridge program.
- Other constraints that influence investment decisions, such as not allowing any bridge to fall below a specified condition.
- Information on desired SOGR and/or existing performance gaps to be addressed.

When conducting an LCP analysis that is focused on achieving the minimum practicable life cycle cost of managing a bridge network, consideration should be given to increasing bridge preservation actions or strategies that reduce deterioration and extend service life. Timing of the treatments within the bridge program should be adjusted when necessary to minimize the life cycle costs.

This chapter introduces a suggested 5-step process for conducting a network-level LCP analysis. It describes the conduct of a comprehensive analysis that follows each of the five steps and provides an example showing how each step in the process can be applied using a BMS.

Step-By-Step Process for Conducting a Network-Level LCP Analysis

This descriptions and figures provided in this section illustrate the use of a process for conducting a network-level LCP analysis for bridges. State DOTs may use other processes that are customized to best suit their specific needs. It is intended to enable State DOTs to develop TAMP investment strategies the consider the results of the LCP analysis as well as the results of financial planning, risk analysis, and performance gap analysis. Background information on using a life cycle planning process to support asset management has been documented elsewhere and is applicable to all assets (FHWA 2017a).

Step 1. Select Asset Classes and Networks

The first step in a network-level LCP analysis is the selection of bridge networks or sub-groups to be included in the analysis. All asset sub-groups must be included in the network-level LCP unless a State DOT demonstrates that excluding one or more asset sub-groups from the life cycle planning process would have minimal effect on the development of investment strategies (23 CFR 515.7(b)). Some factors to consider while defining bridge networks or developing the modeling framework include:

- High-priority structures that have the highest value for the State DOT.
- Bridges that require a significant annual investment to maintain (e.g. border bridges).
- Bridges that are considered to be at risk due to vulnerabilities.

Similar to pavement networks, a bridge network is also generally defined based on attributes such as functional class, jurisdiction, ownership, and traffic. A network classification based on NHS routes within a State for both NHS and non-NHS routes is possible and was provided as an example due to its simplicity. State DOTs have flexibility in how they define the network for LCP purposes and any classification should be aligned with typical practices. State DOTs also have flexibility in selecting the portions of the non-NHS bridge network that they wish to include in the TAMP and analyze using LCP (23 CFR 515.9(l)). The bridge network may be further divided into sub-groups, such as prestressed concrete bridges and steel bridges, to better reflect differences in performance and treatment strategies. The objective of this step is to define bridge groups or networks that are aligned with the way the State DOT manages the bridge network. The classification also gives the flexibility of assigning varying targets for performance measures to different bridge groups.

Example

Table 5 summarizes the basic bridge inventory information that will be used to illustrate the step-by-step procedure to conduct a network-level LCP for bridges in the following sections. The bridge network is composed of 11,000 structures and has a total deck area of 6,400 thousand square meters. The bridge network has been divided into three categories for analysis purposes: (a) Interstates, (b) Non-Interstate NHS bridges, and (c) Non-NHS bridges. The current condition and the desired state of good repair for the three bridge networks are shown in Table 5.

Table 5. Bridge inventory information used to illustrate bridge LCP analysis.

Bridge Network	Percentage Deck Area	Current Conditions (2018)	Desired State of Good Repair
Interstate	30%	90% Good and Fair	97% Good and Fair
Non-Interstate NHS	25%	80% Good and Fair	90% Good and Fair
Non-NHS	45%	75% Good and Fair	85% Good and Fair

The bridge network is further divided into four sub-groups by type of material. The percent deck area by each material within each bridge network is shown in Figure 17. This classification is presented here to emphasize the difference in the deterioration models, treatment alternatives, and treatment rules that would apply to bridge sub-groups. Bridge elements used in a BMS are typically classified by material and most BMS have the functionality to develop models and rules for individual elements. Similar models can be developed and applied for components, but the implementation would depend on the BMS and existing functionality. For the example network, at a minimum, developing performance models and treatment rules for prestressed concrete bridges and steel bridges is needed to conduct an accurate network-level LCP.

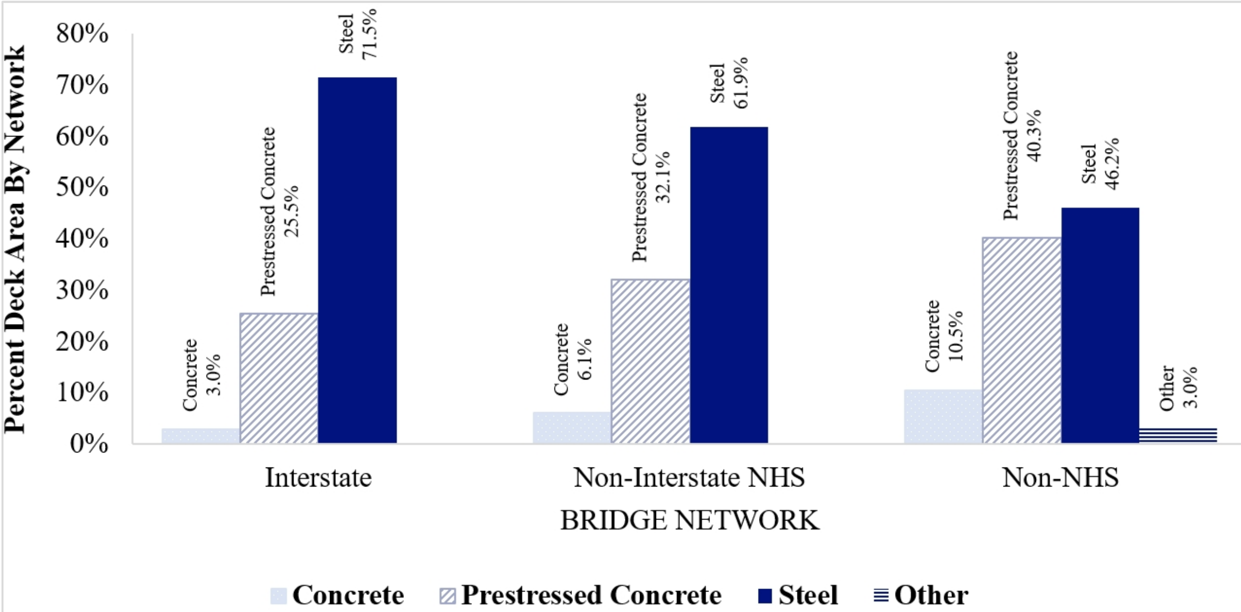


Figure 17. Bridge sub-groups by material.

Step 2. Define LCP Strategies

The second step in the analysis involves the definition of LCP strategies for the bridge network, which involves the establishment of treatment rules. If the bridge network is divided into sub-groups, LCP strategies should be established to suit the characteristics and functions of each sub-group. LCP strategies should consider deterioration models, treatment costs, and condition/ utility improvement benefits, as well as the factors that influence treatment type, timing, and priority. For example, if some treatments are not applied on bridges that are in low traffic corridors, treatment rules should be established to reflect this practice. When available, historic treatment data can be analyzed to determine recommended conditions for condition-based treatments or recommended intervals for cyclical treatments. In the absence of historical treatment data, expert judgement or industry standards may be used.

Example

For the example introduced in *Step 1*, the following three LCP strategies have been defined, as summarized in Table 6:

- **Current Strategy**: Reflects the agency's current strategies for bridge life cycle management. This strategy prioritizes treatments that address structural defects in bridges in *Poor* condition by deck, superstructure, and bridge replacements. Use of preservation treatments is minimal. Different strategies are followed by NHS and non-NHS bridges. For selected conditions and non-NHS bridges the State DOT does not have treatment rules. These are noted with a "Do Nothing" option. For example, in the current strategy, preservation treatments are selected for NHS bridges in *Good* condition but not for non-NHS bridges in *Good* condition.
- **Moderate Preservation**: Gives equal priority to preservation and replacement treatments. Includes a variety of cyclical and condition-based maintenance activities that extend the time assets are in *Good* or *Fair* condition, while focusing on replacement activities for the assets in *Poor* condition.

- **Aggressive Preservation:** Prioritizes treatments that extend the service lives of bridges in *Good* or *Fair* condition with an extensive list of preservation treatments. Treatments for *Poor* bridges include repairs when possible in addition to more costly replacement treatments. The strategy focuses on treating more bridges in the network with less cost per treatment.

Table 6. Example LCP strategies for bridges.

Bridge Condition	Current Strategy	Moderate Preservation	Aggressive Preservation
Good	Do Nothing* Preservation/ Cyclical Maintenance • Thin Polymer Overlay • Patch Deck	Do Nothing* Preservation/ Cyclical Maintenance • Clean/Wash Bridge • Paint Steel Bridge (Full) • Thin Polymer Overlay • Patch Deck	Preservation/ Cyclical Maintenance • Clean/Wash Bridge • Paint Steel Bridge (Full, Zone, Spot) • Clean/Repair/Rehab/Replace Joints • Seal Decks • Thin Polymer Overlay • Polymer-Modified Asphalt Overlay • Scour Countermeasures • Channel Improvements
Fair	Do Nothing* Preservation/ Condition-Based Maintenance • Shallow Concrete Overlay	Do Nothing* Preservation/ Condition-Based Maintenance • Shallow Concrete Overlay • Asphalt Overlay w/Membrane • Replace Deck • Repair Superstructure	Preservation/ Condition-Based Maintenance • Shallow Concrete Overlay • Asphalt Overlay w/Membrane • Repair/Rehab Deck • Replace Deck • Repair/Rehab Superstructure • Repair/Rehab Substructure
Poor	Replacement • Replace Deck • Replace Superstructure • Replace Bridge	Rehabilitation and Replacement • Deep Concrete Overlay • Asphalt Overlay w/Membrane • Replace Deck • Replace Superstructure • Replace Bridge	Rehabilitation and Replacement • Deep Concrete Overlay • Asphalt Overlay w/Membrane • Repair/Rehab Superstructure • Repair/Rehab Substructure • Replace Deck • Replace Superstructure • Replace Substructure • Replace Bridge

Example Treatment Costs: Deep concrete overlay: $50/sq. ft., deck replacement: $80/sq. ft., bridge replacement: $325/sq. ft., superstructure repair $1500/beam end.

