NCHRP Project 02-26 Implementation of Life-Cycle Planning Analysis in a TAM Framework

Implementation Plan

Introduction

Highway infrastructure assets are designed and built to serve long, useful lives. These assets undergo structural aging and degradation driven by traffic and environmental factors, natural and human hazards, and changes in demand and functional use. Many decisions are made through the whole life of the asset from design through replacement.

Life-cycle planning (LCP) lays out the processes and procedures to support decision-making for managing assets over their life-cycle. LCP undertakes a thorough evaluation and balancing of cost (investment), risks, and performance to determine an optimal sequence of maintenance, preservation, rehabilitation, and reconstruction actions over the life-cycle. The optimal sequence of life-cycle activities is predicated on selecting the right treatment at the right time at the asset level and selecting the right project at the network level.

NCHRP Project 02-26 has developed a framework for LCP designed for selecting an optimal subset of projects annually with cost-effective treatment options. The proposed framework identified both high-level and specific work steps that can be incorporated into current agency practices. The research products developed under this study include: (i) a final report, (ii) an LCP guide, (iii) a PowerPoint presentation, and (iv) a technical brief. This implementation plan describes strategies for agencies that are interested in improving the overall transportation asset management (TAM) practice for enhanced LCP analyses.

The intended audience for this implementation plan includes the managers and practitioners of asset management programs at state departments of transportation (DOTs) and local agencies. This includes the managers and engineers of agency asset and performance management programs, and individual asset programs, including pavement, bridges, geotechnical assets, and Transportation Systems Management and Operations (TSMO) assets.

Updating LCP in TAM Process

Highway agencies routinely make decisions regarding the life-cycle of assets. These decisions are the outcomes from applying a combination of historic practices, agency policies and preferences, and data analysis rooted in sound economic and engineering principles, and are driven by service delivery goals, regulatory considerations, financial constraints, and trade-offs. To make effective TAM decisions, highway agencies strive to follow a common approach and set of principles as laid out in the American Association of State Highway and Transportation Officials (AASHTO) TAM Guide. However, each highway agency has a unique set of TAM practices to some extent, which invariably influences the way the agency plans for their assets' life cycles. Furthermore, even within an agency, the TAM practices are not the same for all asset classes. There is no "one size fits all" approach to LCP implementation.

The LCP process will follow the prevailing TAM practices and enablers established for managing a given asset class. All the building blocks of TAM, including asset inventory, condition measurement and forecasting, treatment planning, and financial planning, apply to the LCP practice. Therefore, the LCP practice is inherently tied to the maturity of the TAM practice.

To develop life-cycle plans, the agency must consider the maturity of the overall practice being followed for a given asset class, and the enablers of life-cycle planning in particular. Note that the quality of the life-cycle decisions depends on the degree and sophistication of the TAM practice. The life-cycle management strategies can be grouped into three maturity levels:

- Emerging – The agency has begun to improve the TAM practices for a given asset class, such as building a complete and accurate inventory and collecting condition data. The agency has been applying historically-used life-cycle management strategies to the entirety of the asset class on the network. No decisions are made based on the life-cycle considerations at the individual asset level.
- Strengthening – The agency has been making many key improvements to the LCP enablers for a given asset class and strengthening the overall practice. The agency's TAM practice has matured to perform predictive modeling to select treatment needs at an individual asset level, while the investment needs at the network level are aggregated bottom up from individual project needs.
- Advanced – The agency has established LCP enablers to make decisions on an individual asset's life-cycle needs. In addition, the agency has the capabilities to incorporate risks and uncertainties in treatment and project selection. The agency has a good understanding of the vulnerability of assets under risk and uncertain scenarios, and changes are made to treatment decisions on an asset-by-asset basis accordingly.

The maturity levels of individual LCP enablers are described in Appendix A.

In the continuum of maturity scale, the implementation of the LCP approaches essentially indicates the enhancements to their existing capabilities to achieve the desired maturity level progressively over time. An incremental approach to the implementation of enhancements is suggested to ensure certainty and consistency. Therefore, it is recommended that the agency devise an implementation plan to undertake improvement activities.

