APPENDIX C - LIFE CYCLE PLANNING

LIFE CYCLE PLANNING APPROACH FOR ANCILLARY ASSETS

For each asset included in the TAMP except pavement, bridge and buildings, the following information was compiled to facilitate the LCP analysis:

- **Asset inventory and condition**. The information on the size of the asset network and the distribution of assets in each condition category (e.g., good, fair, poor, etc.) was based on a combination of information available from asset inspection records and estimates provided by asset managers.
- **Network growth rate.** An estimate of how the asset inventory size changes from year to year was determined based on historical data and input from the districts.
- **Condition deterioration models.** The amount of time an asset takes to deteriorate from one condition state to another was modeled based on the expert judgment from the asset managers.
- **Treatment actions.** The type of treatment actions applied to the asset based on its condition state and the average unit cost associated with each treatment action was established based on current asset management practices.
- **Treatment impact matrix.** A treatment impact matrix was established to determine how the asset condition changes after a treatment is applied.
- **Treatment strategies.** Three treatment strategies were evaluated for each asset:
    - **Minimum Maintenance.** Impact of just applying routine maintenance treatments and not investing in any preservation or rehabilitation activities.
    - **Current Strategy.** Impact of following MnDOT's current approach to managing assets.
    - **Desired Strategy.** The adjustment needed to MnDOT's current treatment strategies to achieve the desired performance target in 10 years.

Additional details are provided in the following sections.

ASSET CONDITION STATES

Assets are classified into 2, 3, or 4 condition states, depending on the asset type. Details on the inventory and condition ratings utilized for each asset are available in **Chapter 3, Asset Inventory, Condition and Valuatio**n. Figure C-1 summarizes the number of condition states and the condition categories for each asset.

Figure C-1: Asset Condition States and Categories

ASSET	NUMBER OF CONDITION STATES	CONDITION CATEGORIES
Highway Culverts	4	Good, Fair, Poor, Very Poor
Deep Storm water tunnels	4	Minor/ Moderate, Moderate, Significant, Very Significant
Overhead sign structures	3	Good, Fair, Poor
High-Mast Tower Light Structures	4	Good, Fair, Poor, Beyond Useful Life
Noise Walls (Concrete and Wood)	4	Good, Fair, Poor, Very Poor
Traffic Signals	4	Good, Fair, Poor, Beyond Useful Life
Lighting	4	Good, Fair, Poor, Beyond Useful Life
Pedestrian Infrastructure	2	Compliant, Non-Compliant
Intelligent Transportation Systems	3 or 4 depending on sub asset*	Good, Fair, Poor, Very Poor (Critical) (4) Good, Fair, Poor (3)

ANALYSIS PERIOD AND NETWORK GROWTH RATE

- Long enough that future costs (beyond the chosen analysis period) do not impact the results significantly.
- Long enough that at least one complete asset replacement cycle is included.

Expert judgment (from asset managers) and the expected impact of treatments on the asset life were used to finalize the analysis periods adopted for each asset. The network growth rate was determined based on historical data and expert judgment. Figure C-2 summarizes the analysis period and network growth rate for each asset.

Figure C-2: Analysis Period and Network Growth Rate of Assets

ASSET	NUMBER OF CONDITION STATES	CONDITION CATEGORIES
Highway Culverts	100	0
Deep Storm water tunnels	100	0
Overhead sign structures	50	10
High-Mast Tower Light Structures	50	3
Noise Walls (Concrete and Wood)	100	2 (Wood) 8 (Concrete)
Traffic Signals	50	0
Lighting	50	5
Pedestrian Infrastructure: Curb Ramps and Sidewalk	20 (Curb Ramps) and 30 (Sidewalk)	3
Intelligent Transportation Systems	50	Varies by ITS asset type

CONDITION DETERIORATION MODELS

A Markov process was used to model asset condition deterioration, and a condition transition probability matrix was established for each asset. These matrices describe the time taken to deteriorate from one condition state to another (e.g., good to fair or fair to poor).

An example of a Markov transition probability matrix is shown in Figure C-3. In this example, assets can deteriorate from good to fair and fair to poor. Assets cannot deteriorate from good to poor without being in the fair state at some point in time. If we assume that 100% of the asset network is in good condition today and it takes 20 years for 50% of the network to deteriorate to a fair condition and 10 years for 50% of the assets in fair condition to deterioration to a poor condition, the condition transition probability is based on the following rules:

- 3.4% of the asset network will deteriorate from a good to fair condition every year.
- 6.7% of the asset network will deteriorate from a fair to poor condition every year.