* Option for Non-NHS

These strategies are then programmed into the BMS. One approach to analyzing the effect of different treatment strategies is programming them into the BMS using different treatment rules/ decision trees. The resulting improvements in the bridge condition and other performance measures (e.g. reduced risk, decelerated deterioration) and the deterioration models associated with the treatments are also programmed into the BMS based on the configuration of the tool. There are other approaches including programming the BMS with a full complement of treatments that address all elements and treatment types that significantly affect bridge service life and cost, and varying the strategy by altering the weights or budgets applied to work that improves immediate condition versus work that reduces LCC. There may be other techniques for programming alternative strategies in a BMS.

To illustrate the general process for developing LCP strategies, a simplified approach is demonstrated in this example. State DOTs typically make use of more complex treatment rules/decision trees based on a number of bridge performance measures (such as traffic volume, element or component deficiencies, existing risks or vulnerabilities) in order to determine the most appropriate treatment.

In the example shown in Table 6, different LCP strategies have been established for the NHS and Non-NHS networks. State DOTs may also consider developing separate LCP strategies for the prominent bridge sub-groups as illustrated in Figure 17. The BMS framework might have the functionality to address these different strategies by its analytical framework and existing bridge, component, or element classifications. State DOTs should investigate the preferred way of programming different LCP strategies in a BMS using relevant functionalities.

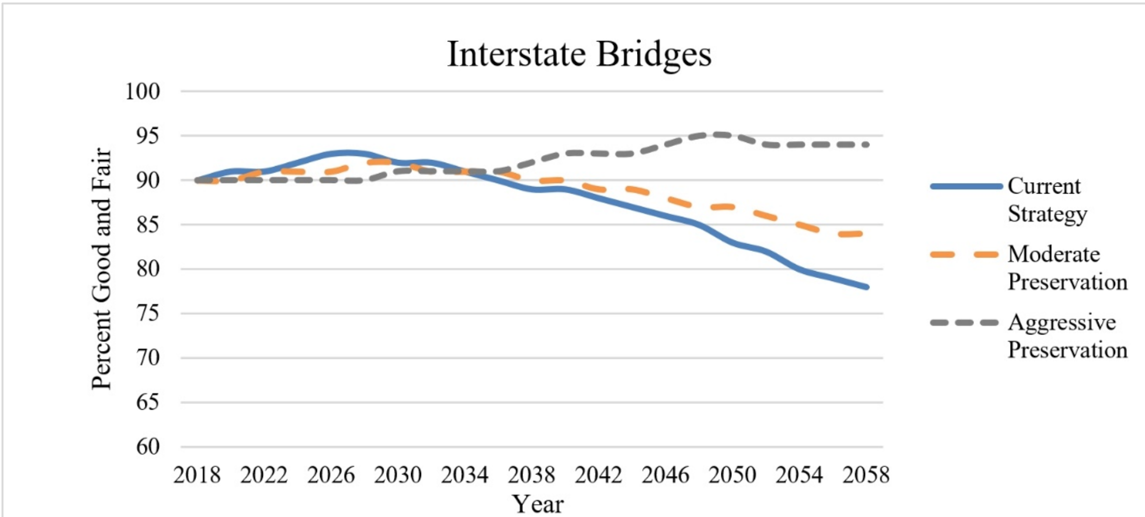
Once the LCP strategies have been defined, the impact of these strategies over the long-term (≥70 years) using an average annual budget based on historical annual investment in bridges is investigated. Alternative budgets and their impacts on the network over the long-term should also be investigated. The results of the three LCP strategies analyzed are shown in Figures 18 and 19 for the next 40 years for brevity of presentation. The percentage of Interstate, Non-Interstate NHS and Non-NHS bridges in *Good* and *Fair* condition for each strategy are shown in Figure 18. The life-cycle cost utility value of Interstate bridges, as discussed in Chapter 3, is shown for each strategy in Figure 19. The condition and LCC graphs can be used individually or combined using utility functions when a multi-objective optimization framework is used.

The following observations can be made from Figures 18 and 19:

- The *Current Strategy* will improve network condition for a short period but result in steeply declining bridge conditions over the next 40 years. This strategy has the lowest network-level LCC utility or greatest LCC. The LCC utility gradually declines as LCC increases and condition declines requiring more expensive work. The LCC utility curve is lower than all other LCC utility curves because it represents the strategy that has highest LCC.
- The *Moderate Preservation* strategy will result in modest improvements in the bridge conditions in the first ten years of the planning period; however, it will lead to declining bridge conditions over the long-term due to insufficient preservation work. LCC utility will gradually decline as LCC increases and condition declines requiring more expensive work.
- Implementation of the *Aggressive Preservation* strategy will initially improve bridge condition at a slower rate compared to the other strategies; however, it will improve bridge conditions steadily in the first twenty years of the analysis and keep the condition stable afterwards. This strategy has the highest network-level LCC utility or least LCC. The LCC

utility is relatively consistent in time. It improves slightly as condition improves but does not substantially improve for the level of funding because some work is left unfunded.

a)



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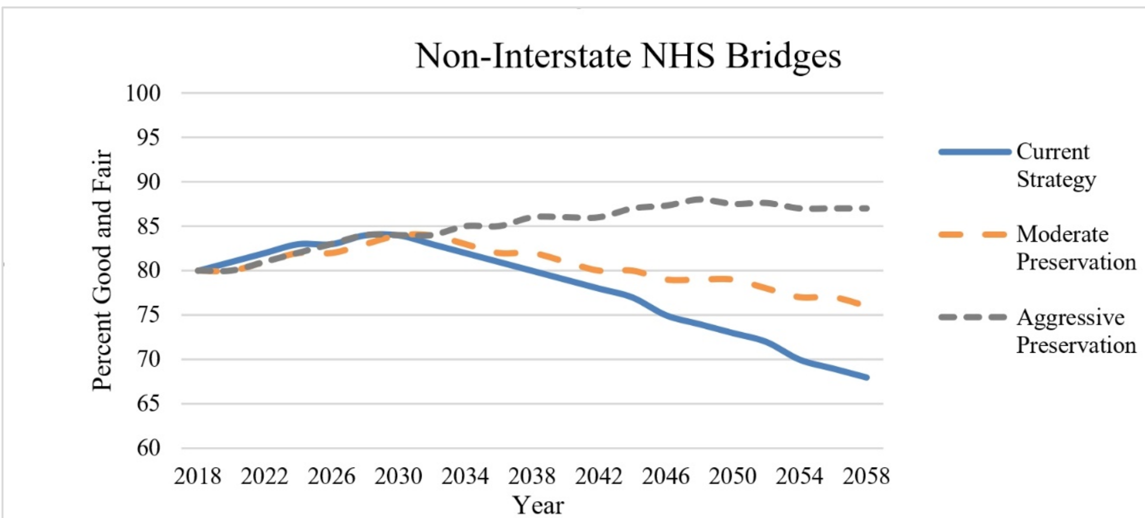

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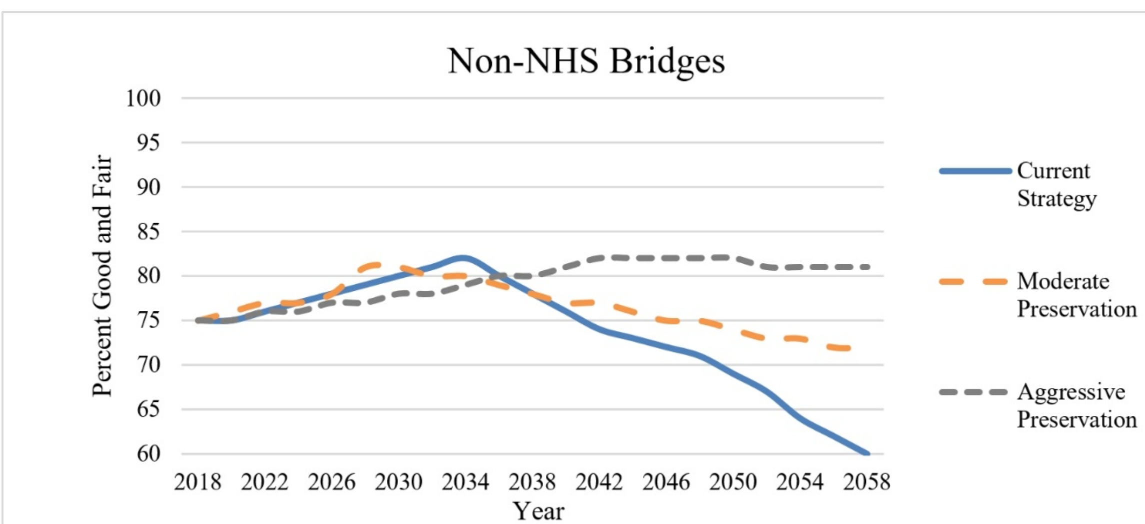

Figure 18. Impact of the three LCP strategies (based on average historical budgets).

