NCHRP Project No. 23-08

Technical Memorandum on Implementation of the:

A GUIDE FOR INCORPORATING MAINTENANCE COSTS INTO A TRANSPORTATION ASSET MANAGEMENT PLAN

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The following Technical Memo on Implementation is supplemental to *NCHRP Research Report 1076: A Guide to Incorporating Maintenance Costs into a Transportation Asset Management Plan.* (NCHRP Project 23-08 of the same title). The full report can be found by searching on *NCHRP Research Report 1076* on the National Academies Press website (nap.nationalacademies.org).

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Technical Memo

Introduction

This memorandum provides a technical summary of the *NCHRP Research Report 1076:* A *Guide for Incorporating Maintenance Costs into a Transportation Asset Management Plan* [TAMP], which was developed under NCHRP Project 23-08. This memo is designed to support highway Maintenance and Asset Management professionals in efforts to develop mature asset management programs that incorporate maintenance plans, activities, accomplishments, and costs. Figure 1 introduces the framework described in the rest of the document. The framework includes six activities, followed by an opportunity to implement, monitor, and improve the practices identified through those steps.

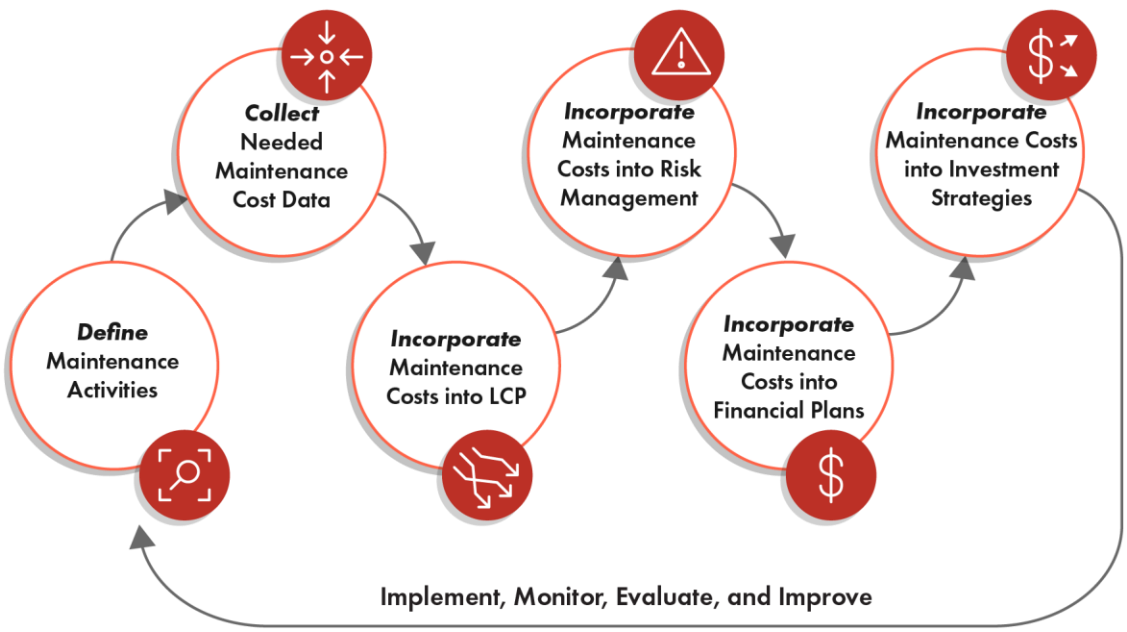

Figure 1. Framework for incorporating maintenance costs into a TAMP.

Federal regulations require that TAMPs include a financial plan containing "the estimated cost of expected future work to implement investment strategies contained in the TAMP" (23 CFR 515.7(d)(1)). Future work activities are reported in terms of work types that are defined as "initial construction, maintenance, preservation, rehabilitation, and reconstruction" (23 CFR 515.5). These definitions highlight the importance of incorporating maintenance costs into TAMPs. However, the following six challenges have been identified as preventing agencies from fully integrating maintenance costs within asset management practices:

- A lack of a common definition for maintenance.
- A lack of quality data on maintenance costs and accomplishments.

- Limited understanding or modeling of how maintenance impacts the asset life cycle.
- Immature risk management practices that do not incorporate maintenance contribution to risk mitigation.
- Separate accounting or budgeting systems between maintenance and capital expenditures, both planned and actual.
- Varying planning periods between maintenance and capital work.
- Unlike other work types, maintenance applies to all life-cycle stages of an asset.

The Guide aids agencies in identifying and addressing challenges that prevent them from quantifying and incorporating maintenance costs into their TAMPs. In addition, the Guide serves as a resource for developing processes and tools to integrate maintenance costs into TAMP components. The Guide incorporates the philosophies and approaches found in several key sources, including:

- *Guide for Transportation Asset Management: A Focus on Implementation* (TAM Guide) (AASHTO 2020).
- AASHTO Maintenance Manual for Roadways and Bridges (AASHTO 2007).
- *NCHRP Research Report 898: A Guide to Developing Financial Plans and Performance Measures for Transportation Asset Management* (SPP et al. 2019).

The Guide is designed to be part of the American Association of State Highway and Transportation Officials (AASHTO) Transportation Asset Management framework and augment the *AASHTO TAM Guide* (AASHTO 2020).

Defining and Categorizing Maintenance Activities

The wide range of activities that can be considered maintenance makes it impractical to establish a single definition for maintenance that is consistent across all agencies. For example, both pavement overlays and repair of localized surface distresses can be considered maintenance by some agencies. Certain types of maintenance activities, such as snow and ice treatments, depend on an agency's location or climate. Of the five work types defined by 23 CFR 515.5 for inclusion in state TAMPs, only maintenance applies to all stages of an asset's life cycle, as reflected in its broad role to fill gaps in capital improvement plans, preserve asset conditions, and support operational needs. To successfully consider maintenance in a TAMP, and recognize its benefits, these activities should be differentiated from capital improvement costs. The Guide offers suggestions for achieving this objective. as reflected in its broad role to fill gaps in capital improvement plans, preserve asset conditions, and support operational needs. To successfully consider maintenance in a TAMP, and recognize its benefits, these activities should be differentiated from capital improvement costs. The Guide offers suggestions for achieving this objective.

STRATEGIES FOR MAINTAINING ASSETS

Since both asset management and maintenance can be applied at all asset life-cycle stages, maintenance activities should be considered as an integral part of the other work types, such as preservation and rehabilitation/replacement. Establishing life-cycle strategies that consider maintenance allows agencies to better understand the comprehensive set of strategies needed to extend asset service lives while minimizing long-term costs. FHWA's *Handbook for Including Ancillary Assets in Transportation Asset Management Programs* (Allen et al. 2019) describes three approaches to establishing maintenance strategies to support asset management.

- Condition-based.
- Interval- or age-based.
- Reactive.

Each of these three approaches can be implemented with a focus on asset condition or risk. Additionally, some agencies have begun managing assets based on risk, creating a fourth approach. These maintenance strategies allow agencies to understand how and when specific activities best support asset conditions and system performance while minimizing the risk or impact of asset failure. These four approaches are described below and summarized in Figure 2.

