Uncertainty caused by variability in the data can often be addressed through the development of quality assurance plans that describe the actions an agency has established to ensure data quality, whether the data is collected in-house or by a contractor. Common quality assurance techniques include documented policies and procedures to establish data quality tolerance limits, independent reviews of collected data, and training of data collection crews. Data management strategies are discussed in more detail in Chapter 7.

To evaluate the accuracy of models and assumptions, agencies can include multiple scenarios in their life-cycle planning analysis to test the impact of different decisions. This type of sensitivity analysis can be helpful in identifying areas in need of further research or developing contingency plans if the initial assumptions turn out to be inaccurate.

To understand whether time and effort should be invested in minimizing uncertainty, a risk-based approach can be used. Assuming the consequence arising from a defined issue or event remains the same, the cost in terms of data collection of reducing uncertainty can be investigated. As an example, the condition state of an asset, as determined using a visual approach, may not provide the required level of insight, which results in poor or unknowable treatment decisions. To minimize the uncertainty, extra testing can be carried out. The level of testing would be defined by the risk–cost reduction ratio. Similarly, with climate change, how much would have to be invested in studies to understand the effects on asset longevity? Thus, through risk management, an agency determines which risks are tolerable and which must be actively managed through investigations, studies or other research. The risks are identified, prioritized, and tracked using a risk register (see Chapter 2). For those risks that should be managed, plans are developed to outline actions that will be taken to mitigate threats or take advantage of opportunities, as discussed in Chapter 6.

How-To

# Life-Cycle Planning for Pavements

**A highway network consists of pavements at different phases of serviceability and addressing the network's needs requires both current pavement condition data to identify the amount and severity of deterioration present, as well as the ability to forecast how those conditions will change over time.** LCP is based on a network-level analysis that considers both economic and engineering factors to determine the most cost-effective strategies to achieve desired pavement conditions. This how-to guide provides an overview of a process agencies can follow to carry out an LCP analysis for its pavement assets.

## 1. Define Subsets of Network for Analysis

Define the various subsets of the pavement network that you will be analyzing. For example, an agency might analyze Interstates separately from the rest of the NHS, especially if the typical treatment strategies differ.

## 2. Establish Treatment Rules and Costs

Establish treatment rules and costs for a variety of treatment options that cover pavement needs over the life of the asset. In addition to setting up treatment rules for the types of treatments the agency normally uses, it may be useful to establish a set of rules that favor an aggressive series of preservation treatments to determine whether that strategy would result in better conditions at a lower cost.

## 3. Input Analysis Parameters

Input the analysis parameters, including the length of the analysis period, the treatment rules, and the estimated funding to be used, into the pavement management system. The analysis period should be at least 10 years, but may be longer to evaluate long-term impacts.

## 4. Run Analysis and Evaluate Effectiveness

Run the analysis and evaluate the effectiveness of the various treatment strategies established during step 2. The analysis is likely to show that include preventive maintenance treatments to keep pavements in good condition will result in better long-term conditions than strategies that include only rehabilitation or reconstruction activities when the same budget is applied to each strategy. Alternatively, the pavement management analysis could be used to show that a preservation strategy can achieve the same network conditions as a more traditional rehabilitation strategy for a lower cost.

## 5. Summarize Results

Summarize the results of the analysis and provide the recommended strategy for each network subset fto be used in developing your TAMP financial plan and investment strategies.

### LCP for Pavements

1. DefineSubsets of Network for Analysis
2. Establish Treatment Rules and Costs
3. Input Analysis Parameters
4. Run Analysis and Evaluate Effectiveness
5. Summarize Results

# Applying Other Life-Cycle Management Approaches

**Assets that are managed using an interval-based or reactive management strategy require different approaches for planning and optimizing work than assets managed using condition.** The life-cycle plans for these assets range in terms of sophistication depending on the available data.