The implementation process entails the following high-level steps:

- Establishing a steering committee
- Conducting a benchmark analysis
- Developing a work plan
- Managing change

Establishing a Steering Committee

To ensure an effective implementation process, the first step is to establish a charter that includes the scope and objectives, members of the steering committee and their roles, implementation schedule, and meeting dates. Life-cycle decision-making is a multidisciplinary approach. Whether the decisions are strategic or routine, the decision-making involves and influences a large cross-section of an agency. It is important that those who are involved in this decision-making are involved in LCP decisions. Furthermore, any enhancements, such as additional data collection, analysis/modeling, and implementation/ delivery, need to be aligned to ensure that all asset management decisions are consistent.

The steering committee should comprise those individuals responsible for making LCP decisions, primarily the managers and practitioners of individual asset programs. The steering committee is recommended to include engineering practitioners (e.g., those in design and management of pavement, bridge, TSMO, and assets) who have an understanding of how assets behave under in-service conditions, the causal factors that explain asset degradation, and the effectiveness of treatment options. Note that the application of engineering principles and practices of assets is imperative to the development of life-cycle management strategies. The steering committee could include maintenance personnel to explore the inclusion of maintenance work orders, frequencies, and costs in the life-cycle plan of assets; and information technology personnel to enable the enhancement of data governance and information system needs.

The steering committee could also benefit from representation of other divisions of the agency to address the following common information gaps for life-cycle analysis:

- Future traffic demand, traffic growth rate, and composition
- Forecasts of future climate and extreme weather events
- Future revenue forecasts for financial planning
- Congestion metrics for user disbenefits computation
- Crash history to establish causal relationship between crash incidents and asset conditions for user disbenefits computation

The primary functions of the steering committee are to support the implementation work, allocate organizational and financial resources, approve proposed improvements, ensure alignment of proposed improvements with business goals, conduct technical reviews and decisions, and monitor progress. If extensive outreach is required with internal and external stakeholders, the steering committee can consider outreach strategies such as workshops and questionnaire surveys.

Conduct a Benchmark Analysis

The purpose of the benchmarking analysis is to gain an internal understanding of the current LCP approach, processes and capabilities; establish their maturity levels; and identify potential improvement opportunities as inputs for devising a work plan. The agency should conduct an internal analysis of the LCP practices for each asset classes of interest. Figure 1 presents the schematic of the process for conducting benchmark analysis of TAM capabilities, as adopted from the AASHTO TAM Guide.

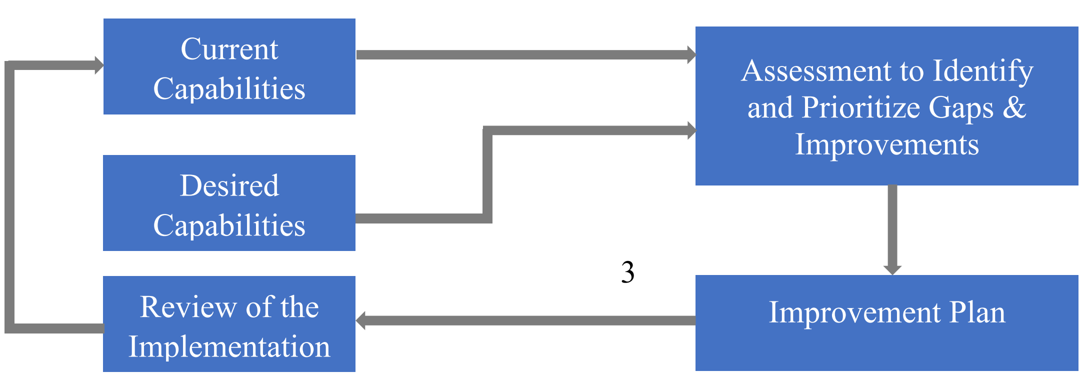

Figure 1. Implementation Process of TAM Improvement (Adapted from AASHTO TAM Guide)

The benchmarking process will typically entail the following steps:

1. Decide what asset classes to prioritize for benchmark analysis. The agency can follow the decision criteria, as outlined in the AASHTO TAM Guide, to decide what asset classes can be selected for advancing LCP practices:
   - Asset classes that require greatest level of management attention.
   - Asset classes that present the greatest risk or are deemed critical to achieving the service outcomes that the agency is providing.
   - Asset classes that have high asset values in terms of total replacement costs and whole life costs.
   - Asset classes that benefit the most from improving the LCP practices, such as those that require a higher share of the maintenance budgets, and those assets that are considered to demonstrate greater benefits upon implementation.
   - Asset classes that require the least effort to advance the practices or those assets where implementation can show results quickly need to be considered.