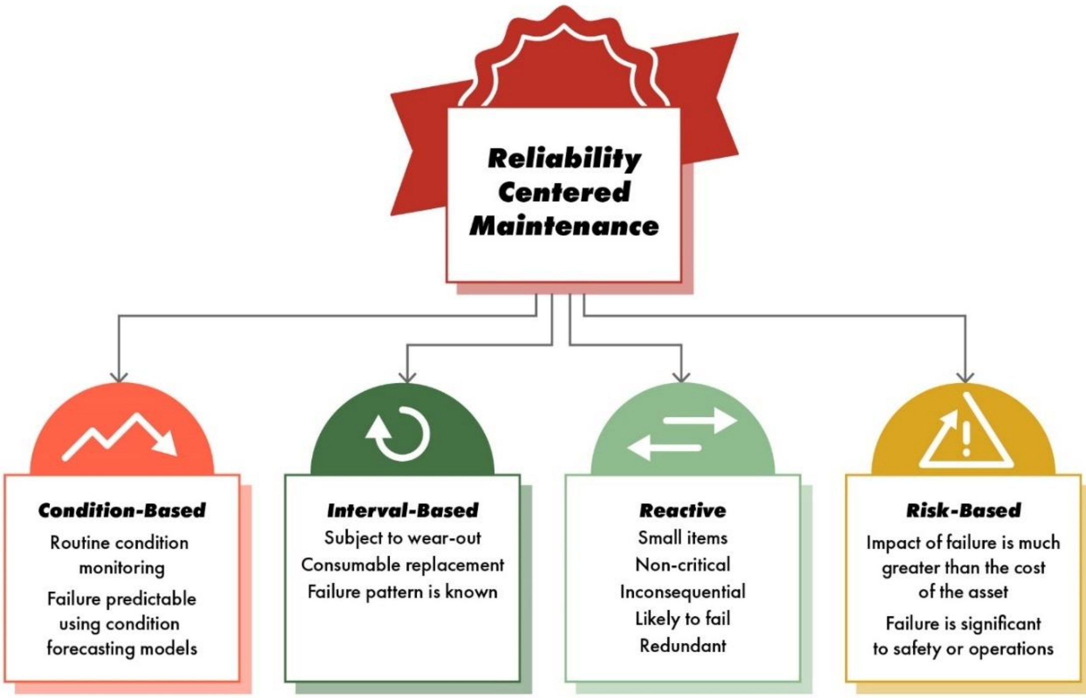

Figure 2. Components of a Reliability Centered Maintenance Program (adapted from NASA 2008).

Condition-Based Management

Condition-based asset management requires the collection of reliable inventory and condition information over the asset's service life. This data is used to develop mathematical models to estimate asset deterioration and predict future asset conditions to evaluate the type and timing of various maintenance actions based on performance, risk, and costs.

Interval- or Age-Based Management

Interval- or age-based strategies do not require knowledge of the asset's condition to schedule and deliver maintenance. Instead, maintenance is delivered at specific times such as in the case of bridge washing or culvert cleaning performed on a recommended fixed interval and replacement of units that have reached a certain age for safety-critical assets.

Reactive Management

Reactive management provides maintenance after the asset's condition has deteriorated below an acceptable level, usually unexpectedly. Some forms of reactive maintenance are necessary for all assets, such as repairs needed in response to emergencies or vehicle collisions. However, some assets may be entirely managed reactively, from initial construction until replacement. Reactive management is typically used for assets with long service lives and minimal preventive maintenance or repair options.

Risk-Based Management

Risk-based management is employed when the potential impact to system performance from a failure of the asset, rather than the assets condition, drives the identification and prioritization of work. In these cases, the risk of asset failure, measured in terms of likelihood and potential impact, is the driving concerns for the agency.

THE IMPLICATIONS OF SELECTING A MAINTENANCE STRATEGY

Effective maintenance management involves collecting many different types of data for each asset class. However, data collection should primarily be aimed at decision-making or risk mitigation. Depending on the management strategy selected, certain types of data are essential while other data is not required but may be beneficial. Agencies must balance data collection costs and benefits to determine which elements to collect, how often, and the degree of accuracy needed. Collection of non-essential data is optional and decision-making on maintenance strategies can be performed without such data. In general, condition- and risk-based approaches require the highest levels of data and data quality.

CATEGORIZING MAINTENANCE ACTIVITIES

In lieu of a standard definition defining which activities are *maintenance* and which are not, transportation agencies need guidance that allows each agency to determine which activities are considered maintenance and understand how each of those activities can be incorporated into a TAMP. The categories presented in Table 1 are defined based on their impact on the following TAMP processes required under 23 CFR Part 515:

- Performance gap analysis (23 CFR Part 515.7(a))
- Life-cycle planning (23 CFR Part 515.7(b))
- Risk management (23 CFR Part 515.7(c))
- Financial planning (23 CFR Part 515.7(d))
- Investment strategies (23 CFR Part 515.7(e))

The primary factor for how an activity impacts these processes is based on the activity's effect on asset condition, service life, and risk. Understanding which category a specific activity fits into allows an agency to determine how to incorporate that activity's costs and benefits into TAM processes. Table 1 presents the impact of each of the maintenance activity category on asset condition and risk, and the funding source and investment strategy for the activity. Building a work history is important in allowing agencies to establish a connection among cost, accomplishment, and performance. For example, unit costs developed from a work order history can be connected with the work accomplished and the resulting improvement in asset performance. Moreover, this information can be used to forecast future cost of delivering maintenance.

Table 1. Maintenance activity categories.

Maintenance Activity Category	Impact on Asset Conditions and Risk	Funding Source and Investment Strategy
Operations and Routine Maintenance	Restores or sustains functionality but does not impact asset conditions (e.g., road patrol, mowing, and snow and ice control).	Does not impact LCP and addressed as fixed cost items that reduce the amount of funding available for activities that improve asset condition. Typically, funded from operations budget.
Preventive Maintenance	Prevents or addresses deterioration to delay a decline in measured conditions but does not significantly improve conditions (e.g., crack seal, chip seal, sweeping, drain cleaning, bridge washing).	Because of its impact on future conditions, this should be incorporated into LCP. This can be listed as maintenance or preservation work type and accounted as maintenance or capital improvement costs. The same activity may be defined as maintenance and preservation based on the budget category from which the expenditure is funded or by the organizational unit that delivers or oversees the work.
Repair	Repairs damage or deterioration. Improves measurable condition and function but does not restore or improve structure, capacity, or functionality (e.g., mill and inlay, deck repair). This may include replacement of parts but not major components.	This can be listed as maintenance, preservation, or rehabilitation work type and accounted as maintenance or capital improvement costs. The quantity of repair, rather than the type, generally qualifies the activity as maintenance. Repairs may also be difficult to discern from routine maintenance.
Unit or Major Component Replacement	Replaces one or more individual asset components, restoring functionality for that component (e.g., sign panel replacement, striping, traffic signal component replacement).	This can be listed as maintenance, rehabilitation, or reconstruction work type and accounted as maintenance or capital improvement costs. For some assets, the entire asset may be replaced under a maintenance action because of the mechanism by which the replacement is delivered or funded. Other assets may be tracked individually, and the replacement of individual components may be considered maintenance.
Organizational Strengthening	Maintenance activities that are not directly asset related. These activities may mitigate risk or improve organizational capacity e.g., training, safety briefings, management system use, planning supervision).	These maintenance activities can be budgeted for "above the line" so that stakeholders and decision makers can clearly see what activities are planned to strengthen the capabilities and the culture of the maintenance organization. These activities can be tracked using the time, labor, and material features in a maintenance management system.

Data to Support Integrating Maintenance into a TAMP

For cost data to be useful in a TAMP analysis, other data elements linking the costs to the asset inventory, activities, accomplishments, and performance improvement are necessary. A key source of this data is accurate work history, which may come from maintenance crew work records or contracts and should include labor, equipment, and material costs as well as work units accomplished. The work history can also be used to connect the costs with the work accomplished and the resulting improvement in asset performance. This can help in evaluating level of service (LOS), performance gaps, and the funding required to achieve performance targets. Many agencies develop an asset and activity matrix that clearly defines the types of maintenance work performed on each asset. The asset and activity matrices must be clearly defined to be incorporated into a TAMP.

HOW MUCH DATA IS ENOUGH DATA?

