Chapter 6

LIFE-CYCLE COST CONSIDERATIONS
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Overview

Minnesota’s transportation infrastructure is constantly under attack from the physical and chemical processes of deterioration, the damaging impact of floods and other hazards, and the normal wear-and-tear from use by thousands of cars and trucks. MnDOT and its partners work tirelessly to offset these effects and keep the state’s valuable assets in service for as long as possible at minimum cost. Strong asset management practices help to minimize the total cost of managing transportation assets by focusing on all phases of an asset’s life-cycle, each of which is shown in Figure 6-1.

Figure 6-1: Typical Asset Life-Cycle Phases

Because the service life of an asset can be lengthened through the timely application of maintenance and rehabilitation activities, MnDOT attempts to manage its transportation assets in a strategic and proactive way. This includes:

- Designing new facilities for durability and long life using state-of-the-art materials and methods
- Deploying well-trained maintenance personnel and advanced technology to apply needed maintenance actions at just the right times in the right places
- Anticipating future maintenance and rehabilitation costs that help defer the need for larger repair costs
- Taking advantage of preventive maintenance opportunities
- Minimizing the impact of work zones on the traveling public
MnDOT has been developing procedures and tools to forecast asset deterioration rates, determine the effectiveness of its maintenance and rehabilitation actions, and estimate the magnitude of future costs in an attempt to improve its ability to manage assets over their life-cycle. With performance-based procedures and tools in place, MnDOT can continue to improve its strategic decision processes to help further reduce agency costs over the long term.

Life-Cycle Cost Analysis

Life-cycle cost analysis (LCCA) is an analytical technique used to assess the total cost of an asset. It takes into account all costs associated with construction, inspection, maintenance, and disposal. LCCA 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.

Because they do not directly extend the life of an asset, annual operational investments (such as snow and ice removal, de-icing roads, and debris removal) have not been included in the LCCA. It should be noted, however, that operational expenses and other indirect costs form a large part of the overall cost of asset ownership. Collectively, construction, inspection, maintenance, operations, disposal, and other indirect costs associated with transportation assets comprise total cost of ownership. As an example, MnDOT spends between $50 and $85 million annually on snow and ice removal on roadways, depending on the severity of the winter. These operational requirements significantly impact the amount of funding available for asset maintenance and rehabilitation activities.

When a new road is built, the state commits not only to the initial construction costs, but also to the future costs of maintaining and operating that road. Over a long time period, future costs can be much greater than the initial cost. Therefore, it is important to manage the facilities as cost-effectively as possible over their entire service life.

Naturally, the owner of a facility would like to postpone future costs as much as possible. If costs can be postponed, the money saved can be redirected to other priorities. In life-cycle cost analysis, this preference is quantified as a discount rate. MnDOT’s policy is to analyze all investments using a real annual discount rate which is currently 2.2 percent. The term “real” means that the effects of inflation are removed from the computation in order to make the cost tradeoffs easier to understand.
Although it is attractive to delay costs as much as possible and take advantage of the discount rate, there are limits. When maintenance is delayed, the condition of each asset worsens, eventually affecting the serviceability or even the safety of the infrastructure. Also, certain kinds of preventive maintenance actions are highly cost-effective, but only if performed at the optimal time. For example, painting a steel bridge at the right time is highly effective in prolonging its life. However, if painting is delayed, too much of the steel may already be rusted and painting is no longer as effective (or even possible). A much more expensive rehabilitation or replacement action is then required.

Additional terms used in LCCA are:

• **Analysis Period**: the time-frame over which the LCCA is performed

• **Life-Cycle Cost (in today’s dollars)**: the total cost to build, inspect, maintain, and dispose of an asset over the analysis period when the costs incurred in future years are converted to current dollars

• **Future Maintenance Costs as a Percent of Initial Investment**: the total future agency costs (including maintenance, rehabilitation, and inspection, but not operations costs) as a fraction of the initial construction cost of the asset (This value represents the future cost commitment that MnDOT makes for every dollar spent on a capital project.)

