Transportation Asset Management Plans

Case Study 3 - Life Cycle Planning Practices

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16. Abstract: This case study on life cycle practices is one of seven case studies of practices in the 2019 transportation asset management plans (TAMPs). The asset management plans demonstrated increasing emphasis upon planning for the whole life of assets and using life-cycle strategies to achieve a state of good repair (SOGR). The plans also demonstrated the value of pavement and bridge management systems in support of life-cycle strategies. Several of the case studies demonstrated substantial savings and achievement of higher conditions because of the life-cycle strategies.

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Case Study Introduction

This case study is one of seven that captures good asset management practices documented in the 2019 transportation asset management plans (TAMPs) required by 23 U.S.C. 119(e). The TAMPs include a wealth of information about the asset management practices deployed by U.S. State departments of transportation (DOTs). The asset management plan framework that the Federal Highway Administration (FHWA) describes in 23 CFR Part 515 provided the structure to document how these practices are applied. This series of case studies distills many of the good practices and presents them in a convenient format for use by other transportation agencies.

The seven case studies are:

Case Study 1: Asset Management Practices and Benefits

Many of the TAMPs provided comprehensive summaries of their asset management practices and the benefits they received from them. Several examples are highlighted in this case study. These include examples from the DOTs in New Jersey, Pennsylvania, Illinois, and Washington State. These examples illustrate how asset management plans can effectively summarize asset management practices and improvement strategies.

Case Study 2: Linking Asset Management to Planning and Programming

This case study examines how TAMPs documented linkages to the DOT's long-range plan, the State Transportation Improvement Program (STIP), and state planning and programming practices. Examples are selected from the TAMPs in Missouri, Maine, Utah, Ohio, Wyoming, and Montana.

Case Study 3: Supporting Life-Cycle Planning

To develop a life cycle plan, one needs to know how assets deteriorate throughout their life cycle. Several TAMPs were notable in documenting how they manage assets with life cycle plans. Included in this case study are examples from the DOTs in Minnesota, Ohio, Tennessee, and New Jersey.

Case Study 4: Managing Risks to Assets

DOTs embrace risk management to support the long-term performance of assets, and for making risk-based investment tradeoffs. This case study summarizes some of the good risk management practices from Washington State, California, Kansas, South Dakota, Louisiana, Rhode Island, Pennsylvania, Texas, Colorado, and Michigan.

Case Study 5: Developing Financial Plans and Investment Strategies

The financial plans and investment strategies reflect priorities for allocating scarce resources to achieve their highest asset management objectives. This case study will examine how several TAMPs described the clear linkages between their asset management objectives, gaps, risks, and investment strategies. Examples are from Kentucky, Michigan, Washington State, New York State, Utah, Vermont, and Illinois.

Case Study 6: Communicating Asset Management Strategies

This case study summarizes examples of communicating asset management strategies with key external stakeholders. Examples are cited from the DOTs in Vermont, California, New Jersey, Washington State, Michigan, Ohio, Colorado, and Nebraska.

Case Study 7: Managing Non-Bridge-and-Pavement Assets

Several State TAMPs included additional assets beyond pavements and bridges. Examples are cited from Minnesota, Connecticut, Utah, and California.

This case study summarizes several of the examples of life-cycle planning (LCP) seen in the asset management plans. The examples illustrate a growing sophistication in the use of LCP. They also provide a growing body of evidence about the cost savings and improved conditions LCP can provide.

Life-Cycle Planning Examples from the 2019 Asset Management Plans

To develop a life cycle plan, one needs to understand how assets deteriorate over their life cycle and what are the cost-effective strategies to sustain them in a state of good repair (SOGR). Life-cycle planning is a process to estimate the cost of managing an asset class, or asset sub-group, over its whole life with consideration for minimizing cost while preserving or improving the condition.

Several asset management plans presented particularly informative examples of life cycle planning. Four of those examples are summarized here from the departments of transportation of Minnesota, Tennessee, Ohio, and New Jersey. There are situations in these case studies that reflect the transition to meeting regulatory requirements, including the evolving structure and application of management systems, addressing the five work types (initial construction, maintenance, preservation, rehabilitation, and reconstruction), and addressing short-term targets and SOGR goals. Accordingly, some States' experience has shown that some adjustments to the described practices may be needed to achieve full compliance with applicable requirements.