Data is potentially expensive to collect and maintain. National requirements have been established for bridge and pavement data, but not for ancillary assets that may be included in a TAMP. The FHWA *Handbook for Including Ancillary Assets in Transportation Asset Management Programs* provides a guide for prioritizing assets beyond pavement and bridges (Allen et al. 2019).

Data collection should be a multi-step process including prioritizing assets, identifying data needs for supporting decision-making based on selected maintenance approach, and establishing a mature data management framework. When collecting asset data, it is important to consider and establish clear data requirements for inventory, condition, and performance data models. Required and recommend fields should be feasible to collect and maintain; optional fields may only be collected under specific circumstances. Data that cannot be reliably collected or maintained should be excluded from the data model. Figure 3. Data collection attributes

(source: Allen et al. 2019). shows examples of required, recommended, and optional inventory, condition, and performance data attributes.

Data elements that are typically needed to support the TAM and the Transportation Performance Management (TPM) activities are shown in Table 2. The elements which serve as input and output to support each activity are also defined. This relationship between the different activities and the data elements can serve as a framework for incorporating maintenance costs into various TAMP processes and identifying the associated data needs.

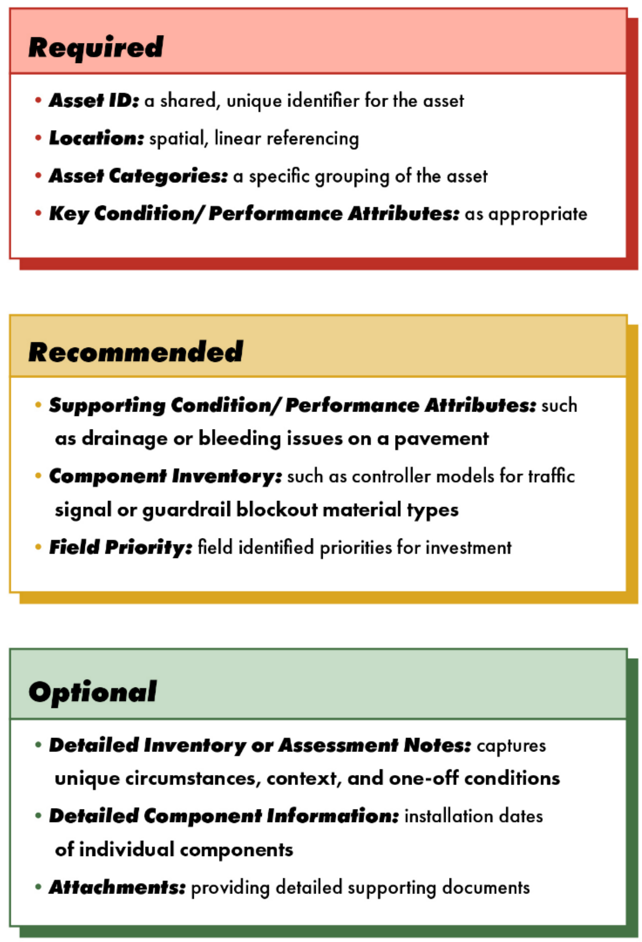

Figure 3. Data collection attributes (source: Allen et al. 2019).

Table 2. Data needs for different TAM and TPM processes (source: Allen et al. 2019).

Data	Target Setting	Consistency Review	Managing Risk	LCP	Financial Plan	Investment Strategy	Gap Analysis
Inventory	Input	Input	Input	Input			Input
Condition	Input	Input	Input	Input		Input	Input
Available Funding	Input	Input		Input		Input	
Investment (Historic & Planned)	Input	Input		Output	Input		
Accomplishments	Input	Input	Input				
Vulnerabilities		Input	Input				
Historical Emergency Response		Input					
Life-Cycle Strategies		Input					
Targets	Output	Output				Output	Output

ASSESSING DATA READINESS

NCHRP Report 814: Data to Support Transportation Agency Business Needs: A Self-Assessment Guide (SPP et al. 2015) serves as a useful resource in helping agencies evaluate if they have the right data to support decisions. The data effectiveness self-assessment contained in the report and presented in Figure 4 can be used to help agencies determine the data needed for meeting expected business needs and also the costs, benefits, and importance of obtaining the data. As the figure shows, the data assessment involves consideration of both data value and data maturity to determine data gaps. The Report also includes suggestions for addressing any gaps that are identified.

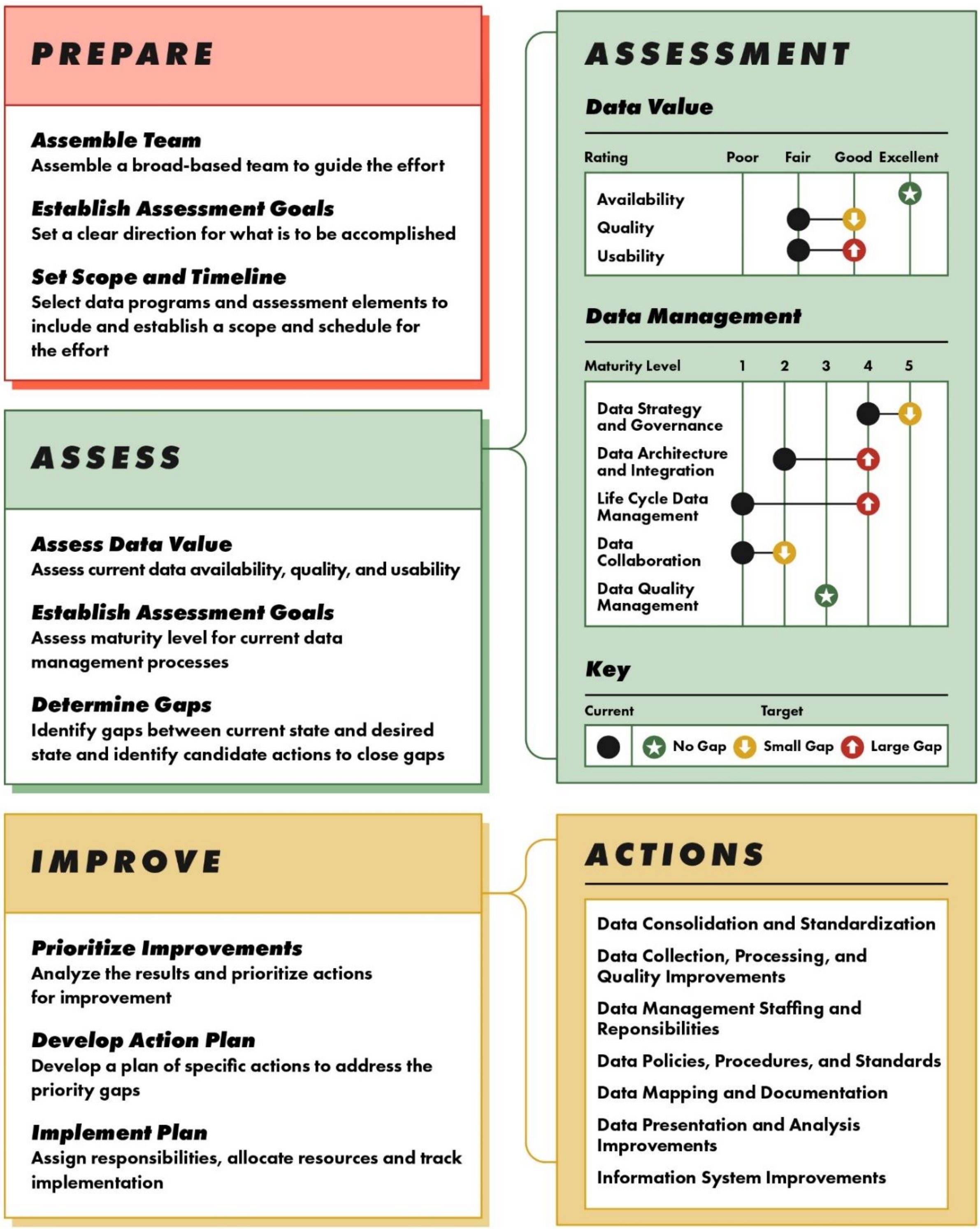

Figure 4. Implementing Data Self-Assessment for Transportation Agencies (Modified from SPP 2022).