Theoretically, once a section of state highway is built, the agency is responsible for all future costs to keep that road in service, including the costs to reconstruct components of the road when they reach the end of their physical lives. However, because of discounting, costs in the far future have very little effect on any decisions made during the 10-year period covered by the TAMP. Forecasts of future deterioration and future needs become very unreliable if these predictions are extended too far into the future. In best practice, the analysis period of a life-cycle cost analysis should be as short as possible while still satisfying the following criteria:

• Long enough that further costs make no significant difference in the results.

• Long enough that at least the first complete asset replacement cycle is included.
The reason for the second criterion is that replacement costs are typically much larger than any other costs during an asset’s life, so these costs can remain significant even if discounted over a relatively long period. A fair comparison of alternatives should therefore include at least the first replacement cycle for each of the alternatives being compared. The following analysis periods have been used in the LCCA:

- **Pavements**: A 70-year analysis period has been chosen to account for at least one complete reconstruction activity (which is estimated to occur 50 years after initial construction, on average) and compare that to a strategy in which reconstruction activity is delayed by a few years (due to short-term funding constraints) and less optimal treatments are selected.

- **Bridges, culverts, and deep stormwater tunnels**: These assets have lifespans that potentially extend for much longer than the 70-year scenarios analyzed for pavements. As a result, based on the second criterion, a 200-year life is used for this longer-lasting asset category.

- **Overhead sign structures and high-mast light tower structures**: An analysis period of 100 years was chosen based on a review of existing literature that suggests that the life of these structures, with routine maintenance and inspection, is expected to be at least 100 years.

The LCCA modeling strategies presented in the TAMP are summarized in Figure 6-2. The “Typical Strategy” reflects MnDOT’s current practices for managing the assets and the “Worst-First” strategy involves complete replacement of the asset when it deteriorates to a Poor condition in the absence of preventive maintenance activities. The “Desired Strategy” (established only for pavements) corresponds to the strategy that MnDOT aspires to adopt in order to further reduce total life-cycle costs.
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The LCCA modeling strategies presented in the TAMP are summarized in Figure 6-2.

<table>
<thead>
<tr>
<th>ASSET</th>
<th>TYPICAL STRATEGY</th>
<th>WORST-FIRST STRATEGY</th>
<th>DESIRED STRATEGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavements</td>
<td>Delay need for reconstruction by applying a combination of surface treatments, crack sealing, and mill and overlays, depending on condition of pavement and available budget.</td>
<td>Reconstruct a pavement as it deteriorates to Poor condition without routine preservation activities.</td>
<td>Apply a major rehabilitation/reconstruction activity at year 50, once the pavement has gone through a few preservation cycles and minor rehabilitation events.</td>
</tr>
<tr>
<td>Bridges and Large Culverts</td>
<td>Perform repair and preventive maintenance on approximately two percent of bridges and large culverts; wash about 75 percent of bridges annually.</td>
<td>Replace entire bridge or large culvert structure as it deteriorates to a Poor condition without any preventive maintenance or repairs.</td>
<td>Insufficient data</td>
</tr>
<tr>
<td>Highway Culverts</td>
<td>Perform various maintenance actions on approximately two percent of culverts annually; flush each culvert once every 10 years.</td>
<td>Replace culvert as it deteriorates to a Poor condition without any preventive maintenance or repairs.</td>
<td>Insufficient data</td>
</tr>
<tr>
<td>Overhead Sign Structures and High-Mast Tower Lights</td>
<td>Perform routine inspections after initial construction to determine maintenance needs.</td>
<td>Perform routine inspections after initial construction, but perform no maintenance.</td>
<td>Insufficient data</td>
</tr>
<tr>
<td></td>
<td>Perform routine maintenance and major structural rehabilitation on an as-needed basis, as identified through inspections.</td>
<td>Replace structure in a 40-year cycle (assuming deterioration to a condition when maintenance and rehabilitation are not expected to be effective).</td>
<td>Insufficient data</td>
</tr>
</tbody>
</table>