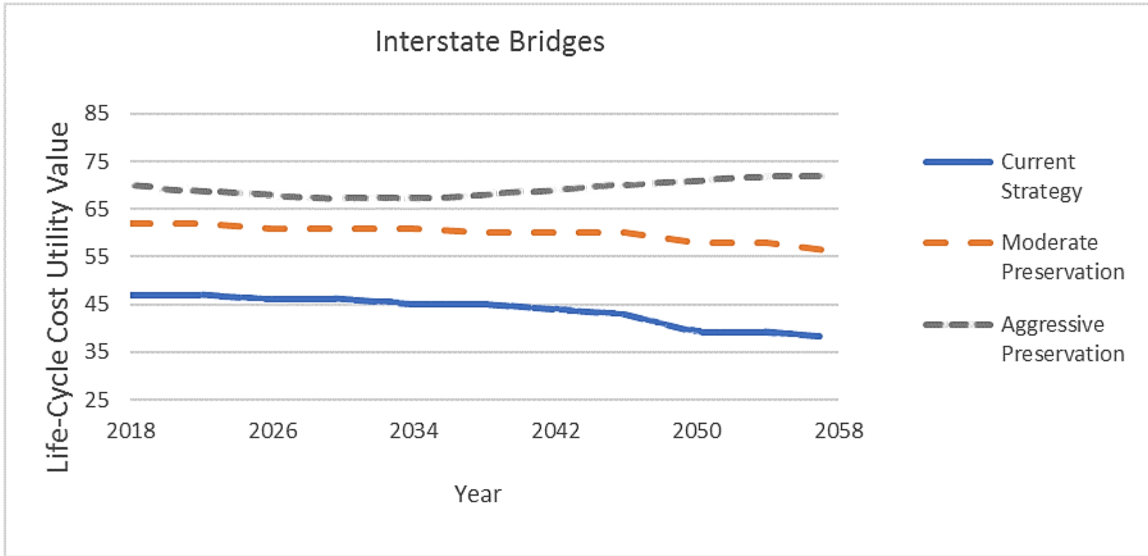

Figure 19. Interstate bridges LCC utility impact of three LCP strategies (based on historical average budgets).

Step 3. Set LCP Scenario Inputs

In this step, the LCP scenario inputs that will be used in Step 4 are defined by the agency. Similar to pavement LCP scenario inputs, these include establishing the analysis period to be used, desired SOGR, risks, performance gaps, anticipated funding levels (which may come from financial planning), and any constraints or requirements, such as minimum bridge conditions.

The primary inputs to an LCP scenario are summarized below:

- **Current Conditions**: Provides a starting point for the analysis and presents current bridge conditions by asset classes or sub-groups as defined.
- **Analysis Period**: Establishes the timeframe that will be considered for the LCP analysis. The analysis period used for bridge LCP might be longer than that of the pavement LCP because the benefits of preservation strategies are realized over longer analysis periods.
- **Discount and Inflation Rates**: Establishes the discount and inflation rates used in the LCP analysis to consider time value of money.
- **Annual Funding**: Determines various budget constraints being analyzed for each year of the analysis.
- **Treatment Definitions**: Describes the types of treatments that will be considered in the LCP analysis, organized by bridge sub-groups as necessary. Treatments are grouped into a small number of categories that sufficiently group the treatments in order to simplify the analysis.
- **Treatment Costs**: Provides the cost numbers for defined treatments.
- **Strategy Rules and Details**: Establishes the conditions under which treatments are appropriate to apply and the basis for prioritization between treatments when funding is insufficient to address all appropriate treatments.

- **Risks**: Recognizes the high-priority risks identified as a part of the risk management analysis efforts during the development of the TAMP. For bridges, this may include changes to future maintenance and rehabilitation cycles that may result from variations in climatic conditions such as extreme temperatures or other site-specific conditions such as an anticipated increase in heavy truck traffic loads after a certain number of years due to planned development in certain areas.
- **Deterioration Models:** Presents impacts of LCP strategies on bridge conditions or other selected performance measures and identifies when treatments are recommended based on strategy rules.

Example

For the example LCP analysis defined in Steps 1 and 2, Table 7 summarizes the LCP scenario inputs.

Table 7. LCP Scenario inputs for the example LCP analysis.

Item	LCP Scenario Inputs
Current Conditions	• Interstate bridges: 90% Fair and Good • Non-Interstate NHS bridges: 80% Fair and Good • Non-NHS Bridges: 75% Fair and Good
Desired SOGR	• Interstate bridges: 97% Fair and Good • Non-Interstate NHS bridges:90% Fair and Good • Non-NHS Bridges: 85% Fair and Good
Analysis Period	• 70 years, but results are shown for 40 years
Discount Rate	• 3%
LCP Strategies	• See Table 6
Performance Curves for LCP Strategies	• See Figure 18
Annual Funding (for entire bridge network)	• $100 million per year (pessimistic scenario) • $150 million per year (reduced funding levels) • $180 million per year (expected annual funding) • $210 million per year (optimistic scenario)

Step 4. Develop LCP Scenario

Step 4 involves the development of LCP scenarios using the strategies defined in Step 2 and the inputs from Step 3. Based on the findings from scenario development, redefined LCP strategies might be developed to address new inputs impacting available funding or State DOT priorities. The development of LCP scenarios will help the State DOT address the following key questions for the bridge network:

- Has the State DOT met or exceeded minimum performance requirements?
- What level of funding is needed to achieve the desired SOGR?
- What condition levels can be achieved at different funding levels?
- Is there a more cost-effective strategy to preserve the bridge network conditions?
- Does the scenario address risks and other constraints the State DOT is currently experiencing or expected to experience in the future?
- If funding is not adequate to meet the desired SOGR, what condition level can be achieved for the available funding?

Incorporating Risks

The FHWA guidance on risk management[4] provides a discussion on identifying and managing high-priority risks, including those associated with extreme weather and geologic events (FHWA 2017b). These risks can potentially influence the LCP strategies (Step 2) and LCP scenario inputs (Step 3) for all asset classes. The impacts of these risks should be considered for the bridge network while developing the LCP scenarios in Step 4.

For example, if seismic vulnerabilities have been identified in a few high-priority Interstate routes, significant investments in seismic retrofit activities might be required to restore their structural integrity. Similarly, if a State DOT has scour-vulnerable structures along major rivers and has also been experiencing more frequent or stronger floods, a significant investment may be needed for scour countermeasures or bridge replacements. Addressing such risks in the bridge program changes the resource allocation and the LCP scenarios may be redefined accordingly. Network-level LCP analysis is iterative in nature; therefore, steps 2-4 may be revisited several times to reach the results that satisfy the State DOT's vision, goals, and limitations.

Other Considerations

The State DOT may also decide to investigate other LCP Scenarios (such as funding needs to meet minimum performance requirements, prioritizing Interstate bridges, addressing functional issues and widening projects, maintaining current conditions or informing cross asset allocation) before putting forth recommendations for the development of the financial plan and investment strategies. The LCP scenarios should sufficiently cover probable strategies that a State DOT may need to assess in long-term plans.

[4] FHWA. 2017. *Incorporating Risk Management into Transportation Asset Management Plans*. https://www.fhwa.dot.gov/asset/pubs/incorporating_rm.pdf

Consideration of risks, performance gaps, and other situations (such as partitioning bridge networks based on sources of funding or including performance measures that impact the overall transportation system beyond bridges) are key factors in developing a well-rounded LCP strategy.

The financial planning process should consider historical trends in maintenance expenditures and the budgets for LCP scenarios should be adjusted to account for routine maintenance investment needs if routine maintenance is not programmed using the BMS explicitly.

Example

Figures 20 through 22 illustrate the results of applying the three LCP strategies (defined in Step 2) to the four LCP scenarios summarized below. The funding levels are limited to four in the example for the sake of presentation; however, a more complete set of funding levels (e.g. in $10M increments) is suggested for investigating a more complete set of funding levels.

- **Expected Annual Funding Levels**: This scenario represents the annual funding levels expected over the next 40 years ($180 million per year).
- **Reduced Annual Funding**: This scenario represents a 17 percent reduction in the expected funding levels ($150 million per year).
- **Optimistic Scenario**: This scenario represents a 17 percent increase in the expected funding levels ($210 million per year).
- **Pessimistic Scenario**: This scenario represents a significant reduction (~45%) in expected annual funding ($100 million per year).

Based on the LCP Scenario outputs (shown in Figures 20, 21, and 22), the agency would likely choose to adopt the *Aggressive Preservation Strategy* to meet its desired SOGR by year 2048 with an increased yearly funding level of $210 million per year. The *Aggressive Preservation Strategy* is also the strategy that has the highest LCC utility and therefore has the lowest LCC (Figure 23). When selecting and programming projects, if the agency uses both condition and LCC benefits, or LCC benefits alone, forecasted condition may be higher or lower than the condition graphs. This effect should be considered when selecting a budget and condition-based goals.