COLLECTING DIFFERENT TYPES OF MAINTENANCE COST DATA

Accurate maintenance cost data is the foundation of any performance-based maintenance program. Historic costs can be used to establish typical unit costs for each maintenance activity. Unit cost should accommodate significant and consistent variations, such as between geographic areas, or delivery mechanisms (e.g., field crews or contract). Establishing unit costs allows the agency to develop more refined performance-based budgets. Below are key maintenance cost reporting data types that should be collected.

- In-House Costs.
- Labor Costs.
- Equipment Costs.
- Material Costs.
- Contract Costs.
- Accomplishment Reporting

In-House Costs

Several Departments of Transportation (DOTs) effectively utilize Maintenance Management Systems (MMS) to capture in-house maintenance cost and accomplishment data. Typical data captured for maintenance work includes labor, equipment, material, and accomplishment units. The utilization of mobile applications can work to reduce data entry errors and enhance data quality overall. These applications allow maintenance crews to select specific assets in the field and, in real time, report maintenance activity data. Additionally, many agencies are working to expand the utilization of automated reporting technologies, such as Automatic Vehicle Location (AVL) and other applications, to further reduce data entry errors, improve data quality, and minimize the level of effort for maintenance crews to report activities. The continued proliferation of comprehensive MMS applications will work to enhance these processes at agencies across the country.

Labor Costs

Leveraging MMS applications enables an agency to track the in-house labor costs to perform maintenance activities. It is important that these labor rates are tied to the appropriate maintenance activity and/or asset. These rates should be "fully-loaded" and include all associated overhead costs for employee labor. The rates within the MMS should be interfaced with the necessary financial or enterprise resource planning (ERP) modules to ensure consistent labor reporting across the agency.

Equipment Costs

Agencies must also account for the full costs to operate and maintain the equipment utilized for roadway maintenance work. As with labor, the equipment rates charged to maintenance work must be "fully-loaded" and include initial capital costs, depreciation, operating and maintenance costs, shop overhead (including mechanic rates), tools, software, facilities used to maintain equipment, etc. Several agencies utilize a revolving equipment fund, which charges maintenance offices rates that include the previously mentioned costs as well as those to replace equipment at the end of its life cycle. It is also recommended that agencies account for the time the equipment is utilized to perform work as well as the time it is assigned to the maintenance activity. This is preferred, as there is an opportunity cost to assign equipment to the activity even if it is not actually utilized.

Material Costs

Material costs to perform roadway maintenance are often significant. As such, it is important that all maintenance work orders include the quantity and costs of required materials. Agencies vary in the methods used to account for material costs. For example, an agency may utilize average material cost; first in, first out

(FIFO); or last in, first out (LIFO). These processes are often established in conjunction with agency accounting departments, thereby making it difficult to standardize an approach across agencies.

Contract Costs

All agencies deliver some maintenance activities through contracts. Capturing costs from contracts requires accessing data sets that are commonly formatted differently from the in-house maintenance cost data. As a result, there is a need to correlate the contract cost data to the activity or task definitions used to track in-house costs. This process is critical to accounting for all maintenance costs in a similar way. The Texas DOT (TxDOT) and Maryland DOT State Highway Administration (MDOT SHA) case studies present different examples of how agencies have approached the challenge of aligning in-house and contract maintenance cost data.

The decision to contract out maintenance activities may involve consideration of the following types of questions.

- Is the equipment purchased or leased?
- Are staff well trained with experience in safe handling and proper installation?
- Are staff available to deliver the work in a safe manner, e.g., with proper traffic control installed?
- What materials are available?
- What is the availability of qualified contractors for installation?
- How competitive are contract costs per work unit?

Accomplishment Reporting

Agencies must also report the amount of work performed, or accomplishment, by maintenance activity and/or asset. This is necessary to develop the unit costs to perform maintenance work. These unit costs are key inputs for developing performance-based budgets. Accomplishment units vary by activity. For example, linear feet of guardrail repair, number of sign faces replaced, acres mowing or vegetation control, cubic feet of sediment removed, or square yards of asphalt repaired are all considered accomplishment units.

Example: TxDOT Tracking Maintenance by Contract Costs

TxDOT contracts approximately 52 percent ($620 million) of its $1.2 billion maintenance budget to routine maintenance. Contracted work is interfaced into TxDOT's MMS in two ways: from its enterprise resource planning (ERP) software and from its construction contract management software. TxDOT typically uses work orders (WO) for contracts less than $25,000. The process for capturing and reporting contract maintenance costs is shown in Figure 5.

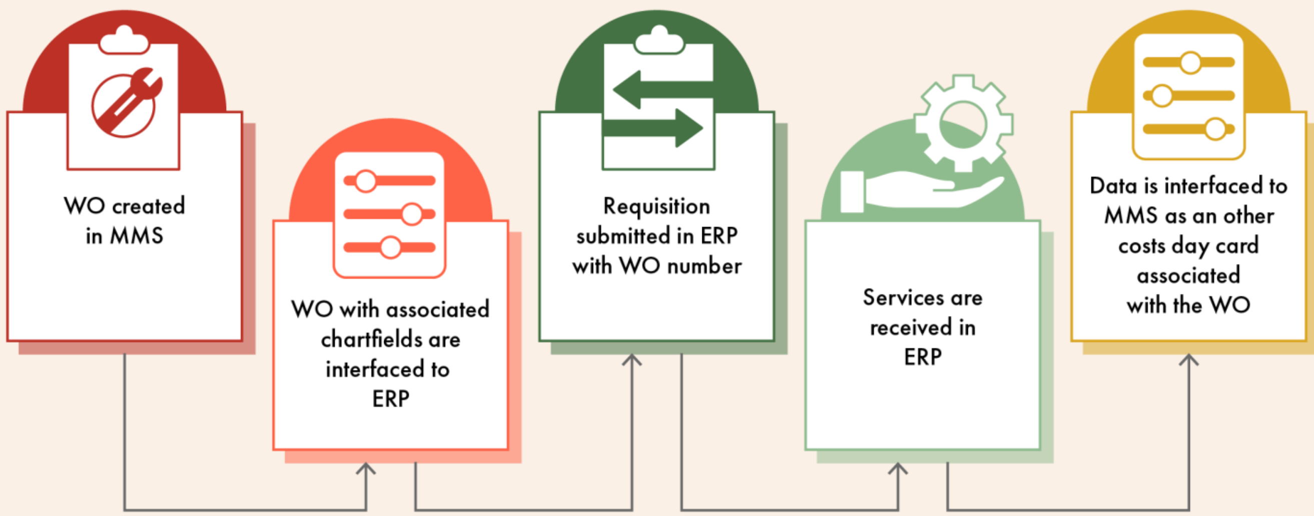

Figure 5. TxDOT contract purchase order data collection process (data source: TxDOT).

For larger projects, TxDOT utilizes AASHTOWare Site Manager, including the Routine Maintenance Contract Administration module. Daily work reports allow inspectors to capture work performed at the job site such as personnel, equipment, work items, quantities, descriptions, etc. Over 3,700 pay items are used on routine maintenance contracts and the Maintenance Distribution Window, a custom upgrade to Site Manager, ties the pay item cost to the MMS function code (i.e., what work is being performed) and amount of work performed.