Notes: Typical Strategy reflects current MnDOT practices; Desired Strategy reflects optimal life-cycle strategy as described in MnDOT’s Pavement Design Manual, there is not sufficient data currently available for other asset categories.
A key goal of a LCCA is to find the optimal level of maintenance where life-cycle costs are kept to an absolute minimum. This point may be known as the “happy medium,” where maintenance expenditures are neither too frequent nor delayed too long. Typically, a well-maintained pavement or bridge, when maintained at a level that minimizes costs in the long-term, is kept in relatively good condition. Over the life of a facility, well-timed maintenance is estimated to cut life-cycle costs roughly in half, compared to a policy where no maintenance is performed at all.

PAVEMENTS

Roadways (see Figure 6-3) are a critical part of MnDOT’s transportation network, providing mobility and access to a wide range of users. The roadway network not only contributes to the economy of the state, but also connects communities and provides access to schools, services, work, and places that matter most to Minnesotans. Pavements are a major part of this roadway network, providing a durable and safe traveling surface.

Figure 6-3: Typical Interstate Roadway in the Twin Cities Metro Area

As discussed in Chapter 1 and Chapter 4, MnDOT maintains an inventory of more than 14,000 roadway-miles of pavements statewide, where the NHS pavements (Interstates, non-Interstate NHS, and locally-owned NHS) comprise over 7,800 roadway miles and the non-NHS pavements comprise almost 6,800 roadway miles of the total inventory. The current replacement values of NHS and non-NHS pavements are approximately $16 billion and $14 billion, respectively. These staggering costs demonstrate the need for a sound framework and methodological approach to manage these assets to the lowest life-cycle cost.
Pavements deteriorate over time due to environmental factors and traffic loading. As pavements age and start losing structural and/or functional capacity, they need to undergo maintenance and rehabilitation to restore them to the appropriate condition and provide a safe riding surface for the users. A typical pavement deterioration model demonstrating the impact of preservation is illustrated in Figure 6-4.

Figure 6-4: Typical Pavement Deterioration Model Illustrating Impact of Preservation

MnDOT has been actively involved in pavement preservation over the last decade to help sustain and improve the conditions of the existing pavement and delay the investments needed in major rehabilitation or reconstruction activities.

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), full-depth reclamation, and asphalt mill and overlays. Typical preservation and rehabilitation treatments on concrete-surfaced pavements include joint resealing, partial depth repairs, minor/major concrete pavement repairs (e.g. dowel bar retrofit, diamond grinding, full-depth repairs), and unbonded overlays. While some treatments discussed above 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 (like 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.
The results of the life-cycle cost analysis highlighting the magnitude of differences in costs for each strategy are shown in Figure 6-5.

**Figure 6-5: Summary of Life-Cycle Cost Analysis Results (Pavements)**

MnDOT’s current policy results in a savings of approximately 58 percent of future life-cycle costs when compared to the worst-first strategy. This is a savings of about $570,000 per lane-mile of pavement or approximately $17 billion over the entire inventory over the 70 year analysis period. Future costs (maintenance and capital) range from 1.1 (desired) to 2.9 (worst-first) times the initial cost of a capital project, depending on the treatment strategy used.

The results of the LCCA show the cost-effectiveness of the preservation strategy used by MnDOT to manage the pavements on the state highway system. The slightly higher life-cycle costs that MnDOT is incurring through its “typical” management strategy when compared to the “desired” strategy is the result of the need to balance investments between competing priorities (e.g., meeting state/federal targets, higher level of investment needed on some critical pavement sections in Poor condition).
BRIDGES AND LARGE CULVERTS

Bridges are large, complex, and expensive assets that are custom-designed and built to satisfy a wide variety of requirements. All culverts of at least 10 feet in diameter (and some important smaller culverts) are inspected and managed as bridges. The bridges addressed in this TAMP (NHS, non-NHS, large culverts) have a replacement value of approximately $4 billion. Although bridges and large culverts are managed using the same system, the LCCA was performed separately because deterioration rates, treatment costs and types are different.