These case studies summarize only a few of the life-cycle planning references in the 2019 transportation asset management plans. All the TAMPs are available on the FHWA website for further review at https://www.fhwa.dot.gov/asset/plans.cfm

Minnesota DOT Life-Cycle Planning Objectives

The Minnesota DOT (MnDOT) TAMP began its life cycle planning section by describing multiple objectives:

- Establish a long-term focus for improving and preserving the system.
- Develop maintenance strategies that consider long-term investment needs.
- Determine the funding needed to achieve the desired state of good repair.
- Determine the conditions that can be achieved for different levels of funding.
- Reduce the annual cost of system preservation without impacting asset conditions.
- Provide objective data to support investment decisions.
- Eliminate existing performance gaps.
- Demonstrate good stewardship to internal and external stakeholders.

The MnDOT TAMP stated life-cycle planning is especially useful when comparing alternate strategies that fulfill the same performance requirements but differ with respect to construction, maintenance, and operational costs. These can be compared in terms of the total costs over the entire life-cycle of the asset. A question that life-cycle planning hopes to answer is: which investments made today are most cost-effective in the long-term to keep the infrastructure in service for as long as possible?

The MnDOT TAMP emphasized that initial cost represents only a portion of the total cost of maintaining and eventually replacing an asset over its life cycle. Over the life of an asset, the cost of maintaining it can be several times more than the cost of constructing it. Therefore, it is important to manage the assets as cost effectively as possible over their entire service life.

The MnDOT TAMP stated the agency attempts to accomplish these objectives through three major phases of managing its system:

- Performance-based, long-range planning (capital planning at the network level)
- Life-cycle-cost-based project design alternative selection
- Life-cycle-cost-based management strategies

Performance-Based Long-Range Planning

The MnDOT TAMP stated that investment decisions start with a series of plans that establish the department's direction and communicate its priorities. Three planning documents incorporate life-cycle planning as a major objective. A 50-year vision document called Minnesota Go; the Statewide Multimodal Transportation Plan; and the 20-year Minnesota State Highway Investment Plan (MnSHIP) are predicated upon life-cycle planning strategies. All three provide the long-range perspective that supports life-cycle planning. MnSHIP directly related to asset management objectives by addressing trade-offs between investment areas such as mobility, safety, and asset management. It also assessed the department's ability to meet performance objectives through the analysis of multiple investment scenarios. The investment direction presented in MnSHIP prioritized investments to maintain the existing State highway pavements and bridges while making limited mobility improvements over the next 20 years. The direction will guide investments so that transportation projects align with statewide goals as much as possible with available funding.

Life-Cycle-Cost-Based Project Alternative Selection

The MnDOT TAMP stated that the second phase of the investment decision-making process considers life-cycle strategies. MnDOT has documented the life-cycle cost savings of periodic preservation and maintenance treatments to extend the life of assets and to lower their life-cycle costs. Those analyses influence project-level scoping decisions for bridge and pavement projects.

Life-Cycle-Based Management Strategies

The TAMP stated that the third phase of MnDOT's effort to minimize life-cycle costs is through consideration of life-cycle management strategies for individual asset classes. The strategies incorporate treatments suggested by the management systems and capture costs that include both capital-funded actions as well as preventive and reactionary work accomplished by MnDOT's maintenance staff.

During the development of MnDOT's 2014 pilot TAMP sponsored by FHWA, life-cycle cost analyses were prepared for several asset classes using either deterministic modeling techniques or Markov Chain network-level analyses. The analyses generally considered "worst first" theoretical strategies (run-to-failure) to other management scenarios representing judgments about current and ideal practices.

MnDOT has improved its ability to model internal maintenance costs for routine, reactive, and preventive maintenance in accordance with asset condition, and has been able to update the life-cycle models accordingly. These models give asset owners an order-of-magnitude representation of possible savings or efficiencies to be gained through application of good practices, and in some cases, an indication of performance advantages.

Long Analysis Horizons to Capture First Asset-Replacement Costs

MnDOT used two tests in developing its planning horizon. The horizon should be long enough that discounted future costs make no significant difference to the results, and that at least the first complete asset replacement cycle is included.

For pavements, a 70-year analysis period was chosen to account for at least one complete reconstruction activity. For bridges, culverts, and tunnels, a 200-year analysis period was chosen because those assets have much longer service lives. Noise walls were analyzed on a 120-year horizon, and overhead signs, high-mast light towers, traffic signals, and roadway lighting were assessed on a 50-year horizon. Curb ramps were analyzed over a 35-year life, and sidewalks on a 60-year horizon. Because Intelligent Transportation Systems (ITS) have so many components that are subject to technological obsolescence, only dynamic message signs were analyzed. They were analyzed on a 15-year life span.