TYING MAINTENANCE COST DATA TO ASSET PERFORMANCE DATA

Once costs are captured, determining the relationship between cost and performance allows for the use of cost data in asset management analyses. As an example, Minnesota DOT provided a relationship between maintenance costs and asset performance by demonstrating how forecasted asset conditions can be used to estimate future maintenance costs.

Example: Minnesota DOT Relating Pavement Condition to Maintenance Costs

MnDOT has developed separate processes for capturing pavement maintenance cost data for contract and state forces work. For contract work, MnDOT has an estimating section that determines Statewide costs per lane-mile based on contract costs detailed in the project lettings.

For state forces maintenance work, MnDOT uses data from work orders and day cards incorporated into the Transportation Asset Management System (TAMS). In both cases, the cost data includes location information. Using this combination of cost and location data, MnDOT develops models describing the relationship between pothole patching costs and the condition of pavements. Figure 6 displays pavement performance based on various investment scenarios: PL0, PL1, PL2, PL-1, and PL-2. Each scenario represents a different level of investment in pavement resurfacing and displays the resulting pavement pothole patching budget.

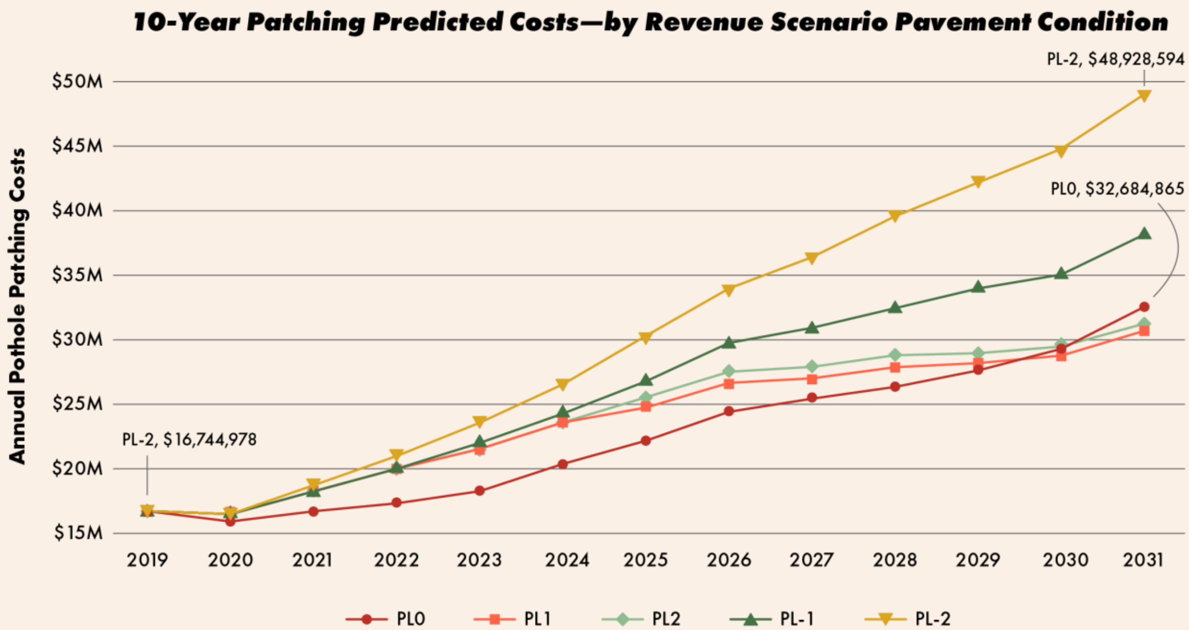

Figure 6. MnDOT pavement patching models output graphic (data source MnDOT).

MnDOT demonstrates strong asset management practices as they relate to connecting maintenance costs and treatments in ancillary assets. MnDOT's TAMS is an integrated system that enables MnDOT to develop maintenance cost data for roadway assets due to varying levels of data availability and MnDOT has adopted different approaches for each asset. TAMS is MnDOT's primary work management system for the Office of Maintenance and is used to track all work performed by MnDOT maintenance field staff. Although the current MnDOT TAMP includes ten ancillary assets, MnDOT manages several other assets in TAMS.

Incorporating Maintenance into Life-Cycle Planning

Federal regulations define LCP as "a process to estimate the cost of managing an asset class, or asset sub-group over its whole life with consideration for minimizing costs while preserving or improving the condition" (23 CFR Part 515.5). The FHWA has outlined a 5-step process for conducting the analysis, as shown in Figure 7. The first step is to decide which asset classes will be analyzed and what portion of the network will be included. The second step is to identify the different strategies that will be considered in the analysis. In step three, the analysis scenarios are defined to determine what conditions can be achieved at different funding levels. The analysis of the different scenarios takes place in step four. The last step in the process, step five, uses the results of the analyses in step four to identify the LCP for the asset that will be incorporated into the TAMP's financial plan.

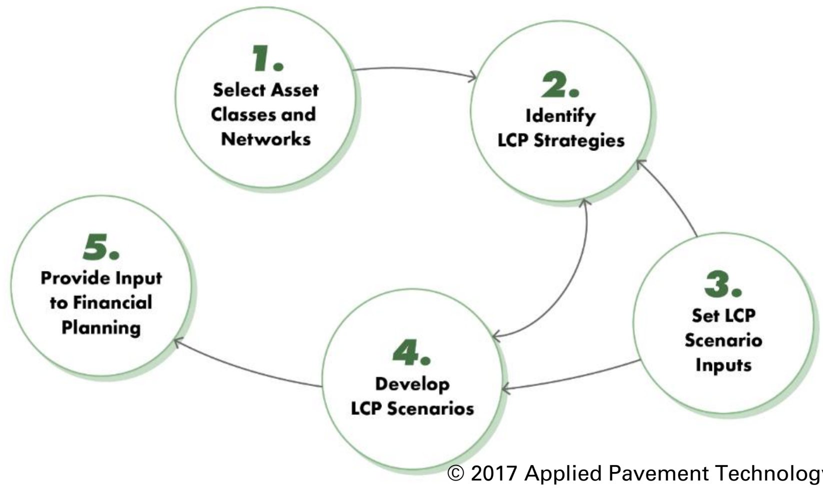

Figure 7. Life-cycle planning (modified from FHWA 2017b).

APPROACHES FOR CONSIDERING MAINTENANCE COSTS IN AN LCP

A key to conducting an LCP analysis is the availability of cost and treatment information to represent the strategies for maintaining assets in a serviceable condition. While many agencies have extensive computerized analysis systems in place for major assets such as pavements and bridges, that prioritize suggested improvement by evaluating which combination of projects and treatments provide the greatest benefit for the level of funding expended, fewer agencies have the same level of detail for other assets such as guardrail, ITS assets, and culverts.

Routine and operational maintenance costs are perhaps the most difficult maintenance costs to incorporate into an LCP analysis since they are commonly applied to restore or sustain functionality without impacting an asset's life cycle. ***Preventive maintenance treatments***, which may be included in the preservation work type presented in the TAMP, are used to prevent or slow deterioration, rather than significantly improve asset conditions. Since these types of treatments impact an asset's life cycle, they should be incorporated into an LCP analysis. For assets such as pavements and bridges with an analysis tool in place preventive maintenance treatments and costs should be incorporated into the decision trees or policies that define the types of treatments considered in the analysis. The following steps can be used as an example:

- Determine whether the preventive maintenance treatments are triggered based on conditions, a cycle, or a combination of the two.
- Use pre-treatment conditions to determine how the treatment will perform.
- In the absence of an analysis tool, maintenance costs associated with preventive maintenance treatments can be estimated based on the expected cycle for their application. An LCP estimate of preventive maintenance needs requires at least the following information:
- An estimate of the size of the asset inventory.
- An estimate of the number (or percentage) of assets in each good, fair, and poor condition category.