Consistent with Federal and industry specifications, MnDOT performs a detailed inspection on all of its bridges on a periodic basis, usually at two year intervals as outlined in the MnDOT Bridge Inspection Best Practices Manual. Preventive maintenance actions – flushing, crack sealing, painting, etc. – are typically performed according to an assigned frequency, which is determined using criteria such as the activity performed, bridge age and type, condition, and traffic volume and control. Most bridges are flushed annually to remove corrosive salts from the bridge deck and other elements like joints, drains, bearing seats, and superstructure elements (e.g. beam ends, lower chord members). Staffing, funding, work zone traffic control limitations on high-volume bridges (typically on Interstate Highways), and other system priorities constrain MnDOT from being able to flush all bridges annually. Reactive maintenance actions, like patching, are performed based on conditions noted in the inspections.

Most bridges in the inventory are designed to last 50 years, but MnDOT experience has shown that many of them can last much longer if well-maintained. Newer bridges are designed for a 75 year life using more advanced materials and construction methods.

Bridges and culverts deteriorate over time. In particular, steel is strong, light, and inexpensive, but is prone to corrosion. Paint and concrete cover the steel and protect it from corrosion [see Figure 6-6 (a)]. But paint and concrete are often exposed to weather, traffic, erosion, animals, chemicals, and collisions, and therefore require regular care. These materials can also crack as they age, thus weakening their structural strength and allowing corrosive water and chemicals to penetrate the materials, worsening deterioration. Certain bridge materials, especially timber may also be subject to attack by insects and micro-organisms.
Figure 6-6: (a) Corrosion on a Bridge Structure Element (b) Large Culvert

Culverts [see Figure 6-6 (b)] tend to be more durable due to the fact that they are generally protected underground and are manufactured under more controlled conditions. They also deteriorate, but at a slower rate than bridges.

Bridges and large culverts in water are vulnerable to scour of their foundations, vessel collisions, and flood damage. Most bridges have expansion joints and bearings to prevent damage due to temperature changes and motion. These features can sometimes be damaged by the constant pounding of trucks passing over them, corrosion, excessive movement, or intrusion by rocks and other foreign materials. The results of the life-cycle cost analysis for bridge structures highlighting the magnitude of differences in costs for each strategy are shown in Figure 6-7.
MnDOT’s typical preventative maintenance strategies extend the average service life of each structure from about 50 years to about 80 years. MnDOT’s current policy saves about 37 percent of future life-cycle costs, a savings of $415,000 per bridge or $581 million for the entire NHS inventory over the 200 year analysis period. Small investments in improved asset management can have a very significant return when considering the large bridge inventory. The results illustrate that future costs (maintenance and capital) are approximately 1.42 (typical) to 2.59 (worst-first) times the initial cost of a capital project.

The results of the LCCA for large culverts highlighting the magnitude of differences in costs for each strategy are shown in Figure 6-8.
MnDOT’s typical strategy results in a savings of approximately 23 percent of future life-cycle costs, a savings of about $17,000 per large culvert, or $10 million over the inventory. The results further illustrate that future costs (maintenance and capital) are approximately 1.4 (typical) to 1.8 (worst-first) times the initial cost of a capital project.

HIGHWAY CULVERTS AND DEEP STORMWATER TUNNELS

MnDOT maintains an inventory of more than 47,000 highway culverts on the state highway system, which includes NHS and non-NHS highways. These have a replacement value of approximately $1.7 billion. Culverts are inspected on an interval that is based on condition and risk: new assets are inspected every six years, while those in Poor condition may be inspected every year or every other year.