2. Review the current LCP practices at each asset class level. Leverage the steering committee meetings and existing documentation to review the current practices. Collect additional information, if necessary.

3. Analyze the current LCP practices to assess their maturity. The agency could consider the following questions for each asset class of interest:

   - Does the agency have a **complete and accurate inventory** of assets?
   - Are **appropriate performance measures** in place that help the agency manage the assets through the life-cycle adequately (e.g., performance measures that indicate the time and timing of future treatment needs, end-of-life condition, service disruption risks in response to hazard events)?
   - Does the agency maintain adequate **construction and maintenance history** to manage the assets through the life-cycle (e.g., maintenance work orders)?
   - Does the agency have a systematic approach to evaluate **data quality** (e.g., data cleaning rules), flow of data across information systems, and update/maintain data changes over the asset life-cycle?
   - Does the agency have **reliable forecasts of future demand** that would affect the ability to deliver the desired performance (e.g., traffic and climate data)?
   - Does the agency have a good understanding of the **causes of asset damage** and distresses? Does the agency have a robust decision criteria (e.g., decision trees) to

select appropriate treatments in response to the types and severity of observed distresses?
- How well can the agency develop **accurate and reliable forecasts** of the type and timing of future intervention needs (e.g., time to an intervention using condition forecasting, time of an intervention using survival models)?
- Does the agency have good information on the proposed asset treatments, and operational and safety improvement actions?
    - **Treatment effectiveness** (e.g., service life extensions and performance jumps upon treatment application)
    - **Treatment costs**
    - **Treatment alternative selection** (e.g., benefit-cost analysis)
- Does the agency have a good understanding of **asset-specific risks** that might result in shorter service life or earlier-than-expected failures?
- Does the agency have a good understanding on the **criticality of assets** on the network?
- Does the agency have **robust objective functions** or criteria for prioritization or optimization of projects under constrained scenarios?
- Does the agency have capabilities to evaluate the **implications of delayed or missed intervention** (e.g., increased depreciation in asset value, increase in life-cycle costs, increase in user disbenefits)?
- Does the agency have a reliable **financial plan**?
- Do agency personnel have sufficient competencies to conduct life-cycle planning? What are the **training needs** for agency personnel?

The agency should evaluate the current maturity of the pertinent enablers, which includes decision criteria, data quality, analytical models, information systems, and processes necessary for a robust life-cycle planning. The analysis will contextualize the current and desired maturities of enablers against the business objectives, which lend themselves to improvement needs.

4. Regardless of whether the maturity analysis will lead to an improvement of an enabler or not, the agency will gain a better understanding of their current practices. This understanding will lead to identifying the gaps in current capabilities, the next evolutionary step in the maturity scale, and potential improvements. The analysis can also take the best practices and those of peer agencies as reference points.

5. Identify opportunities for improvement to advance the maturity of each enabler. Further assessments are necessary to evaluate the feasibility and relative importance of improvements relating to data, systems, skills, and resources for further prioritization. The prioritized list of improvements is established.

Developing and Executing a Work Plan

Once the prioritized improvements are agreed upon, the agency should develop a work plan to communicate the actions. The work plan should document the following:

- Current capability/issue
- Desired capability
- Required improvement activity
- Activity sequence (preceding and succeeding)
- Prerequisites
- Delivery strategy (e.g., internal development or procurement)
- Anticipated costs
- Schedule
- Responsible units
- Supporting units and partners
- Potential barriers and risks
- Mitigation strategy

The agency is recommended to conduct an impact assessment on draft products or releases that evaluates the effects and impact of transitioning from current to proposed capabilities. The impact assessment would be useful:

- To determine how the proposed change would impact the outputs, outcomes, and the overall business objectives;
- To screen for potential errors and issues, and mitigate them accordingly; and
- To investigate the interlinkages of LCP with those across the TAM practice and performance management in-large, including risk management, resilience, and financial planning.