- An estimate of the network growth rate for the asset.
- An estimate of the amount of time it takes for a new asset to move from one condition to another.
- A summary of the types of preventive maintenance activities applied to each of the asset condition states as assets in good, fair, and poor condition.
- A determination of how asset condition changes when preventive maintenance is applied.
- An estimate of the network percentage in each condition state that will receive a preventive maintenance treatment each year.

Repair Costs

Repairs are considered activities that improve asset conditions and functions without improving structural condition or capacity. For assets like pavement and bridges, repairs are generally included in capital improvements and therefore the costs of these repairs are usually already incorporated in the LCP analysis as minor rehabilitation or preservation treatments. For assets without analysis tools in place, the costs can be estimated using the same steps outlined for preventive maintenance activities.

Unit of Component Replacement Costs

Unit or component replacements are used to restore the functionality of an asset (or component) at the end of its service life. Unit replacement is common for electronic components of systems such as traffic signals or ITS installations. For bridges and pavements, replacements are considered at the end of an asset's service life. This treatment type is normally considered in a pavement or bridge management system as a capital improvement. Therefore, the costs associated with replacements are typically already incorporated into their LCP analysis. Unit and component replacements are also common with assets at the end of their service life. The estimated replacement cost can be found using the Manufacturer's Estimated Service Life or as part of the analysis described for preventive maintenance activities.

Organizational Strengthening Costs

Organizational strengthening activities do not address asset conditions, so they are not typically included in an LCP analysis. However, as with costs associated with operations and routine maintenance, they are part of the total maintenance budget and may be included in the TAMP Financial Plan.

Example: Nevada DOT's Inclusion of ITS Assets in 2019 TAMP

NDOT's 2019 TAMP includes a description of the LCP approach used for its ITS assets (such as closed-circuit TV cameras, flow detectors, and ramp meters) (Nevada DOT 2019). Without having an extensive inventory of the ITS assets, NDOT had sufficient information to estimate the number of assets in the inventory and the distribution of those assets into condition categories using the recommended service life provided by each device's manufacturer. NDOT then created deterioration models for each ITS asset that were based on the average amount of time the asset would take to deteriorate from one condition state to another. The matrices were used to model the deterioration of these assets based upon expert opinion provided by NDOT. The matrices described the time required for the asset to deteriorate from one condition state to another. The condition states were modeled based on the degree to which the recommended service life had been exceeded. The condition categories representing Low, Medium, and High Risk were defined as follows:

- **Low Risk:** Device age between 80 and 100 percent of the manufacturer's recommended service life.
- **Medium Risk:** Device age between 100 and 125 percent of the manufacturer's recommended service life.
- **High Risk:** Device age greater than 125 percent of the manufacturer's recommended service life.

To support the analysis, NDOT defined the maintenance activities that need to be performed on ITS assets including inspections, minor repair, major repair, and replacement. NDOT also created a matrix that shows the impact of each activity on asset condition. For instance, a major repair applied to an ITS asset in the medium-risk category would be moved to the low-risk category after the repair was applied.

The LCP analysis evaluated two different strategies – one reflected the preservation approach adopted by NDOT and the other was a "worst-first" strategy in which the devices received no minor repairs or maintenance and would be replaced when they failed. The analysis showed that the long-term cost of employing NDOT's maintenance strategy was much lower than the worst-first approach and provided an estimate of annual maintenance costs for maintaining these assets.

UNDERSTANDING THE COST TO MAINTAIN NEW ASSETS

The addition of new assets to an inventory brings with it a future demand on maintenance to keep them in operational condition and working safely. This added burden on maintenance is often not considered in developing maintenance budgets or future needs. Therefore, in an agency that is growing in terms of its asset inventory, maintenance needs can be significantly underestimated if they are not incorporated into an LCP analysis. One way to address this is to incorporate a growth rate into the analysis. The inclusion of the growth rate enables an agency to incorporate new assets into the analysis so future maintenance needs can be estimated. This is done by inserting an estimated number of new assets into the inventory so they are considered in the calculation of the amount of work needed in each year of the analysis. The growth rate could be based on a review of several years' worth of contracts to see how many new assets are being added each year. The cost of delayed maintenance on assets could be quantified using guidance from NCHRP *Research Report 859*: *Consequences of Delayed Maintenance of Highway Assets* (Chang et al. 2017).

Incorporating Maintenance into Risk Management

Federal regulations define risk management as "the processes and framework for managing potential risks including identifying, analyzing, evaluating, and addressing the risks to assets and system performance." Risks can occur at multiple levels in an agency. This is reflected in the AASHTO *Enterprise Risk Management Guide's* definition of risk management, which describes risk as "the formal and systematic effort to control uncertainty and variability [to an] organization's strategic objectives by managing risks at all levels of the organization." The levels of risk management can be summarized as including the enterprise, program, project, or activity levels. An enterprise-wide risk could be an unexpected reduction in tax revenues. An activity risk could be a breakdown in data collection. Either could impede objectives, although they are managed at different levels. Figure 8 shows the four levels at which risks are managed. The AASHTO *Guide for Enterprise Risk Management* details the Five Ts for risk mitigation:

- Tolerating the Risk.
- Treating the Risk.
- Transferring the Risk.
- Terminating the Risk.
- Taking Advantage of the Opportunity Inherent in the Risk.

MITIGATING RISK EVENTS

Transportation agencies must prepare for and respond to a wide range of risk events. These are documented in the TAMP risk register and often include events such as ***extreme weather or natural disasters, economic disruption, and changes in regulations or requirements***. Maintenance costs primarily go toward either managing conditions or managing risk. For example, operations activities including incident response, emergency response, and winter maintenance are primarily aimed at managing asset risk and they have little bearing on asset condition. Emergency response comprising unplanned repairs and replacement of failed or damaged asset components, including those covered under 23 CFR Part 667, are also directed toward managing risk.

Figure 8. Risk Management levels

RESILIENCE, CLIMATE CHANGE, AND EXTREME WEATHER

Federal statute (23 USC 119(e)(4)(D)) and regulation (23 CFR 515.7(c)(6) and 515.9 (d)(6)) require State DOTs to incorporate resilience into their TAMPs to address risks associated with extreme weather. This includes events such as heat waves, floods and storm surges, that can affect the condition and performance of the NHS. Six State DOTs including Arizona (ADOT 2020), Kentucky (KYTC 2020), Maryland, Massachusetts, New Jersey, and Texas have integrated resilience considerations into their asset management processes (reports are available on the FHWA website at https://www.fhwa.dot.gov/asset/pilot/).

FHWA defines resilience as "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions." Agencies differ in their approaches to preparing for, responding to, and recovering from extreme events. Resilience considerations involve a wide array of policies and actions that impact the entire asset lifecycle. Maintenance plays a key role in asset resilience, before, during, and after extreme weather events. Maintenance activities performed before events ensure assets are functioning as designed. Maintenance forces are among first responders acting during events to assess conditions, address emergency needs, and facilitate safe highway operations. Following events, maintenance crews and contractors support recovery efforts.

MITIGATING THE RISK OF LONG-TERM CHANGE OR TRENDS

Numerous change-related risks can impact how an agency incorporates maintenance costs into its risk management approach. Below is a summary of several trends that agencies are forced to address:

- **Updated Regulations or Engineering Standards**: Agencies need to address asset regulations and engineering standard revisions for specific assets. For example, recently constructed Americans with Disabilities Act (ADA)-compliant curb ramps must now be maintained and, possibly, at a higher cost than previous curb ramps.
- **Evolving Maintenance Expectations**: While performance targets for assets are typically set ahead of a budget cycle, some may evolve during the year. To address these changing priorities, maintenance must utilize resources scheduled for other work leading to lower performance on other assets.
- **Funding Fluctuations:** Decreased department revenue and the resulting lower routine maintenance budgets hamper an agency's ability to address asset performance. As a result, lower-priority assets tend to stay in a low-performing category since available funds are allocated to higher priorities when unexpected funding fluctuations occur.
- **Aging Infrastructure:** As assets age, the cost to maintain them increases. Keeping budgets steady does not address this cost increase, which results in lower-performing assets.
- **Staffing:** As the current workforce retires, many agencies are faced with losing institutional knowledge. This can affect maintenance costs as work may be performed less efficiently.
- **New Infrastructure:** As many agencies deliver expanded transportation networks, the necessary funds to maintain those newly constructed assets are not always included in future budgets.