Culverts are flushed about once every 10 years to remove accumulated debris and a small fraction of them receive condition-based repairs as warranted. These assets are manufactured under relatively controlled conditions (compared to bridges) and, in most cases, have a very long life.

Drainage culverts do gradually deteriorate, exhibiting corrosion, settlement, deformation, scour from floods, impact damage, and buildup of debris. One relatively common problem is leakage where water intrudes into surrounding soil and washes it away, creating air pockets. The presence of these pockets tends to accelerate deterioration and can potentially cause a local collapse of the roadway above.

Figure 6-9 shows the results of the life-cycle cost analysis for highway culverts, highlighting the magnitude of differences in costs for each strategy.

Figure 6-9: Summary of Life-Cycle Cost Analysis Results (Highway Culverts)
MnDOT performs maintenance activities on approximately two percent of the highway culverts per year, including resetting culvert ends, repairing joints, culvert lining, culvert replacement, and paving the lower interior of the culvert. MnDOT’s current policy saves about 29 percent of future life-cycle costs, a savings of $2,500 per culvert, or $119 million for the whole inventory over the 200 year analysis period, compared to taking no maintenance action at all. Under these scenarios, the typical service life of both types of culverts is projected to be about 140 years. The future costs (maintenance and capital) for culverts are significant, ranging from 4.4 (typical) to 6.6 (worst-first) times the original cost of the culvert.

The results of the life-cycle cost analysis for deep stormwater tunnels highlighting the magnitude of differences in costs for each strategy are shown in Figure 6-10.

Figure 6-10: Summary of Life-Cycle Cost Analysis Results (Deep Stormwater Tunnels)

MnDOT maintains an inventory of 7 deep stormwater tunnels that are comprised of a total of 50 individual segments of varying lengths, covering a total length of approximately 70,000 linear feet. All seven tunnels have had detailed inspection studies completed, which identify specific conditions and repairs. The City of Minneapolis also performs a visual walk-through inspection of tunnels every two years. Tunnel conditions range from Good to Very Poor, with a majority of the segments in Poor or Very Poor condition. It should be noted that data for the LCCA are based on MnDOT’s expert opinion and considered to be rough estimates. The best available estimate is that the total replacement value of these assets is approximately $240 million. A reliable maintenance schedule would have benefits similar in relative scale to culverts, but deep stormwater tunnels currently receive little maintenance. The future maintenance costs associated with deep stormwater tunnels range from 2.5 (typical) to 2.8 (worst-first) times the initial cost of the tunnel.
OVERHEAD SIGN STRUCTURES AND HIGH-MAST LIGHT TOWER STRUCTURES

MnDOT maintains an inventory of almost 2,400 overhead sign structures and 476 high-mast light tower structures statewide. Current replacement values of all overhead sign structures and all high-mast light tower structures are approximately $200 million and $19 million, respectively. High-mast light tower structures are inspected on a five-year cycle due to MnDOT’s formalized inspection program; a similar program does not currently exist for overhead sign structures. Instead, a less-formalized element-level inspection process and rating system is used for overhead sign structures. As a result of this TAMP process, MnDOT has developed a uniform statewide overhead sign structure inspection form and is working on creating a corresponding statewide inventory and inspection spreadsheet.

Figure 6-11 shows a typical overhead sign structure in the Twin Cities metro area. Unlike pavements and bridges, which are managed through a fairly mature process, protocols for inspection and management of overhead sign structures and high-mast light tower structures are relatively new. Over the last couple of years, MnDOT has invested significant resources to improve the way these assets are managed.