Figure C-3: Illustration of Markov Transition Probability Matrix

TRANSITION STATES	YEARS	GOOD	FAIR	POOR
Good to Fair	20	96.6%	3.4%	N/A
Fair to Poor	10	N/A	93.3%	6.7%

TREATMENT STRATEGIES

The annual treatment distributions define the percentage of the network in a particular condition state that will receive the treatments identified in each year over the chosen analysis period. Figure C-4 illustrates annual maintenance fractions associated with a treatment strategy.

Figure C-4: Illustration of Annual Treatment Distributions

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	UNIT COST ($/ ASSET
Reactive Maintenance	1%	2%	3%	$90,000
Inspection	20%	20%	20%	$200
Major rehab	0%	0%	5%	$19,000
Replacement	0%	0%	3%	$125,000

In the example shown in Figure C-4, 1% of the assets in good condition, 2% of the assets in fair condition, and 3% of the assets in poor condition receive reactive maintenance each year. Different treatment strategies are generated by changing the annual maintenance fractions associated with each treatment action.

Figure C-4 also shows the example unit costs for each treatment. Treatment unit costs help determine the estimated spending level for the analysis year based on the fraction of assets in each condition category and the applicable maintenance actions associated with the treatment strategy chosen.

TREATMENT IMPACT MATRIX

A treatment impact matrix is used to determine the impact of a treatment application on the condition of the asset. An example impact matrix is shown in Figure C-5.

Figure C-5: Illustration of Impact Matrix

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	REACTIVE MAINTENANCE	INSPECTION	MAJOR REHAB	REPLACEMENT
Good	Good	Good	N/A	N/A
Fair	Fair	Fair	N/A	N/A
Poor	Poor	Poor	75% to Good and 25% to Fair	Good

Treatment application can have several different impacts on the resulting asset condition, as summarized below (and illustrated in Figure C-5):

- **No Impact on Condition:** The application of certain treatments (such as reactive maintenance and inspection) has no impact on the resulting condition.
- **Improve to Higher Condition Category:** Certain treatments improve the condition category by one or more condition states. For example, replacing an asset in poor condition changes the resulting condition to good.
- **Fractional Condition Improvement:** Some treatments have fractional improvements on the asset condition. For example, applying a major rehabilitation treatment to assets in poor condition results in shifting 75% of the assets in poor condition to a good condition category. The remaining 25% of the assets are improved to a fair condition category.

LIFE CYCLE PLANNING INPUTS AND ASSUMPTIONS FOR ANCILLARY ASSETS

The analysis inputs and assumptions used for each assets other than pavements, bridges and buildings are documented below.

HIGHWAY CULVERTS

To compare highway culverts to other assets in the TAMP, staff combined the poor and very poor condition rating into a category called poor.

Figure C-6 presents the deterioration models for each LCP approach evaluated. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-6: Deterioration Models for Highway Culverts

APPROACH	TRANSITION STATES	YEARS	GOOD	FAIR	POOR	VERY POOR
Current	Good to Fair	10	93.3%	6.7%	N/A	N/A
Current	Fair to Poor	14	N/A	95.2%	4.8%	N/A
Current	Poor to Very Poor	6	N/A	N/A	89.1%	10.9%
Desired	Good to Fair	10	93.3%	6.7%	N/A	N/A
Desired	Fair to Poor	16	N/A	95.8%	4.2%	N/A
Desired	Poor to Very Poor	8	N/A	N/A	91.7%	8.3%

Figure C-7 and C-8 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-7: Annual Treatment Distributions for Highway Culverts - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN VERY POOR CONDITION	UNIT COST ($ PER ASSET)
Inspection	17%	17%	30%	60%	$100
Cleaning	0.5%	0.5%	2.5%	4%	$1,000
Reset ends	0%	0%	1%	0.5%	$3,900
Joint repair	0%	0%	0.5%	0.5%	$3,440
Pave invert	0%	0%	0.1%	0%	$1,840
Replace ends	0%	0%	0.5%	0.2%	$5,630
Slipliner	0%	0%	0.5%	0.3%	$14,000
CIPP	0%	0%	3%	9%	$19,500
Replace-Trench	0%	0%	1.7%	6.9%	$31,500
Replace -Jack	0%	0%	0%	0.5%	$91,000

Figure C-9 shows the treatment impact matrix for highway culverts. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:.