## When to Use Approaches Other Than Condition-Based Management

Condition-based management requires a commitment to reliable asset condition information. The necessary level of effort is not likely to be appropriate for some assets. Some assets do not lend themselves to management using a traditional condition-based management approach. The four most common reasons assets do not fit a condition-based approach are as follows:

- **The assets do not have a typical life cycle.** This group of asset classes includes rock slopes or other perpetual features that do not have predictable deterioration patterns.
- **The assessment of condition or performance may not be feasible.** The most common type of assets in this second group are geotechnical or utility assets for which many elements may be buried or otherwise inaccessible. The absence of a rating methodology may also drive the management of assets using something other than a condition-based approach.
- **The life cycle is driven by factors other than condition.** There are many assets that are replaced when they are worn out or obsolete. Technology assets, which are susceptible to obsolescence at a frequency similar to their functional service lives, are examples of assets that fall into this category.
- **The assets have long service lives and the failure of individual assets presents limited risks to safety or system performance.** Examples of these asset classes include guardrail, gravity retaining walls, or highway lighting.
- **The performance expectations require the asset to remain in near-new condition.** For safety-critical assets, replacement may be necessary before signs of deterioration are evident. This is most common in risk-averse industries such as aviation. However, contractual arrangements, such as in public–private partnerships (P3), may require condition or performance targets that warrant a life-cycle management approach other than condition-based.

As discussed earlier, assets that fall in these categories are typically managed using an interval-based approach or a reactive approach. Some agencies also use a risk-based approach for certain types of assets, such as rockfall management. These three different approaches are briefly explained and examples are provided for each approach.

# Alternative Life-Cycle Management Approaches

Three alternative life-cycle management approaches are discussed in this section. These are interval- or age-based strategies, reactive strategies, and risk-based strategies.

## Interval- or Age-Based Management

Interval- or age-based strategies can be utilized for failure-critical assets, assets subject to obsolescence, or assets with no or limited maintenance actions. Age-based strategies replace assets after a given time in service without regard to the asset's condition at that time. This approach can also be used for very short-lived assets, such as paint markings. Advantages include proactive minimization of failure and reduction of uncertainty in funding needs. An agency that replaces signs on a 7-year cycle or replaces pavement lane markings annually is using an interval- or age-based approach to manage its assets.

Interval-based strategies are also useful for assets that do not show physical wear, but are safety- or operations-critical.

## Reactive Management

Reactive strategies can be used for assets that have long service lives and limited maintenance options. Reactive strategies can be based on the results of an ongoing monitoring program or on event reporting. Examples of assets that may be monitored periodically to check that they are working as intended includes retaining walls and overhead sign structures. Assets that may be more likely to be maintained based on a report that the asset is damaged or no longer working include light bulbs and guardrail.

### Practice Example
### Interval-Based Approach to Managing ITS Assets

**Nevada DOT**

Nevada DOT recognized that the level of investment in ITS equipment (e.g.,, closed-circuit cameras, dynamic message signs, flow detectors, highway advisory radios, environmental sensor stations, and ramp meters) was increasing significantly and the importance of this equipment to network operations was growing. As a result, the DOT chose to establish a method of managing its ITS assets that would minimize the risk of failure and provide information to support budgeting activities. However, since the DOT had limited data on its ITS components, a process was developed that relied on the following factors to establish maintenance cycles:

- Historical performance
- Manufacturer's recommended service life
- To determine the condition of ITS traffic cameras, Nevada DOT developed a transition probability matrix with four condition criteria based on the device manufacturer's recommended service life as follows:
  - **Good**—device age is less than 80 percent of the manufacturer's recommended service life
  - **Low risk**—device age is between 80 to 100 percent of the manufacturer's recommended service life
  - **Medium risk**—device age is between 100 to 125 percent of the manufacturer's recommended service life
  - **High risk**—device age is greater than 125 percent of the manufacturer's recommended service life

The transition probability matrix was used to model ITS asset deterioration and program maintenance actions over a 10-year analysis period via the use of a simple spreadsheet tool. The results of this analysis showed an interval-based approach to managing ITS assets would result in an estimated savings of $1.1 million over a 20-year period.

Source: Nevada DOT TAMP. 2018

## Risk-Based Management

While all management strategies are risk-based, there are times when risk assessments are used directly as the measure to establish objectives, set targets, drive decision making, or assess progress. This approach is used when the condition of the asset does not directly represent the level of asset performance and the potential impact of an asset's condition on system performance must be considered. This approach is commonly used for managing slopes and other geotechnical assets.