At a minimum, the impact assessment should compare and validate the outputs of the proposed changes with those of the current capabilities, and the differences between them should be explainable. For example, in a hypothetical scenario, an agency proposes to improve the bridge rating methodology from National Bridge Inventory (NBI) component-level condition ratings to National Bridge Element (NBE) condition states. The agency should perform cohort comparisons of bridge ratings using NBI (current capability) and NBE condition data (desired capability), and forecasts of condition ratings and investment needs over a pre-defined time, and validate whether the observed differences are explainable.

Upon the completion of each improvement activity, the agency should undertake the following activities:

- Detailed documentation of business rules and procedures.
- Perform quality assurance on improvement activities to ensure that the desired objectives and outcomes are achieved.
- Update the relevant sections of TAM plan.
- Roll out plan.

Managing the Change

The agency should put a change management strategy in place to successfully roll out the enhancements to the LCP capabilities. The change management strategy should include the following at a minimum:

- Internal buy-in and support from the leadership and stakeholders. Forming a steering committee would be helpful in coordinating with the stakeholders.
- Establishing and executing a communications plan to disseminate information to other stakeholders on the need, successes, and benefits of the proposed improvements.
- Developing standard operating procedures and guidelines to establish standard practices.
- Providing training courses to educate the existing staff on the proposed improvements and impart them with necessary knowledge and skills.
- Monitoring various improvement activities and reporting on the status and future plans.

Additional Research and Technology Transfer Needs

The agencies should recognize the gaps in current information and analytical capabilities to perform LCP analysis effectively:

- Lack of element-level deterioration models for bridge structures.
- Lack of translation between element- and component-level deterioration for bridge structures.
- Non-availability of maintenance costs and effectiveness.
- Lack of robust models to incorporate the effectiveness of pavement and bridge assets.
- Lack of practice maturity to enable LCP analyses for high-level assets, including intelligent transportation systems and geotechnical assets.
- Lack of design standards and related analytical models for incorporating resilience for highway infrastructure assets.

Many ongoing NCHRP and Transportation Pooled Fund studies are investigating these gaps. The completion of those research studies might address the gaps mentioned above.

To further support the implementation of the LCP framework, suggested future research could focus on the following topics:

Life-Cycle Data Model: The LCP is a data-intensive exercise. The LCP analyses require a high-quality and complete set of life-cycle data to make effective decisions. To support the LCP process, the DOTs will benefit from a single life cycle model. This model will serve as a digital informational construct of the infrastructure system that houses all data relating to the life cycle of an asset or group of assets in a facility. The information requirements of this model encompass a wide range of data collected over the life cycle of the infrastructure system, including but not limited to design, construction, maintenance, and operations details. As the LCP matures to incorporate resilience considerations, the information needs will also include the frequency, spatial coverage, and intensity of natural and man-made hazards, the extent of asset damage, and repair costs. Some of these data types reside in other information systems or repositories within the agency, while other data types might be owned by other governmental agencies and private entities. The DOTs need additional guidance on how to enable the seamless exchange of data to TAM systems from other enterprise systems, such as construction and safety information systems. The guidance can also address how to effectively utilize publicly available and proprietary data to supplement the DOT-owned data for TAM systems.

Risks and Uncertainties in Life-Cycle Planning. Risks and uncertainties have garnered greater attention and urgency in recent years, particularly in response to the effects of climate change and the increased need to effectively respond to a wide range of potential hazards and threats with varying degrees of uncertainty. To mitigate climate change and other risks, investment decisions are being made based only on a quantification of risks to a single asset or portfolio of assets. Often risk assessments provide a "snapshot in time" typically based on elicitation of expert opinions or probabilities of historical events. Because of the dependence on probabilities, uncertainties receive less attention than they deserve.

The risk profiles of assets are likely to change over time as new information is available, and the associated vulnerabilities are likely to change as asset condition changes over time. Furthermore, the relationship between risk intensities and asset condition-driven vulnerabilities has not been comprehensively studied. There is a need to develop a set of practices and quantitative methods that dynamically or continuously account for a broad set of threats and opportunities in LCP as a part of TAM business processes.