MnDOT analyzed different investment strategies for each asset class in the TAMP to calculate an Equivalent Uniform Annualized Cost (EUAC.) The EUAC allows a dollar-per-dollar comparison of different treatment strategies over the life of an asset. To compare the equivalent costs of different treatment strategies, four strategies were analyzed for each of the TAMP's asset classes. One was a "minimum maintenance" strategy or "run to failure" strategy that is like a "worst-first" approach. Second was a strategy to minimally meet SOGR performance requirements; the third was to maintain current investment levels; and the fourth was a reduced funding scenario.

For bridges and pavements, the agency's management systems were used to analyze the strategies. Those systems calculated the marginal cost effectiveness of the treatment strategies to optimize the return on investment. For the other assets, separate analyses were conducted based on historic capital and maintenance costs and the expected life span of the assets.

MnDOT's TAMP stated:

> A key goal of a Life Cycle Planning effort is to manage assets at the optimal level of preservation where life cycle costs are kept to a minimum …The analyses generally compare a minimum maintenance strategy to strategies that employ more aggressive preventive maintenance approaches. While they may be exemplary or network-wide in scope, the analyses give decision makers an indication of the savings that can be realized by either adopting or maintaining an aggressive preventive maintenance approach, attendant performance advantages, and user costs.
>
> Typically, a bridge or pavement maintained at a level that minimizes costs long-term is also kept in relatively good condition and produces a higher level of service over its life, which provides tangible benefits to both the agency and users.

Pavement Life-Cycle Cost Savings

The TAMP stated that MnDOT uses its Highway Pavement Management Application software to develop funding scenarios based on pavement treatment decision trees and performance prediction models. It seeks to optimize the combination of preservation and rehabilitation activities and achieve the best conditions possible given funding constraints. The dynamic application allows for comparisons between a range of treatment option scenarios from "minimum maintenance only" to "full reconstruction."

When maintenance and rehabilitation analysis is done, each section of road goes through a decision tree. The decision tree identifies a fix based on the predicted condition, age, traffic, etc., for each year of the analysis period. Once a treatment is identified, the default curve for the recommended treatment is applied and the area between that curve and the "do nothing" curve is calculated. This area is then multiplied by an effectiveness factor based on the section length and traffic volume. The cost of the recommended fix is also calculated. The effectiveness of the fix is divided by the cost of the fix to generate the cost effectiveness. A matrix is built of all possible treatments, their effectiveness, cost, and cost effectiveness.

The TAMP stated that through the application of life-cycle cost analyses, MnDOT has been able to objectively determine that it is not only cheaper to maintain its pavements through application of preventive maintenance actions, but that the quality of the pavements, and thus service to users, remains higher over time. The typical preservation and rehabilitation treatments used by MnDOT on its asphalt-surfaced pavements include crack sealing, surface treatments (e.g., slurry seals, chip seals, and microsurfacing), asphalt mill and overlays, and full-depth reclamation. Typical preservation and rehabilitation treatments on concrete-surfaced pavements include joint resealing, partial depth repairs, and minor/major concrete pavement repairs such as dowel bar retrofit, diamond grinding, and full-depth repairs. While some of these treatments are applied primarily to extend the service life of the pavement and delay major rehabilitation/reconstruction activities, certain treatments are applied primarily to address safety issues, for example friction loss or hydroplaning due to rutting in the wheel paths. The objective is to slow down the rate of deterioration and provide a smooth, durable, and safe roadway for the users at the lowest life-cycle cost.

For rigid pavements, MnDOT estimated the cost of treatment including joint repair, concrete rehabilitation, grinding, and overlays. In comparing the “minimum maintenance” strategy to the preferred treatment strategy from the MnDOT pavement design manual, the preferred alternative over 70 years included more concrete rehabilitation treatments. However, it required no unbonded overlays which were required in the “minimum maintenance” strategy. The unbonded overlays per-lane-mile costs were more than twice the cost of the concrete rehabilitation. As result, the EUAC of the preferred strategy per lane mile per year was $18,940 compared to $21,170 for the “minimum maintenance” strategy.

Bridge Life-Cycle Cost Savings

The TAMP stated that the Bridge Replacement and Improvement Management System (BRIM) is used for forecasting future bridge conditions. BRIM uses a deterministic deterioration model developed from research that studied historical MnDOT inspection data. There are seven deterioration curves that are based on district, AADT, superstructure type, and deck features, such as rebar type, wearing surface type, and depth of cover. A deterioration curve is assigned to each bridge and is used to forecast future condition considering improvement from future projects programmed in the 4-year and 10-year programs.