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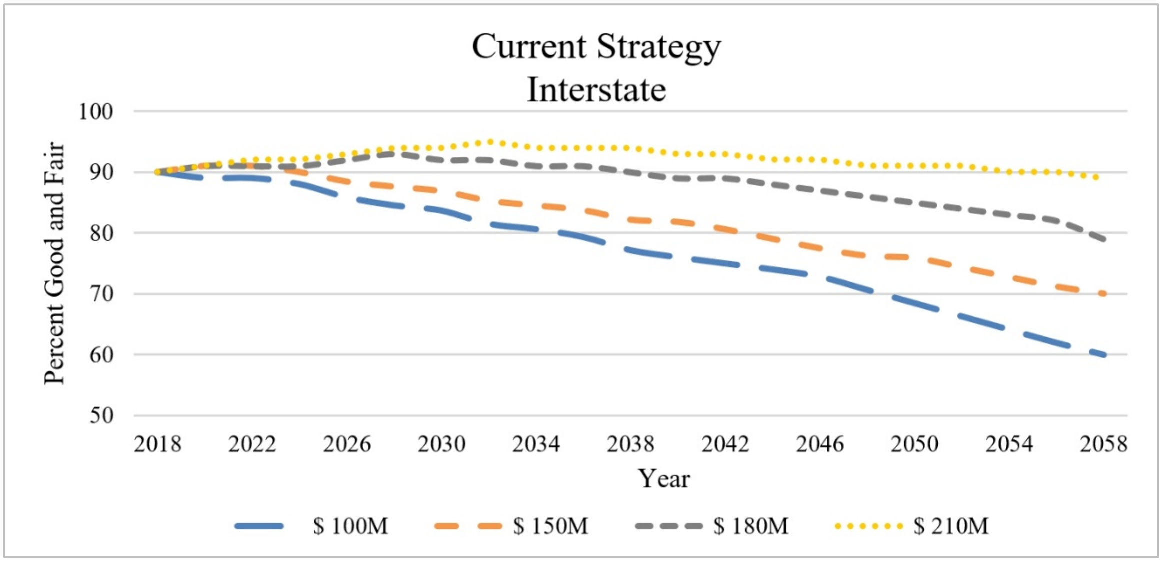

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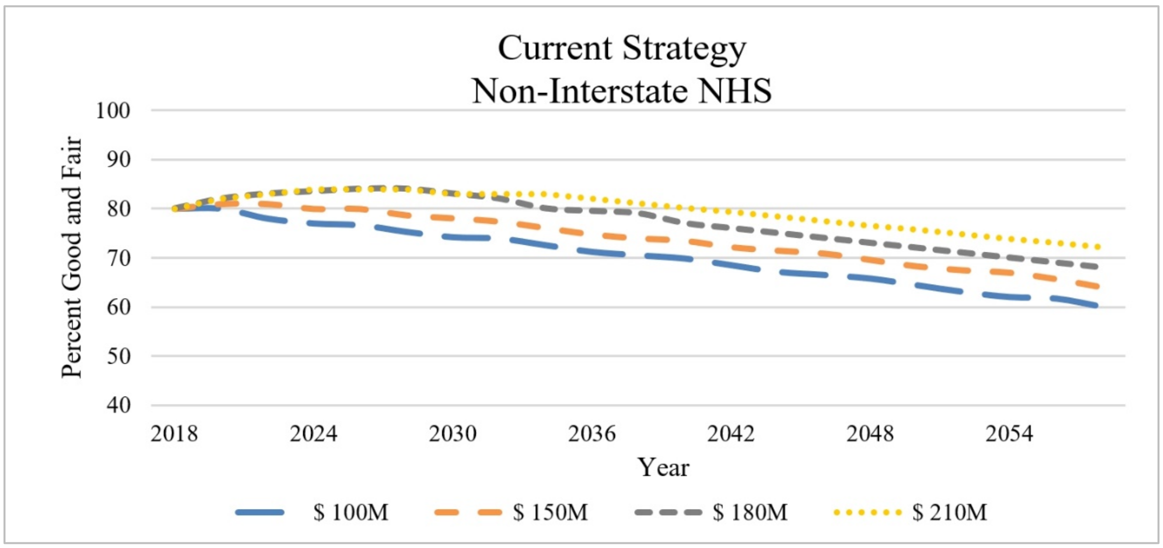

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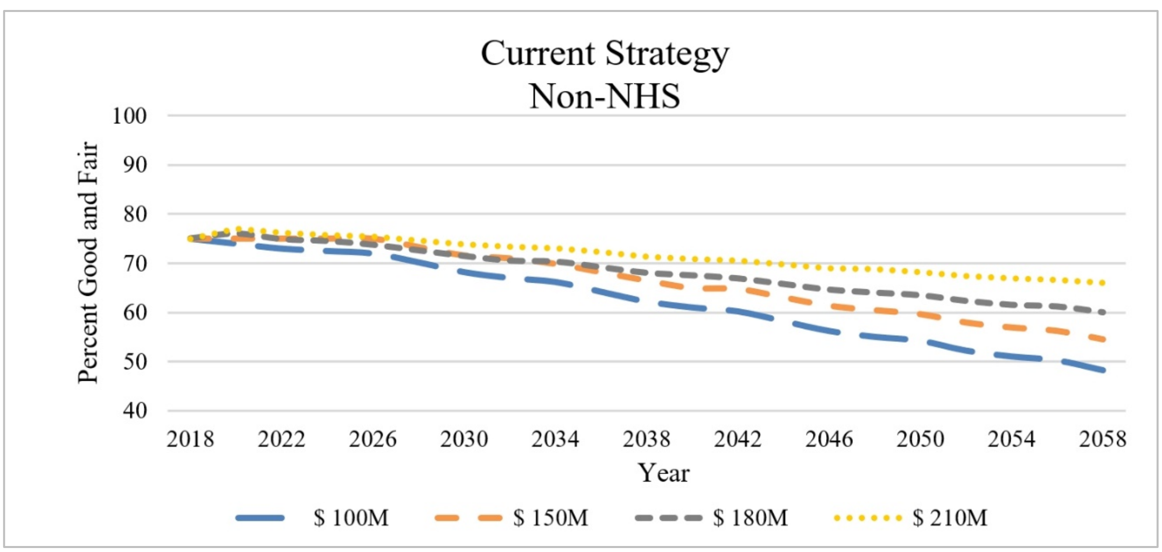


Figure 20. Results of applying the *Current Strategy* to the four LCP scenarios.

a)

b)

c)