Equity in Performance-Based Planning and Programming. When resource allocation decisions are made on performance-based programming principles, it can have implications for equity. One point of conflict between performance-based programming and equity is the likelihood of rural and tribal areas receiving lower priority in funding allocation decisions in comparison with urban areas. For instance, lower-volume roadways in rural areas are likely to have lower priority scoring than roadways in urban areas. The potential for under-investments in rural areas tends to create social, economic, and geographic disparities in how assets are managed and how vulnerable those assets are to natural and human-caused hazards. There is a growing recognition of how natural hazards disproportionately affect socially vulnerable communities in both urban and rural areas. The DOTs have begun to explore social vulnerability indicators, such as Social Vulnerability Index (SoVI), to screen for vulnerable populations, identify their geographic areas, and accordingly, include them in the prioritization of projects. Such indicators are necessary to build redundancy in facility design, address challenges in service disruption and evacuations during the event, and manage recovery in both urban and rural areas. There is a need for guidance and methodologies to support the analyses of potential disparities in asset condition and performance across various geographic areas, redundancy and recovery considerations, and their implications of natural hazards for both users and communities.

Asset Management Data Standards. Data standards are necessary to ensure completeness, consistency, and accuracy of data. Data standards also facilitate the exchange of data across information systems. Data standards are necessary for each asset class, and would typically include a list of attributes by asset element, their descriptions, data types, allowable range of values if applicable, required or optional, and other references. The NBI, National Bridge Elements, and Long-Term Pavement Performance Program serve as references for developing data standards. The New Zealand Transport Authority (NZTA) has developed asset management data standards to provide a consistent, structured, and integrated approach for data management. NZTA has developed excel worksheets to document and maintain data standards for a wide range of asset classes.

Appendix. Maturity Descriptions of LCP Enablers

Enabler	Emerging	Strengthening	Advanced
Asset Types in Inventory	Pavements and Bridges	Pavements, Bridges, and Ancillary Assets	Pavements, Bridges and Ancillary Assets. Includes Transportation System Management and Operations (TSMO) and Geotechnical assets
Asset Register Data	Location and asset subclass	Location, asset subclass, material type, inspection/condition, and age data at a component level	Inventory, asset type, inspection/condition, asset age, cost and work history at a component level
Pavement Condition	Only International Roughness Index (IRI) is used. Other distress, even if captured, is not used when assessing the need for assessment or treatment selection. Age is used in tracking the life-cycle stage of the asset.	Either a single composite or multiple indices of both load-related and non-load-related pavement distresses are used. Load related distresses are used as a surrogate in tracking the lifecycle stage.	Structural adequacy of the pavement is captured along with surface-based distresses.
Bridge Condition	Both National Bridge Inventory (NBI) condition ratings and element-level condition ratings are collected. Element-level condition ratings are not integrated with NBI ratings. Element level condition data, if collected, is not used in deterioration modeling and project-level decision making.	Both NBI condition ratings and element-level condition ratings are collected. Element-level condition ratings are translated into NBI ratings and/or used in the computation of health indices for use in deterioration modeling and project-level decision making.	Physical parameters that cause deterioration, such as chloride-induced corrosion models, are collected to facilitate mechanistic modeling of deterioration. Physical parameters are mapped to element-level data.
Culverts Condition	A general appraisal of the culvert condition based on deterioration, corrosion, abrasion, blockage, etc. using a 5-point, or 10-point scale.	Element-level inspection data on structural (pipes and joints), hydraulic (scour and sedimentation) and geotechnical (embankment) data.	Fundamental models are used in forecasting pipe deterioration and failure.

Enabler	Emerging	Strengthening	Advanced
ITS Assets Condition	Useful life is estimated based on manufacturer recommendations, age, operational status, and obsolescence.	Estimates of useful life available at component level based on factors, such as device history and costs.	Reliability-based models to forecast steady-state failure and early life factor (e.g., mean operating time between failures, mean time to failure)
Geotechnical assets Condition	No condition measure is used. Reactive intervention.	A general appraisal of the condition (e.g., condition index) or the risk (level of risk) posed by geotechnical assets based on inspection, condition states, history and asset characteristics.	The risk or reliability-based condition index determined based on engineering assessment.
Ancillary Assets	No management systems	Management systems that collect inventory, condition and maintenance and rehabilitations modules	Asset management processes in-place
Deterioration Forecasting for major assets	Age-based models or life expectancy estimates are used	Models consider factors other than age, such as traffic, climate, materials, etc. Dependent on historical trends	Models consider other factors. Generally capable of capturing changes in future trends of causal factors
Resilience: Slow Changing Trends	Accelerated deterioration due to factors, such as climate change, construction quality, and truck weight and size, is recognized but not quantified.	Models are available to evaluate the effects of factors, but not incorporated into the LCP/TAM process.	The effects of factors are fully incorporated into the framework.
Resilience: Shock events	Shock events are recorded but not incorporated into the TAM processes.	System-wide risks and asset vulnerabilities are identified. Lacks engineering models and resilience planning. Adaptation measures are undertaken on a project basis.	Shock events are forecasted at the system level, impacts are assessed, and adaptation measures are planned within the TAM framework.
Non-Resilience related Risks	Risks are identified in the risk register, but the risk management process is yet to be incorporated into the AM process.	Risks are identified, analyzed (for impacts), and prioritized. Some risks are managed in an ad-hoc manner, but yet to be fully integrated into the AM process.	Risks are fully integrated into the AM process.