MnDOT did not formally determine the benefit-cost ratio of alternatives for each bridge. However, life-cycle cost principles are built into the work type logic of BRIM and the repair strategies outlined in the MnDOT Bridge Preservation and Improvement Guidelines. The treatment logic in BRIM provides a recommended work type, timeframe, and cost for each bridge. The treatment options include a mixture of preservation, rehabilitation, and replacement alternatives that consider the remaining life of the bridge. The timings of these treatments are based on condition and predicted deterioration. The output is reviewed annually by bridge experts in the Districts and Bridge Office. The treatment logic can be varied to compare various repair strategies. The BRIM work type logic and deterioration modelling assumes that routine preventive maintenance treatments are being performed with frequencies established in the MnDOT Bridge Maintenance Manual.

As it did with pavements, MnDOT conducted a similar analysis for bridges and compared a minimum maintenance approach to a more aggressive preventive maintenance approach. The preventive approach included more frequent joint sealing, deck sealing, deck crack sealing, and less frequent need for reactive maintenance. The analysis suggests that the EUAC can be reduced from approximately $56,000 for the minimum maintenance strategy to $36,000 for a strategy including more aggressive preventive maintenance. MnDOT's typical preventive maintenance strategies are believed to extend the average service life of each structure from about 50 to 80 years and save considerable sums compared to a minimum maintenance-only strategy.

Life-Cycle Savings for Other Assets

Although MnDOT does not have models for its other assets, it calculated the life-cycle cost savings for proactive management of them compared to a worst-first, or minimum maintenance concept. For culverts, the minimum maintenance strategy generated an EUAC per culvert of $507 compared to only $356 for the agency's current strategy of actively maintaining culverts.

For overhead sign structures, MnDOT developed a uniform overhead sign structure inspection form and is working on a corresponding inspection rating system. Typical reactive maintenance involved tightening nuts and removing grout while minor rehabilitation included re-grading of footings, replacing welds, and replacing individual items. MnDOT determined that the need to tighten nuts was one of the costlier maintenance items and, if improved construction techniques reduced the need for periodic tightening, the life-cycle cost could be reduced.

For noise walls, MnDOT considered whether rehabilitation every 20 years or adding splash zone sealing would extend the life of the noise walls from 80 years to 95 to 125. Both wood paneled walls and concrete walls were analyzed. The analysis indicated that the current strategy for concrete walls was the lowest cost although adding splash zone protection to the wood walls could lower the life-cycle cost.

For deep stormwater tunnels, MnDOT lacked cost and deterioration data to calculate an EUAC, but determined that its current strategy of actively inspecting and maintaining the deep stormwater tunnels reduced the risk of failure or high-cost repairs.

Life-Cycle Planning Practices Influence Day-to-Day Activities

The MnDOT TAMP cited several examples of the life-cycle planning activities influencing other agency efforts. These include:

- Creating a pavement preventive maintenance manual.
- Building preventive maintenance treatments into its pavement management system (PMS) decision trees.
- Developing a Pavement Investment Guide and modifying pavement management software to allow Districts to analyze investment scenarios unique to their local areas.
- Training in bridge preservation annually for all new employees (and some in the existing workforce). The training covers needs, benefits, philosophy, causes, and problems related to specific deterioration types, numerous treatment techniques (from deck flushing to full depth joint replacement), appropriate preventive maintenance intervals, and tracking and recording expectations.
- Assigning the Asset Management Program Office responsibility to work between the Materials Office and District maintenance and materials staff to improve the systematic planning of pavement preventive maintenance activities.

- Developing illustrative materials such as a crack sealing exhibit that shows the benefits of performing work in a cost-effective manner.
- Beginning to incorporate calculated internal maintenance cost implications related to MnSHIP performance scenarios as part of the capital programming procedure.

Ohio's Business Case for Life-Cycle Planning

The Ohio DOT (ODOT) asset management plan made a business case for life-cycle planning by documenting the financial savings it brings to the agency. The Ohio DOT included all its State highways and bridges in the asset management plan. The cost savings it reports derive from the entire State Highway System, not only the Ohio National Highway System (NHS) routes.

Using asset condition data and predictive models, ODOT analyzed the impacts of increasing the use of properly timed preservation treatments to extend asset service life. For pavements, the analysis was based on treatment strategies and performance data from ODOT's pavement management system. Ohio is in the early stages of implementing a fully compliant commercial bridge management system. As an interim step, ODOT used spreadsheets analyzing data from its bridge inspection database to estimate deterioration rates and identify life-cycle strategies.