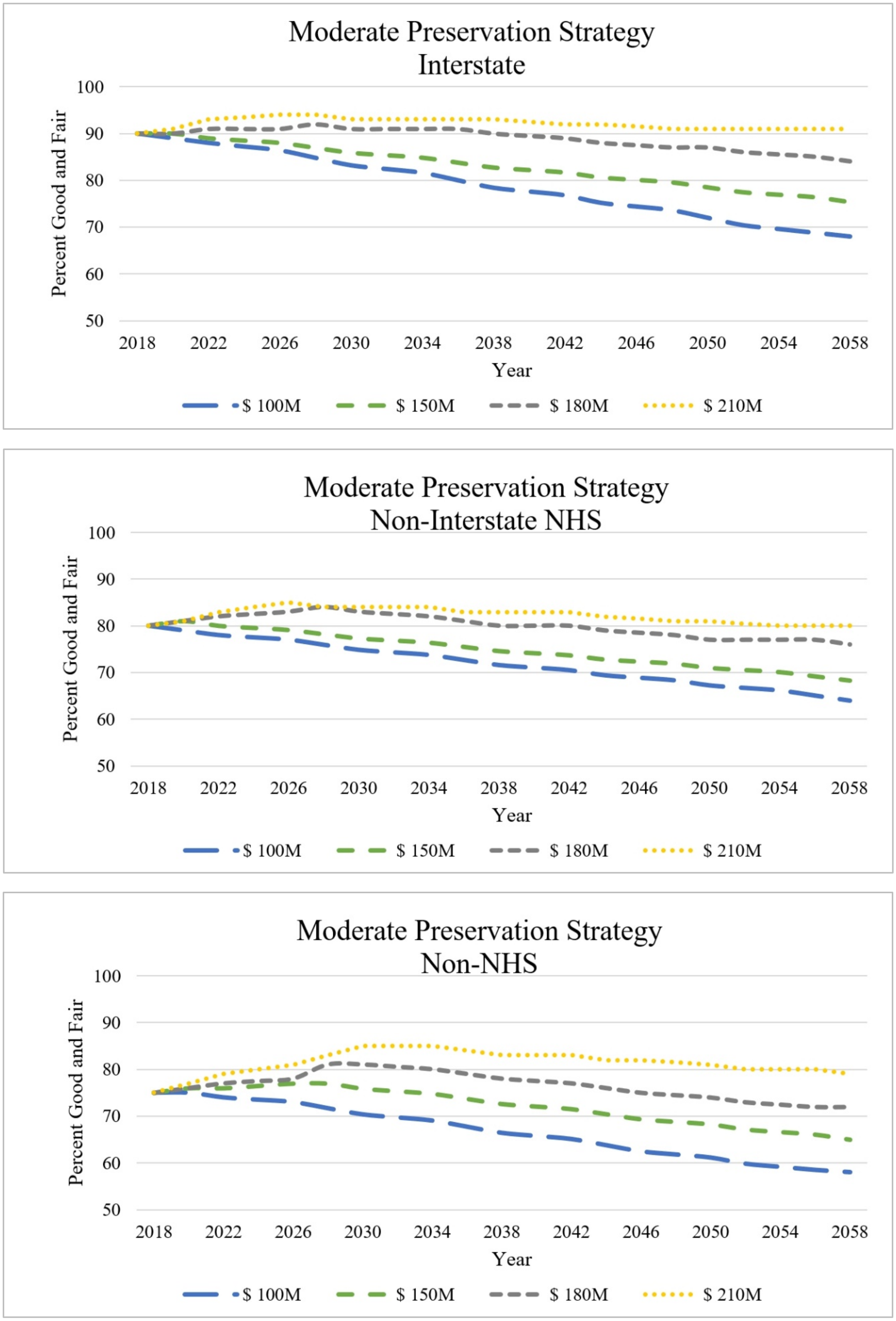
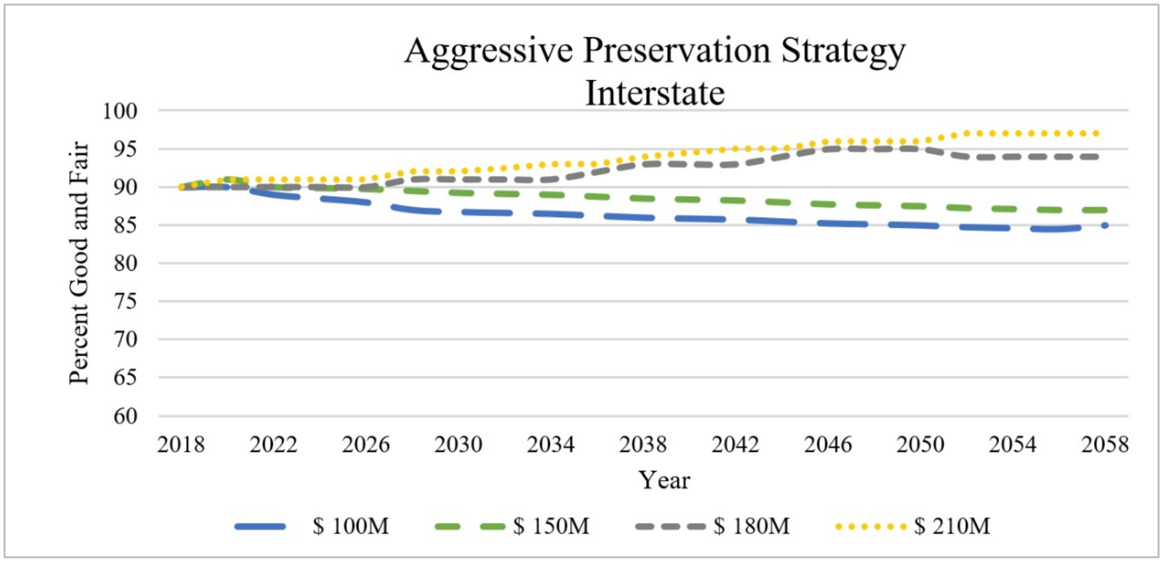


Figure 21. Results of applying the *Moderate Preservation Strategy* to the four LCP scenarios.

a)



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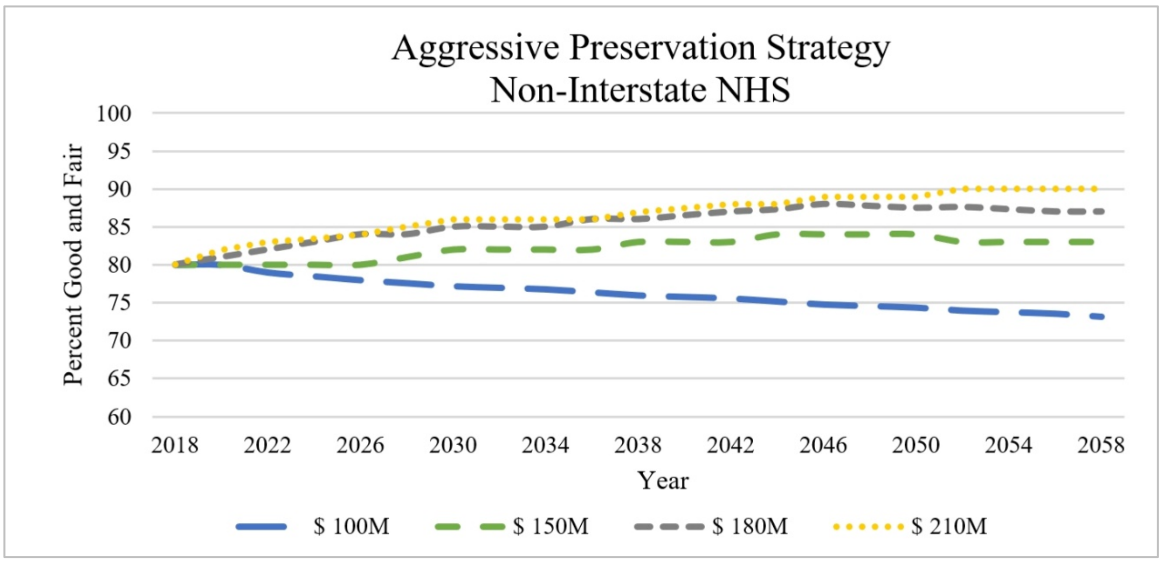

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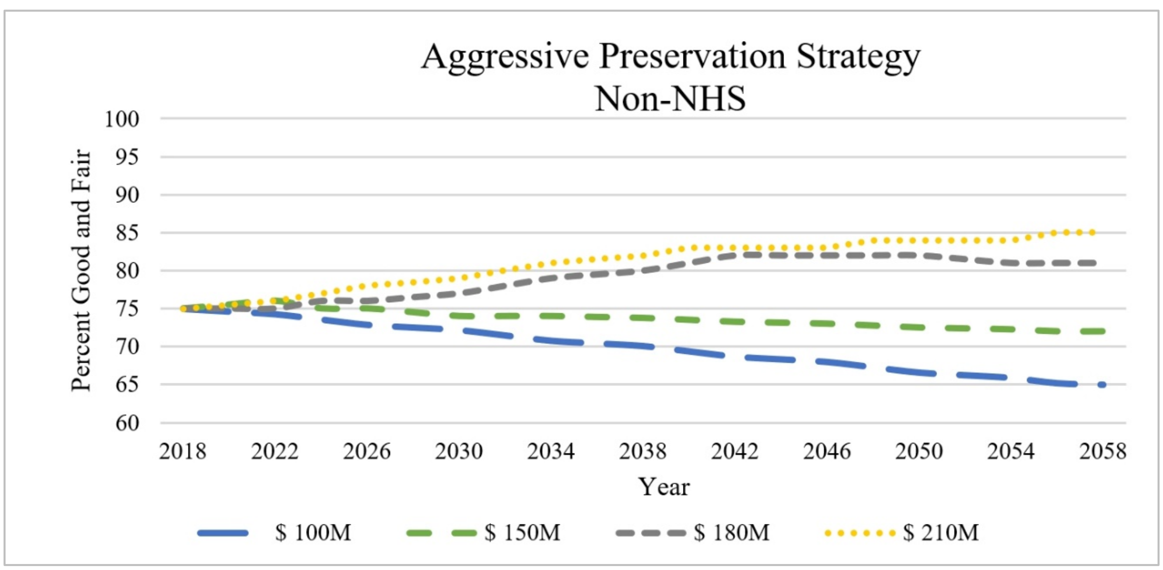

Figure 22. Results of applying the *Aggressive Preservation Strategy* to the four LCP scenarios.

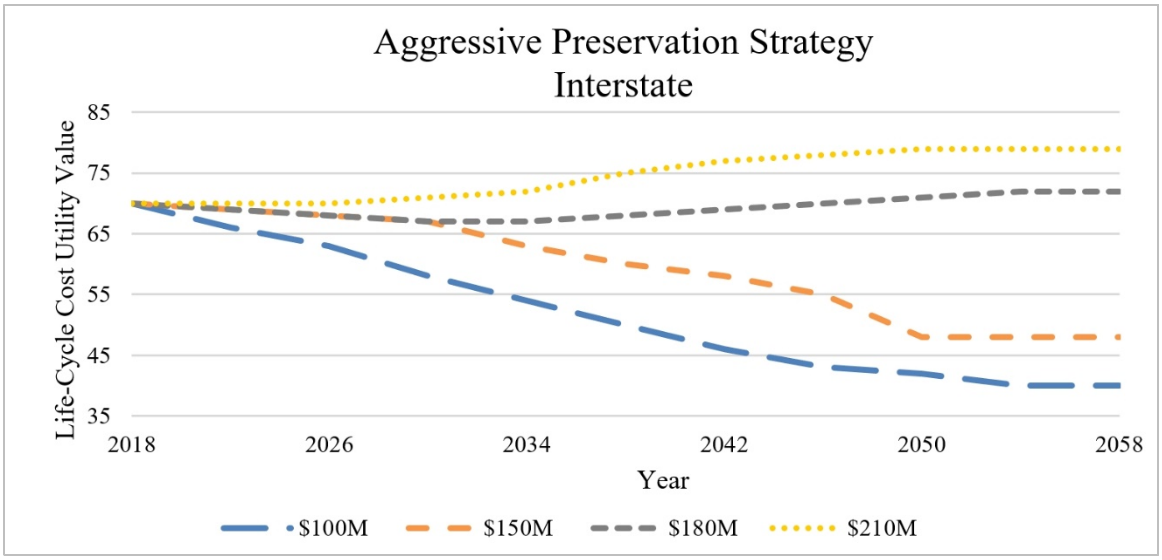

Figure 23. Interstate bridges LCC utility results of applying the *Aggressive Preservation Strategy* to the four LCP scenarios.