- Inspection and cleaning have no impact on condition.
- Reset ends, joint repairs, pave invert and replace ends improves asset condition by one condition state (fair to poor, poor to fair, and very poor to poor).
- Slipliner and CIPP, when applied to assets in in poor and very poor conditions, improve 90% to fair condition and 10% to good condition.
- Replace-trench and replace-jack restores assets in poor or very poor condition to good condition.

Figure C-8: Annual Treatment Distributions for Highway Culverts - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN VERY POOR CONDITION	UNIT COST ($ PER ASSET)
Inspection	17%	17%	30%	60%	$100
Cleaning	0.5%	0.5%	2.5%	4%	$1,000
Reset ends	0%	0%	3%	1%	$3,900
Joint repair	0%	0%	5%	1%	$3,440
Pave invert	0%	0%	1%	0%	$1,840
Replace ends	0%	0%	3%	1%	$5,630
Slipliner	0%	0%	1%	1%	$14,000
CIPP	0%	0%	7.2%	10%	$19,500
Replace-Trench	0%	0%	4%	11%	$41,000
Replace -Jack	0%	0%	0%	1%	$91,000

Figure C-9: Treatment Impact Matrix for Highway Culverts

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	INSPECTION	CLEANING	RESET ENDS	JOINT REPAIR	PAVE INVERT	REPLACE ENDS	SLIPLINER	CIPP	REPLACE TRENCH	REPLACE JACK
Good	Good	Good	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fair	Fair	Fair	Good	Good	Good	Good	N/A	N/A	N/A	N/A
Poor	Poor	Poor	Fair	Fair	Fair	Fair	Good (10%)/ Fair (90%)	Good (10%)/ Fair (90%)	Good	Good
Very Poor	Very Poor	Very Poor	Poor	Poor	Poor	Poor	Good (10%)/ Fair (90%)	Good (10%)/ Fair (90%)	Good	Good

DEEP STORMWATER TUNNELS

The Deep Stormwater Tunnels rating system does not use good/fair/poor terminology. In order to compare tunnels to other assets in the TAMP, staff translated the tunnel rating as follows:

- Minor to Moderate Defects = good
- Moderate Defects = fair
- Significant to Most Significant Defects = poor

Figure C-10 presents the deterioration models used for each LCP approach evaluated. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-10: Deterioration Models for Deep Stormwater Tunnels

APPROACH	TRANSITION STATES	YEARS	MINOR TO MODERATE	MODERATE	SIGNIFICANT	MOST SIGNIFICANT
Current	Minor/Moderate to Moderate	14	95.2%	4.8%	N/A	N/A
Current	Moderate to Significant	32	N/A	97.9%	2.1%	N/A
Current	Significant to Very Significant	14	N/A	N/A	95.2%	4.8%
Desired	Minor/Moderate to Moderate	14	95.2%	4.8%	N/A	N/A
Desired	Moderate to Significant	32	N/A	97.9%	2.1%	N/A
Desired	Significant to Very Significant	14	N/A	N/A	95.2%	4.8%

Figures C-11 and C-12 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-11: Annual Treatment Distributions for Deep Stormwater Tunnels - Current Approach

TREATMENT	% ANNUALLY TREATED IN MINOR TO MODERATE DEFECTS	% ANNUALLY TREATED IN MODERATE DEFECTS	% ANNUALLY TREATED IN IN SIGNIFICANT DEFECT	% ANNUALLY TREATED IN MOST SIGNIFICANT DEFECT	UNIT COST ($ PER ASSET)
Inspection	10%	25%	1%	1%	$14
Routine Maintenance	1%	1%	1%	1%	$30
Repairs (Fill voids behind tunnels, seal cracks)	0%	1%	50%	100%	$700
Minor Rehab (Steel band installation)	0%	0%	0%	0.5%	$1,600
Major Rehab (Replacement)	0%	0%	0%	0.5%	$7,000

Figure C-12: Annual Treatment Distributions for Deep Stormwater Tunnels - Desired Approach