Example: Maryland DOT (MDDOT) State Highway Agency Enterprise Risk Management

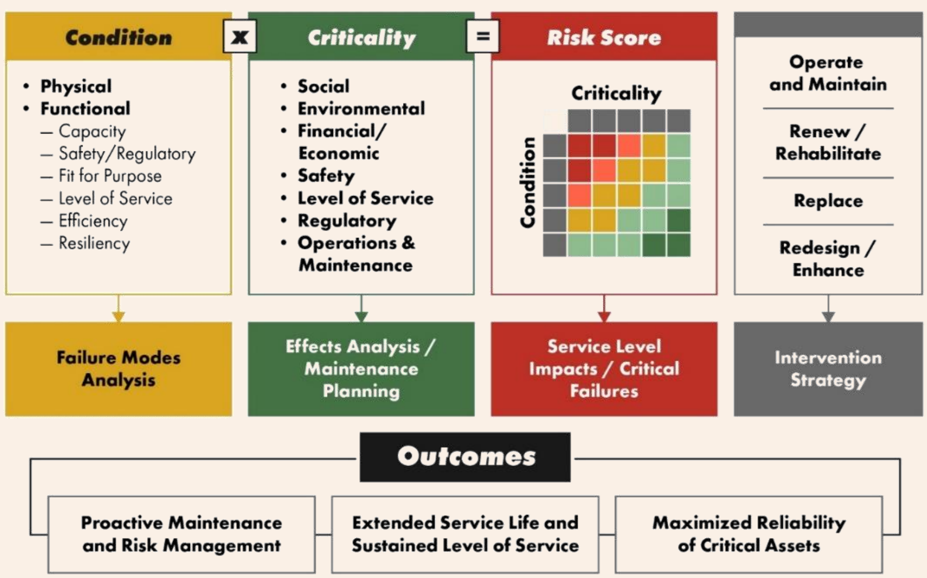

Figure 9. MDOT SHA's triple bottom line risk-based decision-making approach (MDDOT SHA 2021).

Figure 9 illustrates one of the practices currently under implementation at MDOT SHA: incorporating triple bottom line (social, environmental, and financial) risk considerations into the decision-making process. Based on the resulting risk score from asset condition and criticality, the risk-based outcome may encourage the use of proactive maintenance.

PREPARING MAINTENANCE FOR THE FUTURE

DOTs must consider several factors when preparing maintenance programs for the future. As agencies place an increased focus on managing assets from risk and performance-based approaches, it will be important for maintenance managers to evolve to support and enhance these processes. For example, agencies should work to prioritize maintenance activities to address high-risk assets. One way to support this approach includes establishing higher LOS targets for high-risk assets, roadways with higher average annual daily traffic levels, or assets in need of safety-specific maintenance. Tracking costs associated with high-risk assets is necessary to accomplish this, which can answer key questions such as:

1) Do high-risk assets cost more to maintain?
2) Is there an overall improvement in LOS of high-risk assets that links to a lower likelihood of asset failure?

Incorporating Maintenance into Financial Plans

A financial plan is a key component of a TAMP that state DOTs are required to include in their Federally compliant TAMPs (23 USC 119). Financial plans are closely tied to investment strategies. Annual costs to deliver the planned investment strategies by work type must be included in the financial plan (23 CFR 515.7(d)(1)). Maintenance plays a critical role in reducing life-cycle costs, managing risks, and keeping the highway system operating safely. Therefore, it is essential that maintenance costs are included in TAMPs to provide a complete picture of the agency's financial situation and planned investment strategies.

FINANCIAL PLAN DEVELOPMENT PROCESS

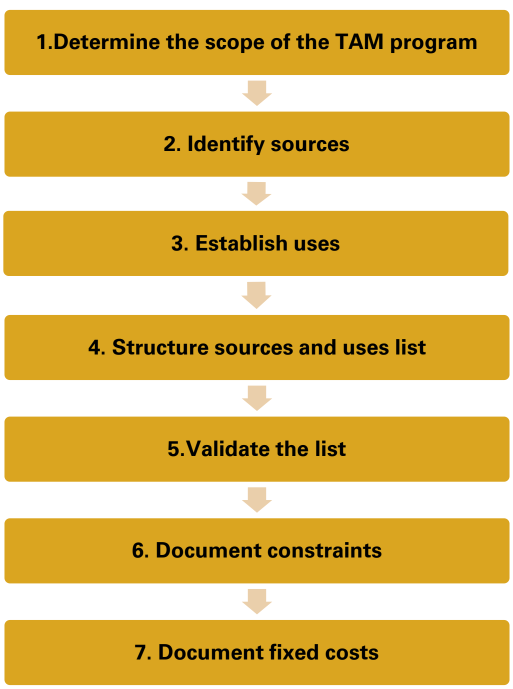

Figure 10. Financial plan development process for maintenance costs.

The process of developing TAMP financial plans and investment strategies has been established through several major guidance documents including:

- Guide for Transportation Asset Management: A Focus on Implementation (AASHTO 2019).
- NCHRP Report 898, A Guide to Developing Financial Plans and Performance Measures for Transportation Asset Management (SPP et al. 2019).
- Developing TAMP Financial Plans (FHWA 2017A).

Figure 10 shows a financial plan development process, modified from *NCHRP Research Report 898* (SPP et al. 2019), that can be used to incorporate maintenance costs into a TAMP.

Step 1—Determine the Scope of the TAM Program: This will determine the types of maintenance costs to be included. In addition to the mandatory inclusion of pavements and bridges, state DOTs may include additional assets or additional parts of their highway networks in their TAMPs resulting in more maintenance activities being included and all applicable uses of maintenance funding needing to be addressed.

Step 2—Identify Maintenance Fund Source: It is important to establish and document a comprehensive list of revenue sources in the TAMP that support maintenance. Maintenance is commonly funded by a combination of budgeted activities and construction contracts. Budgeted activities tend to be established on a short-term, 1- to 2-year basis, while construction contracts are developed and delivered following the same programmatic requirements as other work types utilizing the same fund sources.

Step 3—Establish Maintenance Funding Uses: Maintenance activities set the scope for using funding to maintain the assets. The costs related to these uses must be further constrained to the asset classes and portions of the network addressed in the TAMP.

Step 4—Structure Maintenance Sources and Uses List: Before estimating and forecasting the cost of maintenance work, it can be useful to organize the list of sources and uses. One factor that makes incorporating its costs in a TAMP challenging is that the work may be performed by DOT crews or delivered by contract. Maintenance funding sources can be grouped into categories such as Federal, State, tolls, or local agencies. Uses may be grouped by asset class, location, network, or activity type. Structuring the sources and uses in this way can help highlight priorities as well as identify relationships between the various groups and specific sources or uses.

Step 5—Validate the List: *NCHRP Research Report 898* recommends TAMP leaders use a set of questions when validating the list of sources and uses in the financial plan (SPP et al. 2019). These questions are also applicable to maintenance costs. As these questions are answered, it may lead to changes that impact the answers to other questions resulting in an iterative validation process.