Step 5. Provide Input to Financial Planning

The findings from the LCP scenarios developed in Step 4 serve as inputs to the financial planning process, along with the results of the risk and performance gap analyses. The impacts of each LCP scenario on the bridge network at the end of the analysis period should be assessed and summarized for the decision makers to provide the information that they need to consider for investment planning and trade-off analysis. Both short-term and long-term results should be presented to give decision makers the information to evaluate relevant implications and adjust the performance targets and the desired SOGR as needed.

Example

For the example discussed in Steps 1 through 4, illustrations like Figures 24 and 25 may be developed to guide the financial planning process. Figures 24 and 25 show the resulting bridge conditions in 2028 (10 years) and 2058 (40 years) for the various funding levels if the *Aggressive Preservation Strategy* is adopted.

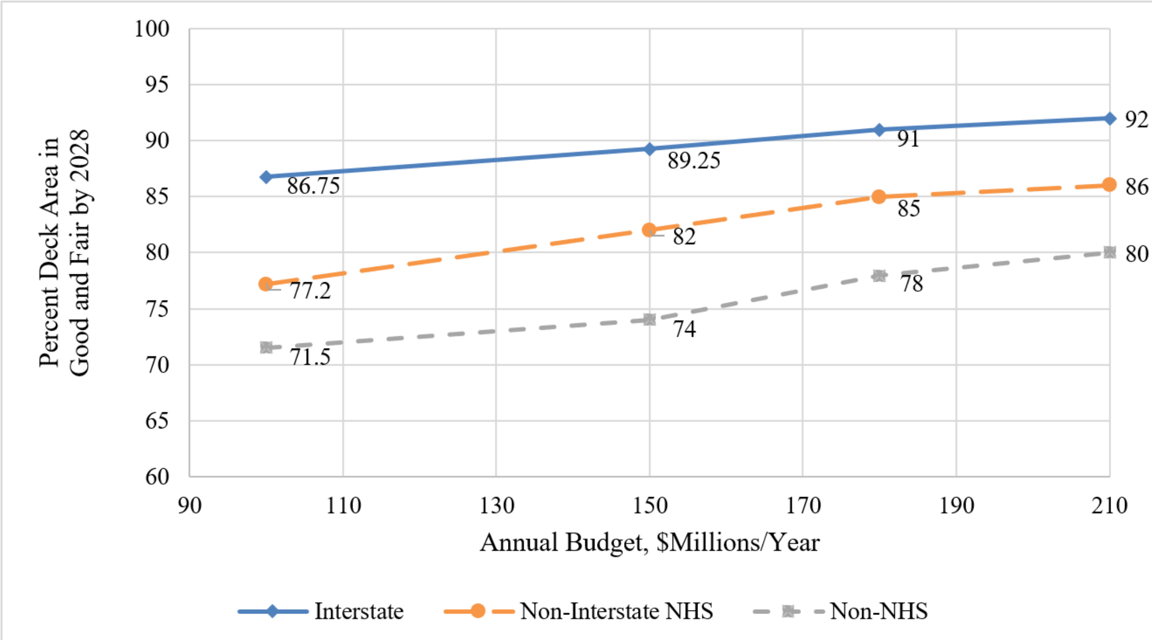

Figure 24. Bridge condition in 2028 vs. annual budget level (for the *Aggressive Preservation Strategy*).

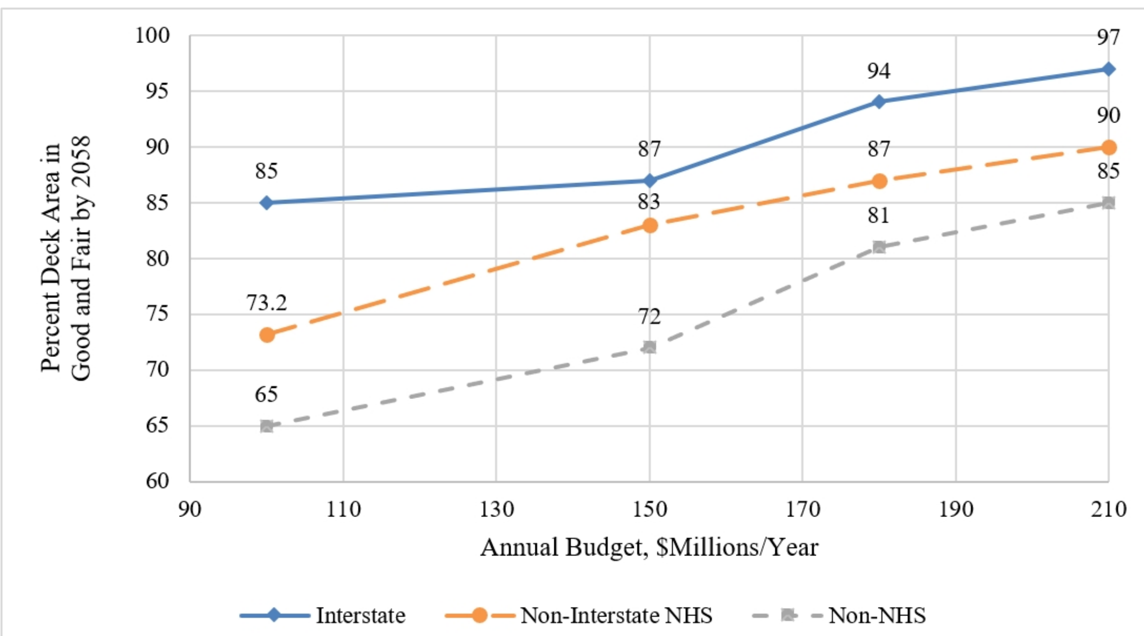

Figure 25. Bridge condition in 2058 vs. annual budget level (for the *Aggressive Preservation Strategy*).

In the example shown, the LCP scenario based on a $210 million annual budget (which represents the optimistic annual funding level) yields the following results if the *Aggressive Preservation Strategy* is adopted:

- By Year 2028
  - 92 percent of Interstate bridges in Good and Fair condition.
  - 86 percent of the Non-Interstate NHS bridges in Good and Fair condition.
  - 80 percent of the Non-NHS bridges in Good and Fair condition.
- By Year 2058
  - 97 percent of Interstate bridges in Good and Fair condition.
  - 90 percent of the Non-Interstate NHS bridges in Good and Fair condition.
  - 85 percent of the Non-NHS bridges in Good and Fair condition.

During the financial planning process, the decision makers can make use of graphics like those presented in Figures 24 and 25 to evaluate the impact of other funding scenarios and develop a desired SOGR based on the varying levels of funding for the bridge program. These graphs can also be used in conducting trade-off analyses, and cross-asset assessments. Based on the State DOT discussions and annual funding levels proposed during the financial planning process, the revised budgets are be used to redefine the LCP scenarios in Step 4 and re-run the analysis.

Presenting LCP Results

During the development of its TAMP, the Michigan DOT compared the current bridge strategy to their condition goal of 95 percent of deck area in *Good* or *Fair* condition. The graph presented as Figure 26 shows that after 2022, bridge conditions start deteriorating due to insufficient levels of funding. It illustrates the increasing gap between the State DOT's goal and bridge network performance over the planning period if the budget is not increased.