For both pavements and bridges, the life-cycle planning showed that the life extension provided by a long-term commitment to timely preservation delays costly replacements and reduces life-cycle costs. The results showed that if just 5 percent of the Ohio NHS bridges were to receive an appropriate preservation treatment annually, up to $50 million could be reallocated across the system to maximize service life. For pavements, the analysis showed that if half of the low-volume roads eligible for preservation were addressed with a chip seal rather than an overlay, at least $75 million could be reallocated to other parts of the highway system each year. In the four years that the life-cycle planning strategies have been followed, ODOT had realized a financial efficiency of over $300 million while addressing more than 1,700 additional lane miles of pavement and 150 bridges.

To help ensure that the planned investments are implemented, ODOT used its life-cycle planning results to drive changes in business practice that led to a more collaborative and coordinated process for developing District work plans to help ensure the timely application of preservation treatments.

Ohio Pavement Life-Cycle Planning

ODOT has implemented a state-of-the-art pavement management system to model the deterioration of its pavement network and to evaluate the long-term impacts of different maintenance and rehabilitation strategies based on factors such as the overall condition of the pavement, the type and severity of distress observed on the pavement surface, and traffic levels.

The Ohio TAMP stated that in addition to deterioration models, the pavement management system includes treatment rules that define the conditions under which different types of treatments are considered feasible. Traditionally, the pavement management system treatment rules established recommendations for when to apply crack sealing, chip sealing (on low-volume roadways), and asphalt mill and overlays. The pavement management recommendations were then provided to the Districts for consideration in developing their annual work plans. The Districts determined the most appropriate treatments for the available funding, based on their knowledge of local conditions. Historically, asphalt mill and overlays were the most commonly used treatment strategy for maintaining the system.

However, the life-cycle planning analysis showed that over a 10-year period, it would be difficult for ODOT to continue to achieve its Critical Success Factors for Pavements with the anticipated funding levels if the traditional overlay strategy was continued. Therefore, an alternate strategy was implemented that focused on increasing the use of chip seals on eligible lower-volume pavements. The analysis found that approximately 48 percent of the pavements on the rural routes outside of cities were eligible for chip seals based on condition values, truck traffic levels, and average daily traffic levels. These results were sufficient to incentivize ODOT to develop and implement new business procedures that help to ensure the timely and appropriate use of chip seals on eligible pavements to support the life-cycle strategy presented in the TAMP.

The typical treatment strategy for rural routes is chip sealing every six to seven years followed by a mill and fill, or overlay, around year 20. Additional repairs are made as needed, and crack sealing occurs about every five years. Higher volume pavements are repaired and resurfaced about every 10 years with crack sealing applied in year five.

In 2016, ODOT began phasing in new requirements for the development of District Work Plans that combine capital and maintenance projects. At that time, Districts' Work Plans were required to match 25 percent of the lower cost treatments (such as chip seals and microsurfacing) recommended by the pavement management system. Since 2017, ODOT has required District Work Plans to match 75 percent of the pavement management system recommendations for these treatments.

Implementing the planned investment strategy will allow ODOT to achieve its targets, or Critical Success Factors, for pavements over the 10-year period addressed in the TAMP. Based on projections from the pavement management system, ODOT expects to achieve an average statewide Pavement Condition Rating (PCR) of 86 on the Priority System, or major routes, and 85 on the General System, or rural routes, by 2028 using the current asset management process.

Ohio Bridge Life-Cycle Planning

While ODOT is implementing a fully functioning commercial bridge management system, it relied on a spreadsheet analysis tool to develop its bridge life-cycle planning analysis. The spreadsheet tool enabled ODOT to conduct a life-cycle analysis for its bridge network as the agency began the implementation of a new bridge management software. The spreadsheet tool used representative rates of deterioration for bridge conditions developed with input from ODOT's Office of Structural Engineering. In addition, various treatment cycles were considered to enable the comparison of ODOT's traditional rehabilitation approach (which predominantly included deck replacement and bridge replacement) with a strategy that increased the amount of preservation work (such as bridge cleaning, deck sealing, and deck sweeping).

ODOT adopted a strategic preservation program for its bridges and is implementing state-of-the-art management tools to identify candidate projects. To ensure that bridge preservation activities are conducted each year, ODOT provides guidance to the Districts to assist in developing their work plans. In addition, the office of structural engineering provides each district with a list of the bridges to be cleaned, swept, and sealed.