Figure 6-11: Overhead Sign Structure

Typical reactive maintenance activities performed on overhead sign structures include tightening nuts and removing grout. Minor rehabilitation activities performed include re-grading footing, replacing welds, removing catwalks/lighting, and replacing individual elements. Typical maintenance actions performed on high-mast light tower structures include tightening and levelling of nuts, removing debris, and replacing components that are not functioning adequately.
Deterioration of these assets results from environmental loading (e.g. winds and other climatic effects like rain, snow, heat) and past improper installation of select components (e.g. nuts not tightened adequately during initial installation).

The results of the life-cycle cost analysis for overhead sign structures highlighting the magnitude of differences in costs for each strategy are shown in Figure 6-12. Future costs (maintenance and capital) associated with overhead sign structures range from 1.3 (typical) to 1.9 (worst-first) times the initial cost. The condition of the majority of the overhead sign structures is generally Fair to Good. Data for life-cycle cost analysis are based primarily on expert opinion and the best data available.

Figure 6-12: Summary of Life-Cycle Cost Analysis Results (Overhead Sign Structures)
As with overhead sign structures, expert opinion was used to develop estimates for the maintenance costs associated with high-mast light tower structures. Future inspections and a consistent format for documenting the maintenance work performed on these structures and associated costs will help improve the life-cycle cost estimates. As demonstrated through the analysis, future costs (maintenance and capital) associated with high-mast light tower structures are estimated to range from 0.96 (typical) to 2.0 (worst-first) times the cost of the original structure.

The results of the life-cycle cost analysis for high-mast light tower structures highlighting the magnitude of differences in costs for each strategy are shown in Figure 6-13.

Figure 6-13: Summary of Life-Cycle Cost Analysis Results (High-Mast Light Tower Structures)
Summary of Life-Cycle Cost Estimates

**Figure 6-14** summarizes annualized life-cycle costs for each asset while **Figure 6-15** summarizes system-level, life-cycle cost analysis results by asset.

### Figure 6-14: Annualized Life-Cycle Cost Estimates by Asset

<table>
<thead>
<tr>
<th>ASSET CLASS</th>
<th>ANNUALIZED COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavements</td>
<td>$12,000 per lane-mile</td>
</tr>
<tr>
<td>Bridges: Large Bridges</td>
<td>$16,000 per bridge</td>
</tr>
<tr>
<td>Bridges: Culverts 10 feet or greater</td>
<td>$1,300 per large culvert</td>
</tr>
<tr>
<td>Hydraulic Infrastructure: Highway Culverts</td>
<td>$150 per small culvert</td>
</tr>
<tr>
<td>Hydraulic Infrastructure: Deep Stormwater Tunnels</td>
<td>$30,000 per mile of tunnel</td>
</tr>
<tr>
<td>Other Traffic Structures: Overhead Sign Structures</td>
<td>$900 per structure</td>
</tr>
<tr>
<td>Other Traffic Structures: High-Mast Light Tower Structures</td>
<td>$400 per structure</td>
</tr>
</tbody>
</table>

The information in **Figure 6-14** shows how much it costs per year to maintain an asset when construction, inspection, maintenance, and disposal costs are totalled and divided by the LCCA period (number of years).

### Figure 6-15: System-Level Life-Cycle Cost Estimates

<table>
<thead>
<tr>
<th>ASSET CLASS</th>
<th>REPLACEMENT COST</th>
<th>FUTURE COST: WORST-FIRST</th>
<th>FUTURE COST: CURRENT POLICY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavements (NHS)</td>
<td>16,000</td>
<td>15,700</td>
<td>6,600</td>
</tr>
<tr>
<td>Pavements (non-NHS)</td>
<td>13,600</td>
<td>13,400</td>
<td>5,600</td>
</tr>
<tr>
<td>Bridges</td>
<td>4,000</td>
<td>1,600</td>
<td>1,000</td>
</tr>
<tr>
<td>Highway Culverts</td>
<td>1,700</td>
<td>400</td>
<td>285</td>
</tr>
<tr>
<td>Deep Stormwater Tunnels</td>
<td>240</td>
<td>140</td>
<td>130</td>
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<tr>
<td>Overhead Sign Structures</td>
<td>200</td>
<td>140</td>
<td>80</td>
</tr>
<tr>
<td>High-Mast Light Tower Structures</td>
<td>20</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: All amounts are million dollars, in today’s dollars