**Practice Example**

### Risk-Based Geohazard Management Program

#### Colorado DOT

CDOT responds to between 50 and 70 geotechnical emergencies a year. The traditional approach to managing rockfalls was based on the size and frequency of rockfalls. This approach did not consider the criticality of the facilities that could be impacted by a geohazard event. Since 2013, the CDOT has used a risk-based approach to evaluate and prioritize geohazard mitigation activities based on the size of the geohazard areas and the frequency of falls. CDOT's approach includes a measure of Risk Exposure (RE), which is based on three components:

- Average annual daily traffic (AADT).
- Likelihood of a vehicle being affected by a geohazard event. This metric considers site distance, the number of previous rockfall accidents, and a measure of how frequently a vehicle is below the hazard on a daily basis.
- Reduction Factor. This considers the effectiveness of prior mitigation actions to reduce the RE score.

CDOT's geohazards program uses the RE to allocate an annual budget of about $10 million to manage geohazards. Due to the inherent uncertainty of geohazard management, in addition to the geohazard management program, maintenance staff regularly patrol highways known to have geohazards. If a hazard requiring immediate action is identified, maintenance crews respond promptly. Using the RE for prioritization allows CDOT to focus its efforts on reducing the impact of geohazards on users of the highway system.

# Implementing Life-Cycle Management

**Implementation of life-cycle management often requires agencies to review existing data sets, processes, and policies to ensure that the recommended scenarios are reflected in the projects and treatments that are programmed and constructed.** Within transportation agencies, this often requires improved coordination between business units such as planning, programming, engineering, maintenance, and operations. Information about strengthening organizational communication and coordination was discussed in Chapter 3.

This section focuses on the aspects of implementation that are most directly related to using life-cycle management results to maximize the service lives of infrastructure assets as cost-effectively as possible. It highlights the need to evaluate agency policy, data issues, and work processes to support life-cycle management.

## Linking Life-Cycle Strategies to Asset Management Policy

Agency policies influence the types of decisions that are made within an agency and the priority with which activities are funded. The life-cycle management approach selected for each asset class will impact the type of policies, procedures, and data required to support investment decisions to ensure alignment between planned and actual work activities.

Aligning the organization to support the implementation of life-cycle management strategies involves many of the same types of organizational change processes discussed in Chapter 2. As part of this alignment, an agency must ensure that it has in place the processes and resources needed to deliver the work activities required for executing the selected life-cycle strategies.

Chapter 2 introduced the importance of establishing asset management policies to help integrate asset management at all level of an organization. An asset management policy can support life-cycle management by establishing processes for setting realistic performance objectives and treatment strategies that focus on a commitment to sound, long-term investments. The following examples demonstrate how agencies can select a life-cycle approach that supports the agency's higher-level policies.

## Data Required for Implementation

All life-cycle management approaches need inventory and performance information but the extent, detail, accuracy, and precision of the required information varies greatly given the chosen approach.

Assets that are managed using a condition-based approach rely on detailed inventory and performance information so that current and future conditions can be estimated, and the benefits and costs associated with each viable strategy can be evaluated. Interval-, time-based, and reactive approaches can be performed with less detailed information about the assets. Agencies using these approaches may estimate the size and age of the inventory at early levels of maturity. Over time, the type of information available and the level of detail associated with it may improve, allowing the agency to mature in terms of its analysis capabilities.

Table 4.3 provides examples of typical management strategies for common highway asset classes and the types of information used to support each one. The information in Table 4.3 reflects general trends in transportation agencies. In practice, each agency must identify the specific elements and data requirements needed to support their needs within resource constraints. Chapter 7 addresses methods of collecting information efficiently (see Table 7-3) and Chapter 6 stresses the importance of keeping inventory and performance data current. Establishing data governance structures to manage asset data is also an important consideration, as discussed in Chapter 7.

## Incorporating Life-Cycle Management into Work Planning and Delivery

Life-cycle management approaches and corresponding life-cycle strategies are the means by which agencies identify the work necessary to meet their asset management goals within funding constraints. However, for those asset management goals to be met, the necessary work must actually be delivered. This requires the recommendations from life-cycle analyses to be incorporated into the business processes by which the agency identifies, prioritizes, programs, designs, and delivers work. In most agencies this includes multiple business processes and funding streams. The following subsections describe how life-cycle management can be incorporated into common processes within transportation agencies.

### Planning and Programming

The planning process seeks to identify the set of investments that will effectively and efficiently achieve an agency's goals and objectives. As an agency alters its approach to managing assets, this may change assumptions previously influencing the planning process. Significant changes in an agency's approach to managing its assets can require updates to long-range or strategic plans. Similarly, changes in long-term objectives or plans can prompt a change in life-cycle strategy or approach.