Using data from its bridge inspection database and projected deterioration rates, ODOT analyzed the impact of various investment strategies and budget levels on future bridge conditions. The results demonstrated that the combination of planned investment levels and increased use of preservation treatments on bridges is expected to improve conditions. Based on this analysis, ODOT should continue to surpass its statewide average goal of 6.98 as a statewide average bridge condition (out of 9) over the next several years. The improved conditions should lead to nearly all State-maintained bridges in Fair or better condition during this time.

Ohio Conduit Life-Cycle Planning

ODOT also included conduits, or culverts, in its risk-based asset management plan and summarized its life-cycle planning strategies for them. The conduit life-cycle planning analysis was like the bridge analysis, which used a spreadsheet tool to analyze the benefits associated with different treatment strategies for a representative conduit. The spreadsheet tool used the result of conduit inspections to determine current conditions and a probabilistic analysis was conducted to forecast future conditions. Different levels of investment were considered, representing different types of treatments to address forecasted deterioration.

The following types of routine maintenance and corrective actions were considered:

- Routine maintenance (cyclic) - cleaning
- Routine maintenance (reactive) - repairs
- Corrective actions - joint sealing/internal band sealing, paved invert, spray-on lining, sliplining, pipe bursting, pipe jacking
- Replacement - open-cut replacement

The Ohio TAMP stated that the preservation strategy improves conduit conditions over an alternate strategy that uses only rehabilitation and reconstruction strategies. In this example, the use of planned preservation treatments while the conduit is still in relatively good condition added approximately 25 years to the life of a conduit. Similar results were generated for other conduit sizes, illustrating the long-term benefits associated with conduit preservation investments.

Tennessee's Life-Cycle Planning Analysis to Sustain Bridge and Pavement Conditions

The Tennessee DOT's (TDOT) asset management plan stated its pavement management system allows it to conduct numerous "what if" scenarios to analyze future condition levels and investment needs. At the network level, the pavement management system provides several output reports to enable TDOT managers to gauge success in meeting the agency's goals. Examples of the types of reports are:

- Historical reports of expenditures, type of treatments (work types), resulting performance by highway system
- Condition by highway system
- Estimated funding levels to achieve specific condition, by highway system, over 10 years
- Estimated condition based on various funding scenarios by highway system, over 10 years
- Treatment work types (preservation, maintenance, rehabilitation, reconstruction), by highway system, with 10-year cost and quantity projections

The pavement management system's Network Maintenance & Rehabilitation (M&R) Optimization/Work Program Development function was run to determine feasible maintenance, preservation, and rehabilitation strategies for each pavement section. The pavement management system also performed network optimization based on performance and funding constraints. This step provided a life-cycle analysis of costs and performance based on decision trees for treatment selection and performance prediction models. The system has the capability to perform multiple optimization scenarios based on user-defined constraints. Optimization scenarios can suggest work plans that include multiple treatments on a given section within the analysis period. A theoretical best treatment is identified when the greatest projected benefit is achieved.

Once the TDOT Maintenance Division was satisfied with the M&R output, the results were provided to TDOT's senior management for review and funding consideration. These analyses along with other records and reports on accomplishments, network pavement conditions, historical funding allocations, expenditures, type of pavement treatments, regional allocations and results provided a comprehensive overview of TDOT's pavement management program effectiveness. The outcome of this review was a proposed funding allocation for the annual pavement management program.

Using the pavement management system, TDOT forecasted that through 2028, Interstate pavement conditions will decline from 50 percent Good to about 45 percent Good but the percent Poor will be much less than 5 percent. NHS routes will improve from 45 percent Good to about 60 percent Good with only about 1 percent Poor.

The TAMP stated that TDOT is developing a bridge management system to perform similar forecasts and analysis as does the PMS.

New Jersey Life-Cycle Planning

The 2019 New Jersey DOT's (NJDOT) asset management plan showed the agency's close linkage of its analyses for condition gaps, and life-cycle planning, and its investment strategies. The size of condition gaps under various funding scenarios influenced selection of a preferred investment scenario that sought to maximize condition performance with the agency's limited funding.

The NJDOT TAMP analyzed all State Highway System (SHS) pavements and bridges and not only those on the NHS. Pavement and bridge management systems were used to analyze current and forecasted conditions.