TREATMENT	% ANNUALLY TREATED IN MINOR TO MODERATE DEFECTS	% ANNUALLY TREATED IN MODERATE DEFECTS	% ANNUALLY TREATED IN SIGNIFICANT DEFECT	% ANNUALLY TREATED IN MOST SIGNIFICANT DEFECT	UNIT COST ($ PER ASSET)
Inspection	10%	25%	10%	10%	$14
Routine Maintenance	2%	2%	2%	2%	$30
Repairs (Fill voids behind tunnels, seal cracks)	0%	1%	75%	100%	$700
Minor Rehab (Steel band installation)	0%	0%	0%	1%	$1,600
Major Rehab (Replacement)	0%	0%	0%	1%	$7,000

Figure C-13 shows the treatment impact matrix for deep stormwater tunnels. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:

- Inspection and routine maintenance have no impact on condition.
- Repairs (fill voids behind tunnels, seal cracks), minor rehab (steel band installation), and major rehab (replacement) restore assets to a Minor to Moderate Defects (good) condition state.

Figure C-13: Treatment Impact Matrix for Deep Stormwater Tunnels (Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	INSPECTION	ROUTINE MAINTENANCE	REPAIRS	MINOR REHAB	MAJOR REHAB
Minor to Moderate Defects (Good)	Minor to Moderate Defects	Minor to Moderate Defects	N/A	N/A	N/A
Moderate Defects (Fair)	Moderate Defects	Moderate Defects	N/A	N/A	N/A
Significant Defects (Poor)	Significant Defects	Significant Defects	Minor to Moderate Defects	Minor to Moderate Defects	Minor to Moderate Defects
Most Significant Defects (Poor)	Most Significant Defects	Most Significant Defects	Minor to Moderate Defects	Minor to Moderate Defects	Minor to Moderate Defects

INTELLIGENT TRANSPORTATION SYSTEMS

Figure C-14 summarizes the deterioration models for each ITS asset.

Figure C-14: Deterioration Models for ITS Assets

(Years to Deteriorate from One Condition State to Another)

Note: Assumed probability of deteriorating from one condition state to another = 90%

ITS ASSET	GOOD TO FAIR	FAIR TO POOR	POOR TO BEYOND USEFUL SERVICE LIFE
Fiber Communication Network Miles	15	5	5
Fiber Network Shelters	10 (Current Approach) 15 (Desired Approach)	5	5
Traffic Management System Cabinet	8 (Current Approach) 10 (Desired Approach)	8 (Current Approach) 6 (Desired Approach)	5
Dynamic Message Signs	9	4	2
Traffic Monitoring Cameras	5	4	3
Traffic Detector Stations/Site-Loops/Radar	15 Functional to Non-Functional	-	-
E-ZPass Readers	10	3	2
Reversible Road Gates	9	4	4
Ramp Meters	25	25	-
Road Weather Information Systems Sites	20	15	5
Automatic Traffic Recorders Sensors	6	3	3
Weigh-In-Motion System Sites Senors	6	3	3

Figure C-15 presents the average unit costs for each treatment category for ITS assets.

Figure C-15: Unit Cost by Treatment Category for ITS Assets (Unit Cost)

ITS ASSET	ROUTINE MAINTENANCE	PREVENTIVE MAINTENANCE	MINOR REHAB	MAJOR REHAB	REPLACEMENT
Fiber Communication Network Miles	$0	$0	$15,000	$15,000	$90,000
Fiber Network Shelters	$0	$250	$700	$2,500	$110,000
Traffic Management System Cabinet	$150	$0	$350	$600	$14,000
Dynamic Message Signs	$250	$250	$800	$1,000	$81,500
Traffic Monitoring Cameras	$0	$0	$250	$600	$3,300
Traffic Detector Stations/ Site-Loops/Radar	$0	$0	$125 (Loops) $150 (Radar)	$600 (Loops) $400 (Radar)	$3,250 (Loops) $6,500 (Radar)
E-ZPass Readers	$550	$0	$0	$0	$12,500
Reversible Road Gates	$0	$225	$200	$1,500	$9,500
Ramp Meters	$0	$0	$150	$350	$6,000
Road Weather Information Systems Sites	$400	$0	$5,000	$20,000	$90,000
Automatic Traffic Recorders Sensors	$400	$200	$1,250	$0	$30,000
Weigh-In-Motion System Sites Senors	$400	$200	$1,250	$0	$150,000

Figures C-16 through C-39 shows the annual treatment distributions for the LCP approaches evaluated for each ITS asset.