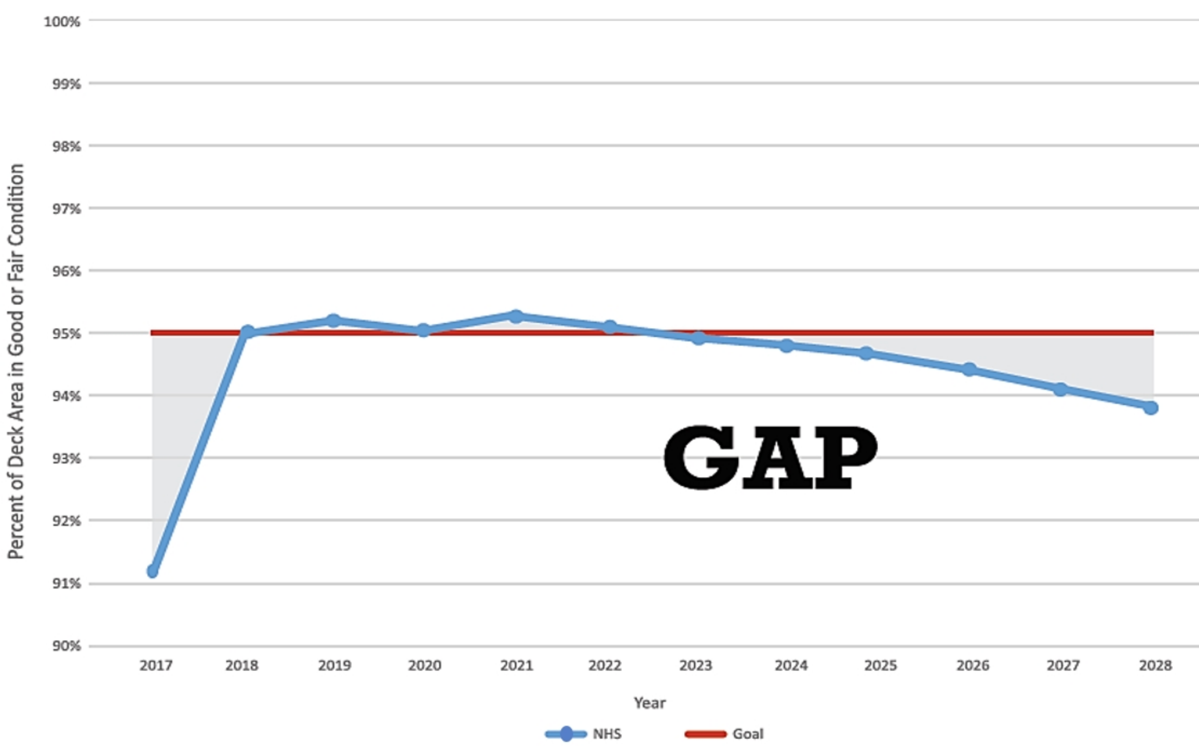

Figure 26. Comparison of the LCP analysis results with the target for the Michigan DOT (MDOT 2018).

The California DOT presented the impact of increased annual funding on pavement and bridge conditions by presenting percent *Good, Fair* and *Poor* values with pie charts, as shown in Figure 27. Another way of presenting the change in conditions is presented in Figure 28.

Current Funding

NHS Assets	Annual Funding ($M)	Good	Fair	Poor
Pavements				
Interstate (lane miles)	**$386**	**40.7%**	**47.5%**	**11.8%**
Non-Interstate NHS (lane miles)	**$632**	**22.0%**	**63.1%**	**14.9%**
On the SHS	$533	37.8%	46.9%	15.3%
Off the SHS	$99	3.9%	81.7%	14.4%
Bridges				
NHS (deck area)	**$431**	**77.8%**	**18.6%**	**3.5%**
On the SHS	$338	81.2%	16.1%	2.7%
Off the SHS	$93	47.6%	41.2%	11.2%

Expected Funding

NHS Assets	Annual Funding ($M)	Good	Fair	Poor
Pavements				
Interstate (lane miles)	**$751**	**60.0%**	**39.0%**	**1.0%**
Non-Interstate NHS (lane miles)	**$1,161**	**34.0%**	**60.8%**	**5.2%**
On the SHS	$995	57.6%	40.9%	1.5%
Off the SHS	$167	6.7%	83.8%	9.5%
Bridges				
NHS (deck area)	**$707**	**80.4%**	**17.5%**	**2.1%**
On the SHS	$566	83.5%	15.0%	1.5%
Off the SHS	$141	52.1%	40.3%	7.6%

Figure 27. Example showing a way to communicate LCP results (Caltrans 2018).

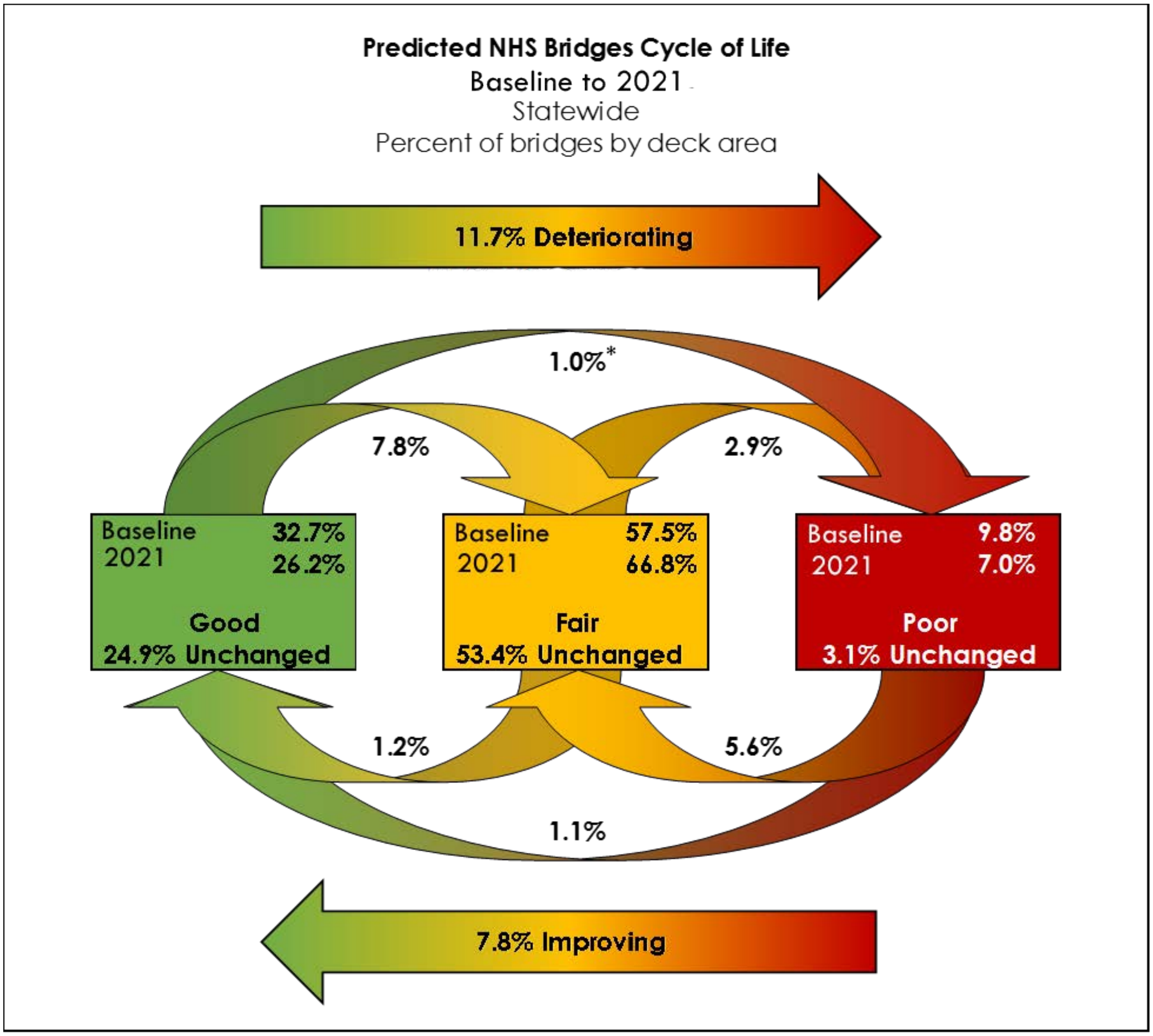

Figure 28. Example showing changes in bridge conditions over time (Van Zee 2018).

References

- California Department of Transportation (Caltrans) 2018. *California Transportation Asset Management Plan*. Fiscal Years 2017/18-2026-27. Caltrans, Sacramento, CA.
- Federal Highway Administration (FHWA). 2017a. *Using a Life Cycle Planning Process to Support Asset Management*. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2017b. *Incorporating Risk Management into Transportation Asset Management Plans*. Federal Highway Administration, Washington, DC.
- Federal Highway Administration (FHWA). 2017c. *Developing TAMP Financial Plans*. Federal Highway Administration, Washington, DC.
- Michigan DOT 2018. *Initial Transportation Asset Management Plan Certified July 2018*.
- Van Zee, E. 2018. "Integrating Bridge Preservation into your TAMP." *Proceeding of the 2018 National Bridge Preservation Partnership Conference.*

CHAPTER 6: TIPS FOR A SUCCESSFUL LCP ANALYSIS

Introduction

The ultimate success of an LCP analysis can be measured by the degree to which the recommended strategies are reflected in a transportation agency's program and incorporated into funding allocation decisions. This chapter highlights several factors that are especially important to ensure the success of an LCP and the likelihood that the analysis results can be used successfully to support investment decisions.

Important Considerations

The considerations discussed in this section represent typical issues that arise during the LCP process.

Capturing Maintenance and Capital Costs

Maintaining an asset over its life cycle entails the application of different types of interventions depending on the type and amount of deterioration present. A typical life cycle strategy considers low-cost maintenance and preservation treatments while an asset is still in relatively good condition, as well as rehabilitation and reconstruction activities as an asset approaches the end of its service life.

For some State DOTs, the incorporation of the full range of treatments in a life cycle analysis poses challenges for several reasons. First, there may be differences between treatments in terms of funding, with some treatments classified as capital improvements and others considered to be maintenance. This differentiation may influence who performs the work (inhouse staff versus contractors), whether the treatment must first go through a design phase, and whether there may be restrictions associated with funding sources.

A second challenge occurs with capturing maintenance treatments in a way that can be used by a pavement or bridge management system. Maintenance treatments are often tracked along a stretch of highway (such as crack sealing was done on Highway 69 between mileposts 3 and 25), which makes it difficult to correlate to existing pavement management systems. An additional challenge is that often business processes have not been established to ensure that maintenance work conducted by inhouse personnel is reported back to pavement management for use in performance modeling.