The information in **Figure 6-15** shows that timely preservation work is very effective in reducing life-cycle costs for pavements and bridges, primarily by extending the lifespans of these assets. Currently, MnDOT does not have fully-implemented tools to optimize preservation policies. As a result, it is believed that greater cost savings could be achieved through fine-tuning the timing and application of preservation actions. For assets like overhead sign structures and high-mast light tower structures, routine inspection of the structures to ensure that they are operating as intended is expected to reduce life-cycle costs.
Improving Life-Cycle Management

The primary purpose of life-cycle cost analysis is to answer the question: Which investments, made today, are most cost-effective in the long-term to keep the infrastructure in service? Often, the answer to this question is preventive maintenance or preservation work on assets that are in relatively good condition. Life-cycle cost analysis is used to identify and prioritize the best opportunities and timing for this strategic activity. In transportation asset management, state-of-the art life-cycle management is quantitative and scientific, based on research and analysis of historical condition and performance data. Predictive models for deterioration, cost, action effectiveness, and risk allow an agency to reliably forecast the outcomes of policies and program development decisions. Combined with the ability to generate policy and program alternatives, this approach enables better-informed decision-making.

MnDOT has tools in place for pavements and bridges to help optimize life-cycle management. However, these tools are not fully implemented because either the necessary research for predictive models has not been performed or maintenance costs could not easily be merged with performance data to document the increased costs of maintenance if capital improvements are not performed. However, the agency does have sufficient data to support such research for several of the major asset classes.

During the development of this TAMP, MnDOT developed a set of spreadsheet models to approximate a life-cycle cost analysis. Such models could be extended to make use of research results for any asset class, provided that a complete inventory and routine inspection process is in place. Examples of LCCA spreadsheet models are included in the life-cycle cost section of the Technical Guide.

Key conclusions from the LCCA that serve as drivers for improving existing management practices and investment strategies are summarized below:

- Investments in pavement preservation have significantly reduced life-cycle maintenance costs. MnDOT should continue to proactively maintain its pavements and should closely manage preventive maintenance activities for the entire state highway system.
• Strive to lower network life-cycle costs by considering major rehabilitation or reconstruction activities for pavements that are over 50 years old (in lieu of treatments like mill and overlays that become less effective as the pavement structure ages). When funding allows, MnDOT should invest in long-term fixes at the end of a pavement’s life. Quantifying the benefits of performing the right fix for roads over 50 years old will allow MnDOT to have considerable life-cycle cost savings. For example, MnDOT’s Materials Office works closely with the districts to recommend the most appropriate pavement life-cycle cost fixes at the project level – based on targets, financial commitments, investment strategies, age, and history.

• Invest in research studies to better understand deterioration of bridges, culverts, deep stormwater tunnels, overhead sign structures and high-mast light tower structures, thereby improving the accuracy of long-term investment decisions. For example, the effectiveness of slipliners to extend culvert life is understood only anecdotally, as is the phenomenon of void formation around the culvert joints. Such understanding would help MnDOT select more appropriate maintenance actions and develop new and more effective treatments.

• Make a conscious effort to move from a reactive to a more proactive approach for culverts, deep stormwater tunnels, overhead sign structures and high-mast light tower structures. Overhead sign structures and high-mast light tower structures must be inspected more consistently in order to anticipate problems that other agencies have found to be common, especially fatigue cracking.

• The LCCA demonstrated the ongoing maintenance and capital commitments associated with adding assets to the state’s inventory. These costs represent significant future liabilities that are not always accounted for in traditional planning and programming processes. Therefore, MnDOT should develop a process for considering them when contemplating capital improvements.
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