Figure C-16: Annual Maintenance Fractions for Fiber Communication Network Miles - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	0%	0.2%	0%	0%
Major Rehabilitation	0%	0%	0.2%	0%
Replacement	0%	0%	0%	10%

Figure C-17: Annual Maintenance Fractions for Fiber Communication Network Miles - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	0%	2%	0%	0%
Major Rehabilitation	0%	0%	2%	0%
Replacement	0%	0%	67.5%	100%

Figure C-18: Current Approach Annual Maintenance Fractions for Fiber Network Shelters - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	50%	75%	100%	100%
Minor Rehabilitation	5%	25%	35%	35%
Major Rehabilitation	3%	25%	35%	35%
Replacement	0%	0%	5%	70%

Figure C-19: Current Approach Annual Maintenance Fractions for Fiber Network Shelters - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	50%	75%	100%	100%
Minor Rehabilitation	5%	25%	26%	0%
Major Rehabilitation	3%	25%	26%	0%
Replacement	0%	0%	55.5%	100%

Figure C-20: Annual Maintenance Fractions for Traffic Management System Cabinet - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	100%	100%	100%	100%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	20%	30%	20%	0%
Major Rehabilitation	0%	10%	5%	0.5%
Replacement	0%	0%	0%	80%

Figure C-21: Annual Maintenance Fractions for Traffic Management System Cabinet - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	200%	200%	200%	200%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	40%	20%	20%	0%
Major Rehabilitation	0%	10%	5%	0.5%
Replacement	0%	0%	24%	99.5%

Figure C-22: Annual Maintenance Fractions for Dynamic Message Signs - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	100%	100%	100%	10%
Preventive Maintenance	100%	100%	100%	10%
Minor Rehabilitation	3%	100%	100%	5%
Major Rehabilitation	3%	60%	100%	5%
Replacement	0%	0%	5%	90%

Figure C-23: Annual Maintenance Fractions for Dynamic Message Signs - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	200%	200%	200%	200%
Preventive Maintenance	200%	200%	200%	200%
Minor Rehabilitation	3%	100%	20%	0%
Major Rehabilitation	3%	60%	20%	0%
Replacement	0%	0%	56.5%	100%

Figure C-24: Annual Maintenance Fractions for Traffic Monitoring Cameras - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	10%	20%	30%	0%
Major Rehabilitation	5%	10%	10%	0%
Replacement	0%	0%	5%	100%

Figure C-25: Annual Maintenance Fractions for Traffic Monitoring Cameras - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	100%	100%	100%	0%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	20%	30%	40%	0%
Major Rehabilitation	5%	10%	10%	0%
Replacement	0%	0%	23%	100%

Figure C-26: Annual Maintenance Fractions for Traffic Detector Stations/Site-Loops/Radar - Current Approach

CURRENT APPROACH TREATMENTS	FUNCTIONAL	NON-FUNCTIONAL
Routine Maintenance	0% (Loops) 0% (Radar)	0% (Loops) 0% (Radar)
Preventive Maintenance	0% (Loops) 0% (Radar)	0% (Loops) 0% (Radar)
Minor Rehabilitation	15% (Loops) 0% (Radar)	0% (Loops) 0% (Radar)
Major Rehabilitation	15% (Loops) 1% (Radar)	0% (Loops) 0% (Radar)
Replacement	0% (Loops) 0% (Radar)	30% (Loops) 88% (Radar)

Figure C-27: Annual Maintenance Fractions for Traffic Detector Stations/Site-Loops/Radar - Desired Approach

CURRENT APPROACH TREATMENTS	FUNCTIONAL	NON-FUNCTIONAL
Routine Maintenance	0% (Loops) 0% (Radar)	0% (Loops) 0% (Radar)
Preventive Maintenance	0% (Loops) 0% (Radar)	0% (Loops) 0% (Radar)
Minor Rehabilitation	15% (Loops) 20% (Radar)	0% (Loops) 0% (Radar)
Major Rehabilitation	15% (Loops) 1% (Radar)	0% (Loops) 0% (Radar)
Replacement	0% (Loops) 0% (Radar)	88% (Loops) 88% (Radar)

Figure C-28: Annual Maintenance Fractions for E-ZPass Readers - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	50%	100%	100%	100%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	0%	0%	0%	0%
Major Rehabilitation	0%	0%	0%	0%
Replacement	0%	0%	0%	100%

Figure C-29: Annual Maintenance Fractions for E-ZPass Readers - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	50%	100%	100%	100%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	0%	0%	0%	0%
Major Rehabilitation	0%	0%	0%	0%
Replacement	0%	0%	87%	100%