Enabler	Emerging	Strengthening	Advanced
Life Cycle Cost analysis (LCCA)	No LCCA	Deterministic LCCA	Probabilistic LCCA to incorporate uncertainties with inputs
Asset Valuation	Gross replacement costs are available. Rule-based asset valuation (e.g., fair condition = 50%)	An asset is valued based on its current condition.	Asset valuation takes into account the lifecycle stages.
Cost Models	Unit costs (e.g., per unit quantity or per cost mile) are available.	Historical costs and their corresponding cost indices are tracked	Short-term cost inflation estimates are available.
User Cost Models	No user costs are captured.	Only service costs (travel delay, vehicle operating costs (VOC), and crash costs due to work zone exposure) are captured. No condition-related user costs (e.g., IRI related VOC, friction-related crash, vertical clearance related detour).	Both condition-based and service costs are captured. Models are available to capture condition-related user costs
Safety Data	Safety data is incomplete. Data not available at all crash severity levels and road segments	Crash rates are available at all crash severity levels and road segments. Crash prediction models are available. Gaps in analytical models and tools. Limited safety analysis possible at the project-level.	Crash rates are available at all crash severity levels and road segments. Analytical tools are available to perform network-level LCP analysis. Capabilities to include safety impacts of safety, expansion, and operations (e.g., ITS) programs.
Mobility Data	Basic mobility data (e.g., VMT, speed from National Performance Management Research Data Set (NPRMDS) is available. Significant gaps due to issues such as conflation challenges, mismatched segments, and lack of data consistency at the segment level.	Mobility data (e.g., speed, travel time) is available. Analytical models are available to perform project-level assessments.	Mobility data and analytical models are available to incorporate mobility impacts of safety, expansion, and operations programs into network-level LCP analysis.
Traffic Forecasting	Short term forecasts based on trend analysis of historical traffic	Long term forecasts based on trend analysis of historical traffic	Long-term forecasts based on demand factors and tied to long-range transportation planning goals

Enabler	Emerging	Strengthening	Advanced
Revenue Forecasting	Short-term revenue forecasts are available.	Long-term revenue forecasts are available.	Long-term revenue forecasts incorporate risks and uncertainties
LCP Treatment Selection	Treatment type and timing selection are based on condition triggers and decision-tree rules. If multiple treatments are evaluated at the time of selection, the treatment with the greatest benefit-cost ratio is selected. No multiyear optimization is performed.	Treatment type and timing selection are based on a benefit-cost analysis performed using multiyear optimization, (i.e., 5-10 years)	Treatment type and timing selection are based on life-cycle optimization.
Prioritization/ Optimization	Project selection is based on the "worst first score" based on factors including condition, region, traffic, functional class, etc.	Project selection is based on the optimization of treatment timing and projects (multiyear plans) to maximize network condition within the budget constraints	Project selection is based on optimization to maximize network condition and reduce lifecycle costs within the budget constraints
Resource Allocation	Funds are allocated by the program of work (e.g., separate budget for maintenance and rehabilitation)	Funds are allocated at the asset level (e.g., combined budget for maintenance and rehabilitation)	Funds are allocated across highway programs (e.g., pavements, bridges, mobility and safety)
Relating Asset Preservation to Other System Performance Goals	Condition measures are not linked to other system performance goals	Condition measure(s) are qualitatively linked to other system performance goals	Quantitative models are used to relate asset condition measure(s) with measures of other system performance goals