Coordination is needed between long-range transportation planning, performance-based plans such as the TAMP, and programs of

**Examples**

### Linking Maintenance Strategies and TAM Policies

**The following hypothetical examples show how policy and management strategy work together to deliver transportation services and manage risks.**

**Reactive Strategy Example—Agency A** has determined its guardrail inventory is generally in good condition and typically replaced as part of pavement rehabilitation projects. On average, replacements occur at least every 30 years, which is more frequent than the expected service life ranging from 40 years for cable to 75 years for concrete barrier. As a result, the agency can accept a life-cycle strategy of maintaining a complete inventory and annual inspection of a random two-percent sample.

This life-cycle strategy introduces the risk of a rail being damaged by collisions or other events and left in service, presenting a danger to highway users. To manage this risk, the agency implements a policy of repairing all damaged guardrail within three weeks of becoming aware of damage. Additionally, internal procedures are put in place to notify area maintenance managers of incidents reported through the state police accident reporting system, and standby maintenance contracts are established for guardrail repair to ensure adequate resources are available in compliance with the new policy.

**Condition-Based Maintenance Example—Agency B** has determined it can provide significant, long-term performance improvement in average bridge condition and service life if it can increase its investments in bridge maintenance activities like sealing concrete, repairing joints and spot painting steel. To fund this initiative, however, the agency must replace three fewer bridges on average each year. The short-term impact of this new life-cycle strategy is an increase in the risk of unsafe conditions occurring on bridges that would have been replaced under the previous strategy. To overcome this risk, the agency increases the frequency of inspections on bridges exceeding the level of acceptable risk according to analysis from its bridge management system, and a series of standby contracts are established to provide rapid response of specific structural repairs to extend the service lives of poor bridges by addressing only critical structural deficiencies or risks.

work, such as TIPS and STIPs (see Chapter 2). In particular there is a need for alignment between the financial planning procedures and documentation between these different efforts and products. Although programs tend to be relatively short term, often 1 to 4 years in length, agencies must identify investment needs several years in advance to ensure projects can be delivered when required. Complex reconstruction or modernization projects can take 10 years or more to deliver from scoping to construction. Thus, it is important to keep planners informed of changes in selected life-cycle strategies. Changing new life-cycle strategies may lead to significant differences in the projects selected.

**Table 4.3 Typical Maintenance Strategies and Supporting Data**

| Asset Type | Typical Maintenance Strategy | Typical Information Collected and Used |
|---|---|---|
| **Pavements** | Predictive, condition-based maintenance | • Linear referencing system<br>• Segmentation with unique IDs<br>• Inventory (e.g., width, pavement type, and other identifying attributes)<br>• Condition data (e.g., ride quality cracking, rutting, faulting, and others)<br>• Deterioration models<br>• Available treatments<br>• Treatment unit costs |
| **Bridges** | Predictive, condition-based maintenance | • National bridge inventory (NBI) Data<br>• National bridge element (NBE) condition data<br>• Vulnerabilities (e.g., scour, seismic, flood)<br>• Deterioration curves<br>• Treatment options<br>• Unit costs |
| **Overhead Sign Structures** | Monitoring-based or interval-based maintenance | • Inventory data, modeled after NBI<br>• Element level condition data, modeled after NBE<br>• Design life<br>• Structural specification (e.g., proper bolt torque) |
| **ITS Assets** | Interval-based maintenance | • Location<br>• Asset ID<br>• Inventory data to identify type or class<br>• Installation date<br>• Manufacturer recommended service life |
| **Guardrails** | Reactive maintenance | • Location<br>• Type<br>• Functional requirements |

Source: FHWA. *Handbook for Including Ancillary Assets in Transportation Asset Management Programs.* 2019. Prioritizing Assets for Inclusion in Transportation Asset Management (TAM) Programs.

## Project Engineering

Life-cycle management is a framework for identifying the appropriate treatments throughout an asset's service life to maximize performance. Project engineering includes the processes for packaging work into contracts for delivery. Thus, project engineering is responsible for ensuring the right treatment is delivered at the right time and within the anticipated cost. Additional details on work packaging to support asset management are provided in Chapter 5.