Even if these reporting challenges are overcome, some State DOTs have found it difficult to model the performance of certain types of maintenance and preservation treatments because the condition is very dependent on conditions immediately prior to application. Without sophisticated modeling tools available, it can be difficult for State DOTs to model differences in the use of a preventive maintenance treatment that is applied as a preservation action and the same treatment used as more of a stop-gap measure intended to buy time before a more substantial treatment is applied.

Over time, as technology and improved data analysis systems become more common in State DOTs, it is likely that many of these challenges will be overcome so that both maintenance and capital improvements are considered in an LCP analysis.

Determining Treatment Effectiveness

Another important component of an LCP analysis is the ability to predict the performance of each of the various treatment options, so the cost-effectiveness of an LCP strategy can be estimated and evaluated. For the reasons discussed in the previous example, this can be a challenge if business processes are not established to ensure that the data used by the pavement or bridge management system is current.

A compounding issue for bridge management is the transition from evaluating treatment needs based on a composite index, such as the National Bridge Inventory (NBI) rating, to element-level ratings. This shift forces State DOTs to ensure that their analysis models include impact rules that describe, for each possible treatment, the effectiveness of the action at the element level. Initially, these models may be developed based largely on expert judgement, but over time, a State DOT should be able to use historical conditions to improve its models to better reflect actual performance trends.

Implementing Results

The 10-year investment strategies included in an agency's TAMP should reflect the results of the LCP. Similarly, a State DOT's multi-year improvement program should demonstrate that the investment strategies outlined in the TAMP have been implemented (as required under 23 CFR 515.13). This alignment helps ensure that a State DOT's investments reflect sound, long-term investments that help to reduce the annual cost of system preservation.

In some State DOTs, the implementation of selected LCP strategies might lead to changes in existing business processes to ensure that field decisions reflect State DOT investment priorities. For instance, some State DOTs have established more collaborative processes to build district work plans to ensure the right mix of treatments. Other State DOTs have established processes that require district programs to "match" a certain percentage of recommendations from a pavement management system to ensure alignment.

Frequently Asked Questions About LCP

There are many other important considerations that should be considered for a successful LCP. Several frequently asked questions that help highlight these points are featured below.

Is it important to analyze performance over a period that is longer than the 10-year period covered in the TAMP?

Yes, especially for assets with long lives, like bridges. In many instances, the long-term impacts of different LCP strategies are not evident over a relatively short 5- to 10-year window. For that reason, it is important that longer analysis periods are considered. For example, an analysis period for pavements might look 20-40 years into the future and a bridge analysis may evaluate impacts over a 70- to 100-year period. It may also be important to consider the asset condition (value) at the end of the analysis period, especially when shorter analysis periods are used to fully capture an asset's remaining life.

How reliable are deterioration models when considering performance 20- to 40-years out?

It is typically true that there is more variability when modeling performance over a long period of time than forecasting 2- to 5-year performance. However, at a network level, the trends reflected in a long-term analysis are most likely reasonable enough to use for LCP purposes. The predictions are not being used to determine which specific pavement section or bridge will require work, but more generally reflect the number of pavement sections and/or bridges that will require work over the analysis period. Over time, as State DOTs build their historical condition databases, a State DOT can expect to be able to use this information to refine their deterioration models and build more confidence in the long-term projections.

What types of treatments should be included in the LCP analysis?

An LCP analysis should consider all types of treatments that might be applied over an asset's life cycle, including treatments that could be categorized as maintenance, preservation, rehabilitation, and reconstruction or replacement.

How many LCP scenarios should I consider?

It is beneficial to consider multiple LCP strategies to evaluate the long-term impacts of different treatment strategies at different funding levels during a State DOT's financial planning processes. The number of LCP scenarios can be determined by each State DOT, but in general the scenarios should help determine how much money is needed to maintain asset conditions, to achieve a desired state of good repair, or what conditions are achievable at expected funding levels.

Do I need a management system for evaluating life cycle strategies for assets other than pavements and bridges?

No. State DOTs that include other assets in their TAMP are required to meet 23 CFR 515.7(g) stating that "each State DOT shall use bridge and pavement management systems meeting the requirements of §515.7 to analyze the condition of NHS pavements and bridges for the purpose of developing and implementing the asset management plan required under this part. The use of these or other management systems for other assets that the State DOT elects to include in the asset management plan is optional (e.g., Sign Management Systems)."

Evaluating the Effectiveness of the LCP Process

To be most successful, asset management processes should adapt to meet the changing demands in a State DOT. This section provides factors that a State DOT can use to evaluate the effectiveness of its LCP processes. The next section offers suggestions for improving any of the areas that need enhancement.

Data

The availability of comprehensive, quality information enables a State DOT to have confidence in the results generated from an LCP analysis. When evaluating the effectiveness of the data used for LCP, State DOTs might consider the following factors:

- Availability of asset performance data to develop deterioration models and identify treatment needs over the life cycle.
- Consistency in the historical performance data between vendors and/or raters.
- Inclusion of costs associated with both maintenance and capital treatment types in the analysis.
- Availability of treatment histories (including availability of both maintenance and capital activities) to determine the impact of treatments on asset performance.

Models

To evaluate the effectiveness of the models used to support LCP, the following factors might be considered:

- Availability of customized deterioration models for different asset sub-groups and component elements.
- Ability to evaluate treatment effectiveness at the sub-group and component levels.
- Consideration of a range of treatments over the life of an asset, including maintenance, preservation, rehabilitation, and reconstruction.
- Validation of decision trees to practice.
- Representation of treatments over an asset life cycle.
- Existence of treatment effectiveness models for improved conditions or extended service life, including how the impact on bridge components and elements is considered.
- Availability of documentation that tracks factors leading to changes in the models being used.

Tools

The following factors impact the effectiveness of available tools to support an LCP analysis:

- Satisfaction of minimum requirements for pavement and bridge management systems under 23 CFR 515.17.
- Confidence in LCP scenario results that predict conditions over an extended time period.
- Reasonableness of the data and analysis results for setting long-term condition targets or a desired state of good repair.
- Ability to develop investment strategies that separate treatments by work type, including maintenance, preservation, rehabilitation, reconstruction, and new construction.

Processes

To evaluate the effectiveness of the business processes used to support LCP, the following factors might be considered:

- Consistency between programmed and recommended treatments.
- Availability of reliable work history information consisting of both maintenance and capital information.
- Links between TAMP investment strategies and recommended LCP scenarios.
- Involvement of an effective, cross-functional team contributing to LCP.

Suggestions to Improve LCP Analysis

The following suggestions and examples are offered to illustrate steps that can be taken to improve the effectiveness of an LCP analysis.

Data

Improvements to data availability, accessibility, and reliability can have a significant impact on the types of treatments that can be considered in an LCP analysis, the amount of confidence in predicted outcomes, and the similarity between actual and predicted conditions. Improvements to data may include the following types of activities:

> The Ohio DOT established a TAM Audit Group and a Data Governance Group under its Asset Management Leadership Team to establish data governance and data collection standards for all asset data collected by the Department and to ensure that the standards are followed. This has helped ensure that standards are in place before data is collected and that the data is collected consistently across the State DOT.

- Establishing data governance programs to ensure consistency in the data collected and protect data from loss or corruption.
- Improving the consistency in how maintenance and capital work activities are reported.
- Implementing processes to improve agency-wide access to shared data.
- Storing and updating work histories for both maintenance and capital enhancements.
- Establishing quality assurance programs to ensure data quality.
- Documenting data sources and assumptions used in the analysis.

Models

Prediction models are used in LCP to forecast treatment needs and to predict the outcomes that will result from the use of various treatments over an asset's life cycle. Treatment and impact rules are also important to an LCP analysis to determine when different treatment categories are viable and how their use impacts asset performance. Improvements to models may include the following types of activities:

- Incorporating maintenance treatments into pavement and bridge management systems.
- Establishing effectiveness models at both the component and element level.
- Building initial models for new and innovative preservation treatments based on expert opinion.
- Evaluating the reliability of models using historical data.
- Expanding the range of treatments considered in the LCP analysis to better represent asset needs over their life cycle.
- Improving data quality.

Tools

Analysis tools allow State DOTs to quickly and efficiently evaluate the impacts of different LCP strategies over an analysis period. Improvements that may enhance the ability of analysis tools to support LCP may include the following types of activities:

- Implementing software enhancements to ensure that a range of treatments can be optimized over the life cycle of one or more asset classes and asset sub-groups.

- Developing business processes that ensure the on-going improvement and applicability of LCP tools.
- Conducting workforce development training to improve the analytical capabilities of those involved in conducting LCP.

Processes

Business processes are important to help ensure that data is current, analysis tools reflect State DOT practices, and LCP results are fully implemented. Improvements to business processes to better support LCP may include the following types of activities:

- Developing processes that inform the management systems of maintenance work completed.
- Evaluating the match between planned and actual investments and addressing any inconsistencies.
- Establishing a "match" between recommendations from the management systems and field work plans.
- Maintaining a cross-functional team to address on-going LCP issues.

As part of its efforts to reduce life-cycle costs, the Ohio DOT implemented several business process changes. One change included the development of a target to ensure that 75 percent of the projects funded in the District Work Plans match the pavement management recommendations. This business process change is helping the Ohio DOT ensure that its planned strategy is implemented.