For both pavements and bridges, the TAMP included four funding scenarios that demonstrated the condition gaps that would result under each scenario. The magnitude of the gaps was shown, the consequences discussed, and the resulting investment strategies were documented. The four scenarios are:

- **Planned Funding** - This scenario was based on the total funding for the assets' maintenance, preservation, rehabilitation, and replacement, by year, in the Fiscal Year (FY) 2018-2027 Statewide Transportation Improvement Program (2018 STIP) and in the TAMP financial plan.
- **Funding to Achieve State of Good Repair Objectives** - This scenario identified funding required to accomplish the TAMP State of Good Repair Objectives for the SHS by the end of the TAMP analysis period which is calendar year (CY) 2029.
- **Funding to Maintain CY 2017 Condition** - This scenario determined the funding required to maintain the same level of performance of the SHS at the end of the TAMP analysis period as it was at the beginning of it, as of CY 2017.
- **Continuation of FY 2018 Funding Levels** - This scenario identified what performance would be if funding levels at the beginning of the TAMP analysis period were extended throughout the TAMP analysis period.

In addition to the four scenarios each for bridges and pavements, another scenario was conducted only for pavements. It was an illustrative scenario conducted only to demonstrate the consequences of a worst-first approach. Based on the same level of investment, the life-cycle planning approach produced almost three times as many Good lane miles as did the worst-first scenario.

New Jersey Pavement Life-Cycle Planning

The 2019 New Jersey TAMP stated the agency has conducted gap analyses since 2011 when SOGR objectives were first adopted. The gap analysis has been used to continually adjust pavement life cycle planning and investment strategies. Using its pavement model, the gap analysis, and the risk analysis allowed it to establish its pavement investment strategies to achieve the highest conditions over the long term with the limited funding.

The pavement condition gaps were generated by the agency's pavement management system which optimized the expenditures based upon a network-wide life-cycle planning approach.

The New Jersey TAMP described pavement life-cycle planning as:

> Lifecycle planning for pavements involves developing long-term treatment strategies from a roadway network perspective considering the role the roadway plays in meeting overall transportation objectives, as well as considering the engineering properties of different types of pavement and the factors that will impact future conditions. Rather than focus on the needs of each mile of pavement, lifecycle planning establishes treatment strategies for the full roadway network, using data aggregated from the entire asset population. The treatment strategies represent combinations of pavement management actions that keep pavements operational at the lowest practical cost.
>
> Lifecycle planning is a core component of pavement management, as it establishes a cost-effective and practical approach to managing pavements. Lifecycle planning provides data-driven input to NJDOT's processes for prioritizing maintenance work, developing repair and rehabilitation plans, selecting projects for implementation, and allocating funds to pavement preservation.

The TAMP grouped treatments into five work types of maintenance, preservation, resurfacing, rehabilitation, and reconstruction. Although the TAMP covered 10 years, the pavement management system identified the recommended life-cycle treatments for a 20-year planning horizon to cover needs over an entire life-cycle planning analysis period. Depending upon a pavement's condition, and based on project-level data, the pavement management system recommended preservation, resurfacing, rehabilitation, or reconstruction. It also considered factors such as traffic level, structural integrity, and geometric constraints. Based on treatment costs, deterioration models, and condition reset values, the management system presented multiple treatment strategies. It also recommended a preferred strategy based on optimized network performance and life-cycle costs.

Using the 2018 funding level and trigger rules, the first scenario typically run was an unconstrained preservation budget to determine what level of preservation the system recommends annually. That information was then used to develop additional scenarios which considered risks such as the inability to deliver the optimum preservation program. The results of the life-cycle planning scenarios were used in the development of the New Jersey Transportation Capital Program and the STIP. Additional model runs were performed as part of performance gap analysis, where combinations of investment levels and life-cycle planning strategies were used to forecast pavement asset performance under different investment scenarios.

NJDOT's life-cycle planning strategy for pavements maximized the use of pavement preservation to the greatest extent possible. Based on analysis of historic pavement conditions, NJDOT has determined that the usual time between preservation treatments is approximately 10 years for most of the treatment types. The treatments address surface distress resulting from regular use and exposure to the elements. Following new construction, or complete reconstruction, of an asphalt pavement, the surface will typically need a preservation overlay after 10 to 12 years of service. Approximately every 10 years, each section of pavement will need to receive an appropriate treatment. The exception would be micro-surfacing and slurry seal, which are the thinnest, least expensive treatments and require reapplication more frequently. Since preservation treatments are typically less than 20 percent of the cost of reconstruction, maximizing their application provides the most cost-effective means of maintaining and improving network-wide conditions.

To perform analyses on the entire NHS, NJDOT used information gathered from other NHS owners regarding their life-cycle planning strategies to estimate projected conditions on the non-NJDOT NHS. The derived analysis was performed in a separate spreadsheet tool and was expected to continue being performed outside of NJDOT's PMS for the foreseeable future.