Step 6—Document Constraints: Once the list of TAM sources and uses is defined and annual costs are identified, agencies should document any constraints on the funding sources. Federal Aid or State funded construction contracts generally come with eligibility requirements that limit the type of work and locations for which the funding can be applied. The constraints on this funding are generally developed to direct the funding toward a specific objective or program. Funding sources that support field maintenance crew work also have constraints on labor, equipment, and materials expenditures. Asset managers should collaborate with agency budget staff to understand the relationships between the fund source constraints and asset management uses.

Step 7—Document Assumptions about Fixed Costs: Maintenance costs typically include several fixed costs. Fixed costs such as facilities and training are usually included as planned expenses outside of the investment strategy work types. Showing costs this way allows an agency to illustrate the different ways the maintenance budgets are used. Agencies at earlier stages of maturity in their asset management programs may represent all maintenance costs as fixed. Separating maintenance costs into those directed to maintain specific asset classes in the TAMP could be a first step toward including maintenance costs into the financial plan. Even for mature agencies, several fixed maintenance costs exist such as organizational strengthening activities or operational needs, the budgets for which can be treated as fixed costs that are not available to achieve TAM objectives.

FORECASTING MAINTENANCE COSTS

NCHRP Research Report 898 provides an overview of several processes for forecasting uses, or costs, within a TAMP (SPP et al. 2019). For maintenance costs, the forecast should consider both fixed costs that tend to support routine maintenance and organizational strengthening activities that are not easily tied to asset management performance measures and variable costs that are related to the expected level of maintenance effort and accomplishment to implement life-cycle and risk mitigation strategies.

Maintenance costs forecasting includes both fixed costs and performance-driven variable costs related to delivering a maintenance work plan. The budget for delivering a given year of the work program is determined by summing the cost of each maintenance activity based on the selected approach and estimates for fixed costs. In this approach to cost forecasting, maintenance cost forecasts are primarily based on the amount of work expected to be performed, the unit cost of performing the work, and the expected increase in that unit cost over the forecast period. Fixed costs represent amounts of the budget set aside for activities that cannot be planned (e.g., emergency response) or activities that are needed to deliver the rest of the program (e.g., organizational strengthening and overhead).

Fixed maintenance costs may either be deducted from the available funds before determining funding for asset management uses or separated out as a line item. These are typically forecast based upon historic expenditures with consideration for assumptions, inflation, and uncertainty (SPP et al. 2019). Costs associated with emergency maintenance work form a large proportion of the fixed costs.

Variable costs that can be related to asset performance can be estimated using the relationship between investment levels and asset conditions, commonly performed as part of annual maintenance. Understanding the relationship between investment level and resulting conditions allows for developing a work program for each asset that will deliver an expected level of accomplishment and resulting level of service for a known budget. The accomplishments (e.g., feet of guardrail replaced, or acres of turf mowed) can be based on any of the four maintenance approaches described earlier.

The costs for each activity are typically based on the type of activity standards discussed earlier that specify crew sizes, work duration, equipment used, and material required to complete each work activity. Developing a forecast of maintenance costs and resulting conditions allows agencies to evaluate and understand trade-offs related to changes in priorities.

Incorporating Maintenance into Investment Strategies

Investment strategies are very closely connected with financial plans. Like financial plans, they are a required component of Federally compliant TAMPs for state DOTs (23 USC 119). In an integrated TAM program, investment strategies are informed by the needs and challenges of planning, engineering, maintenance, and operations activities, which in turn are guided by the objectives of the financial plan. Investment strategies are developed using results from life-cycle planning, risk management, and performance gap analysis. The process is presented in *NCHRP Research Report 898* (SPP et al. 2019) and is largely focused on capital program strategies. The Guide adjusts the process to include maintenance performed through projects, maintenance by contract, or through delivery of services from maintenance field crews. This is done with data from MQA programs that are stored in an MMS. The adjusted steps are discussed below:

Step 1—Define the role of maintenance in each scenario: Including maintenance involves identifying the types of maintenance needs that will be required under each scenario and determining the type and amount of maintenance activities that are needed. Maintenance activities are generally needed both to help achieve the forecasted conditions and to address system deficiencies if forecasted conditions do not meet the desired state of good repair.

Step 2—Identify Existing Commitments to Future Investments in Maintenance: Agencies must assess the commitments, including maintenance budget commitments and programmed and planned projects, already in place for future maintenance work. Historic data can be used to estimate future investments, establish unit costs, and estimate expected costs for developing investment scenarios.

Step 3—Incorporate MMS and MQA Data to Improve Predictions of Future Conditions: This step involves running the asset management systems to predict future conditions for each scenario. Maintenance costs can be incorporated into this analysis at three points. First, agencies should account for the assumed maintenance costs in an asset management system. Asset deterioration for pavement and bridge management systems can be forecasted based on performance curves developed from historic data. Second, agencies should use performance-based management to estimate maintenance needs of ancillary assets. Third, agencies should determine the cost to address funding gaps for other work types.

Step 4—Perform Initial Budget Allocations Including Maintenance: Once the categories are established, initial allocations are assigned based on the expected level of performance from investments in each category. Cross-asset trade-off helps determine how to allocate funding across multiple types of assets or investments. At a minimum, this process defines how to allocate funds available for asset management uses between distinct asset classes. Cross-program trade-off applies the principles of multi-objective decision analysis to determine how to balance funding between different programmatic objectives or performance areas such as safety, asset conditions, and system performance. Maintenance work can play a key role in accomplishing each performance area.

Step 5—Identify Candidate Projects and Field Crew Capacity: With the budget allocated and current projects accounted for, the next step is to identify potential means of using the remaining budget to achieve the asset management objectives and address risks. For maintenance work, this includes an iterative process to identify contract and field crews.

Step 6—Select Projects and Maintenance Priorities for Each Scenario: In the event that the list of commitments and candidate projects exceed available funding, it may be necessary to evaluate several scenarios at each investment level that represent ways to prioritize the use of funding. This may increase the number of scenarios identified in Step 1. Evaluating an array of scenarios provides an understanding of the threats or opportunities related to changes in funding and provides insight into how maintenance needs might change.

Step 7—Review Predicted and Future Conditions and Maintenance Needs: Each of the identified scenarios will have different impacts on conditions and maintenance needs. Scenarios resulting in improved conditions for a given asset class will increase the need for preventive maintenance of that asset class. Scenarios that result in deteriorated conditions may require additional resources to be dedicated to repairs or routine maintenance to keep the system safely operating.

Step 8—Finalize Funding Levels by Use: The scenario results from steps 6 and 7 are evaluated to determine the best level and mix of funding. This may require a return to the trade-off practices in step 4. This process requires more than reviewing resulting asset conditions and determining which scenario provides the best overall conditions or the best trade-off between assets. Maintenance managers need to be consulted to develop an understanding of the impact on their resources to deliver the maintenance needed by each scenario.

Step 9—Document Maintenance Strategies for Addressing Gaps: In addition to identifying the maintenance costs in a table of planned expenditures, the TAMP should also include a description of the purpose, priorities, expected accomplishments, and expected impact of the maintenance investments.

Step 10—Documenting Assumptions and Strategies: The final step is to document the work performed through the previous nine steps including investment scenarios, projects, allocation approach, and prioritization approach

Continual Improvement

By incorporating maintenance costs into a TAMP, agencies establish a coordinated strategy for achieving asset management goals and managing risks using comprehensive investment strategies. Successful implementation of those strategies involves putting the plan into practice while responding to changes or unexpected events. Continual improvement is a critical aspect of performance-based management practices. Incorporating maintenance costs into a TAMP is not an effort with a clear endpoint. Rather, it is the establishment of ongoing practices that support annual and multi-year planning and programming efforts. Maintenance management typically involves annual evaluation, planning, and budgeting followed by continual performance and reporting. The annual maintenance management cycle provides a natural integration with the annual TAMP consistency review required for state DOTs under 23 CFR 515.13.

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