Maintaining strong internal controls ties project decisions to their impacts on anticipated asset performance. Project schedule changes may cause inappropriate treatments to be applied to assets, resulting in unnecessarily high costs or poor performance. Scope changes often lead to cost changes, and while cost changes may be addressed for a specific project, the funds added to that project would not be available to address other system needs.

## Use of Agency Maintenance Forces

Effective delivery requires adequate labor capacity with appropriate training, proper equipment, and necessary materials. Changes in an agency's management approach can alter the requirements for any of these aspects of maintenance management. The necessary treatments cannot be delivered if a properly sized and equipped crew cannot be assembled. Maintenance staff cannot administer treatments for which they are not properly trained or correctly supplied. Therefore, it may be important to have maintenance management staff actively engaged in the process of identifying preferred life-cycle management approaches.

### Practice Example
### Life-Cycle Management across a Diverse Portfolio

**The City of Fredericton, New Brunswick**

The City of Fredericton has, over the past 15 years, implemented several life-cycle management strategies that have significantly changed how it delivers municipal services with its infrastructure. Three examples are briefly summarized below:

- Long-term life-cycle planning: Infrastructure accounting policy changes led to the city establishing long-term replacement forecasts for each asset class to estimate the sustainable level of funding required for investment for capital budgeting. This required a complete inventory of their assets and changes in how future replacement costs were estimated, as well as changes to the analysis period used for long-term planning. At least one life cycle for all assets had to be captured in the forecast horizon.
- The city implemented a Lean Six Sigma strategy to assess and improve processes and service delivery. This methodology helped identify efficiency opportunities but also identified intervention strategies that were not previously considered in project scoping.
- The city reviewed service requirements in terms of labor and equipment required as part of the lean approach, and in some circumstances managed to create time savings or hard dollar savings, or both; hence it shifted resources to have different roles for service delivery. In some cases, the service delivery was contracted to external service providers.

How-To

# Determining What Data Is Needed to Support Life-Cycle Management

**Once a maintenance strategy for an asset class or subclass (e.g., condition-based, interval-based, or reactive) is selected, data is required to support the types of decisions needed to manage the asset.** The type of data collected will vary based on the selected strategy and t the specific decisions needed to manage the asset class. The objective is to make informed, data-driven decisions on the appropriateness, timing, and priority of treatment options over the service lives of specific assets. These decisions are supported by field collection of inventory and condition data, as well as the development of higher-level measures and analysis results from that data. The following sections describe methods for determining what data is essential or desirable to support maintenance decisions and the delivery of work.

Regardless of the life-cycle approach selected (i.e., condition-based, interval-based or reactive), data is required to support the types of decisions needed to manage the asset. The type of data collected will vary based on the selected approach and the asset class or subgroup. As described in this chapter, data is needed to support decision making about the type and timing of actions that can be taken to delay or address asset deterioration, damage, premature failure, or other performance decline. In some cases, the data can directly trigger decisions, such as accident data informing a process to repair or replace guard rail. In other cases, the data is used to support analyses that inform decision-making processes, such as condition-based management.

While supporting investment decisions may be the primary purpose for collecting and managing asset data, agencies may have other purposes, such as internal or external reporting or mandates. Agencies need to make hard choices about what data is essential to support business practices and what data is merely desirable. Once that is determined, the agency must next evaluate the benefit derived from the desirable data along with the cost and benefit of collecting and managing that data. This how-to guide provides a simple three-step approach to identifying and evaluating essential and desirable asset data, to determine which data should be collected to support life-cycle management. This approach is based on material from the FHWA document, *Handbook for Including Ancillary Asses in Transportation Asset Management Programs*, (2019). The handbook provides additional detail and several examples of data elements typically collected to support life-cycle management of different assets. Additional details on data collection and management can also be found in Chapter 7 of this guide.

**What Data Is Needed**

1 Determine the Essential Data to Support the Maintenance Strategy

2 Determine Desired Data to Support the Maintenance Strategy

3 Align Business Processes

## 1. Determine the Essential Data to Support the Maintenance Strategy

While the management approaches discussed in this chapter vary in their degree of complexity, all three require some essential data, which can be categorized into asset class and subclass information, unique identifier information, individual asset location information, and action trigger(s). The following sections describe how to determine the best means of addressing each of these data elements.