Life-Cycle Planning Influenced the Pavement Investment Strategies

The pavement investment strategies detailed in the TAMP were based on pavement management scenarios, the risk analysis, and agencies policies. The investment strategies included increasing preservation expenditures to prevent pavement assets from deteriorating to a point of requiring even greater investment.

The investment strategy indicated that between 2019 and 2029, pavement preservation funding would increase from $15 million annually to $100 million. Rehabilitation spending would increase from $290 million in 2019 to $410 million by 2027 and $390 million thereafter. Reconstruction spending would vary, but the annual amount would decline from $65 million in 2024 to $30 million in 2025 and thereafter.

New Jersey Bridge Life-Cycle Planning

The NJDOT plan stated that the agency relies on its Bridge Management System (BMS) processes and procedures and life-cycle strategies, which include preventive and corrective maintenance (preservation), rehabilitation, and replacement to achieve the highest bridge conditions possible with its limited resources. Due to the current limitations of the bridge management system software, the NJDOT has relied upon manual analysis for life-cycle planning. It forecasted that by 2029, 91.6 percent of SHS bridges will be Good or Fair which is 2.4 percent below the SOGR objective of 94 percent by deck area. For NHS bridges, they will exceed the 2-year and 4-year targets, and by 2029 slightly exceed the SOGR target of 95.0 with a condition forecast of 95.3 percent in Good or Fair condition.

The New Jersey bridge management system forecasted four scenarios based on continuing current funding, the planned level of funding, funding needed to achieve the SOGR objectives, and funding needed to maintain current conditions.

As with pavements, the NJDOT plan stated that the agency categorized treatments as maintenance, (preventive and corrective), rehabilitation, and reconstruction. NJDOT was taking steps to integrate preventive maintenance treatments into its Bridge Management System. Until that is complete, preservation treatment needs will continue to be identified by the engineering staff. The engineers review inspection reports, component condition rating and element ratings, and, when potential candidates are identified based on the established rules, they conduct a detailed review. Costs are estimated and work is either assigned to in-house crews or compiled into a bridge preventive maintenance contract for public bidding.

The TAMP stated that the NJDOT has implemented a Bridge Preventive Maintenance Program that undertakes actions to extend the life of a bridge component before reaching the point requiring major rehabilitation or replacement. This program was a key part of the life cycle plan and a significant improvement over prior “worst-first” approaches. Before the program was initiated, a component or the entire structure was replaced at the end of its service life without extending that life through maintenance and preservation treatments.

New Jersey Bridge Investment Strategy

The investment strategy for State Highway System bridges consisted of increasing expenditures on preservation treatments to prevent a bridge from deteriorating to a point of requiring even greater investment, as well as prioritizing rehabilitation and reconstruction treatments to improve the conditions of several key bridges, to reduce life-cycle costs, and to improve network conditions. The annual NJDOT preservation expenditures gradually increase from $100 million in 2019 to $150 million by 2029. The rehabilitation expenditures increase from $45 million to $165 million by 2029. The reconstruction program fluctuates year by year as the bridge replacement projects are delivered but it averages $215 million through 2029. Reconstruction funding peaks at $390 million in 2023 and declines to $165 million by 2027 and beyond.

The responsibility for approximately 53 percent of bridges by deck area on the NHS is dispersed across 83 non-NJDOT entities. NJDOT, as part of its consultation with other NHS owners, conducted a data collection survey and communication activities to assemble the local investment data. The New Jersey DOT consulted with the State’s turnpike owners to capture their investment plans and used a survey of local owners to estimate the locals’ NHS investment levels. This cooperative effort provided the best available data from which to predict the expenditures that will be applied to the non-NJDOT NHS bridge assets. Based upon local investments through 2022, the DOT estimated the local level of investment on the NHS that is likely to occur through the 10 years of the TAMP.

Linking the TAMP to the 10-Year Investment Program

The New Jersey TAMP stated that its analysis provided the framework for data-driven scenario analysis that influenced its STIP and its 10-year investment program. Because the TAMP was developed while many legacy projects were under development, the TAMP assumed that the already developed projects will continue. However, future STIPs will be developed with the TAMP providing the following support.

- Describe current asset conditions by program category.
- Provide the source and use of funds by asset program category.
- Facilitate dialogue among NJDOT Senior Leadership about the current 2018 STIP level of performance, trade-offs among asset programs, and impact on core missions.
- Initiate transition to performance-based resource allocation.