Figure C-30: Annual Maintenance Fractions for Reversible Road Gates - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	100%	100%	100%	100%
Minor Rehabilitation	100%	40%	70%	39.5%
Major Rehabilitation	0%	60%	30%	0.5%
Replacement	0%	0%	0%	60%

Figure C-31: Annual Maintenance Fractions for Reversible Road Gates - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	0%	0%	0%	0%
Preventive Maintenance	100%	100%	100%	100%
Minor Rehabilitation	200%	25%	70%	14.5%
Major Rehabilitation	0%	75%	15%	0.5%
Replacement	0%	0%	15%	75%

Figure C-32: Annual Maintenance Fractions for Ramp Meters - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR
Routine Maintenance	0%	0%	0%
Preventive Maintenance	0%	0%	0%
Minor Rehabilitation	0%	0%	2.5%
Major Rehabilitation	0%	0%	1%
Replacement	0%	0%	96.5%

Figure C-33: Annual Maintenance Fractions for Ramp Meters - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR
Routine Maintenance	0%	0%	0%
Preventive Maintenance	0%	0%	0%
Minor Rehabilitation	0%	0%	2.5%
Major Rehabilitation	0%	0%	1%
Replacement	0%	0%	96.5%

Figure C-34: Annual Maintenance Fractions for Road Weather Information Systems Sites - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	200%	200%	200%	0%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	20%	20%	20%	0%
Major Rehabilitation	16.7%	16.7%	16.7%	0%
Replacement	0%	0%	0%	90%

Figure C-35: Annual Maintenance Fractions for Road Weather Information Systems Sites - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	200%	200%	200%	0%
Preventive Maintenance	0%	0%	0%	0%
Minor Rehabilitation	20%	20%	10.3%	0%
Major Rehabilitation	16.7%	16.7%	16.7%	0%
Replacement	0%	0%	73%	100%

Figure C-36: Annual Maintenance Fractions for Automatic Traffic Recorders Sensors - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	5%	5%	5%	0%
Preventive Maintenance	100%	100%	100%	0%
Minor Rehabilitation	0%	1%	1.5%	0%
Major Rehabilitation	0%	0%	0%	0%
Replacement	0%	2%	5%	90%

Figure C-37: Annual Maintenance Fractions for Automatic Traffic Recorders Sensors - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	5%	5%	5%	0%
Preventive Maintenance	100%	100%	100%	0%
Minor Rehabilitation	0%	1%	1.5%	0%
Major Rehabilitation	0%	0%	0%	0%
Replacement	0%	2%	62.3%	100%

Figure C-38: Annual Maintenance Fractions for Weigh-In-Motion System Sites Senors - Current Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	5%	5%	5%	0%
Preventive Maintenance	100%	100%	100%	0%
Minor Rehabilitation	0%	1%	1.5%	0%
Major Rehabilitation	0%	0%	0%	0%
Replacement	0%	2%	5%	90%

Figure C-39: Annual Maintenance Fractions for Weigh-In-Motion System Sites Senors - Desired Approach

CURRENT APPROACH TREATMENTS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Routine Maintenance	5%	5%	5%	0%
Preventive Maintenance	100%	100%	100%	0%
Minor Rehabilitation	0%	1%	1.5%	0%
Major Rehabilitation	0%	0%	0%	0%
Replacement	0%	2%	56%	100%

Figure C-40 shows the treatment impact matrix for ITS infrastructure. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:

- Routine and preventive maintenance actions have no impact on asset condition.
- For assets in poor or better condition, minor rehabilitation improves asset condition by one condition state (fair to good, poor to fair).
- Major rehabilitation improves conditions by two condition states (beyond useful service life to fair and poor to good).
- Replacement restores assets to as-built condition.

Figure C-40: Treatment Impact Matrix for ITS Infrastructure Assets

(Treatments and Resulting Asset Condition after Treatment Application)

Note: For dynamic message signs and fiber network shelter assets, minor rehabilitation and major rehabilitation treatments have no impact in condition.

CURRENT CONDITION	ROUTINE MAINTENANCE	PREVENTIVE MAINTENANCE	MINOR REHAB	MAJOR REHAB	REPLACEMENT
Good	Good	Good	N/A	N/A	N/A
Fair	Fair	Fair	Good	N/A	N/A
Poor	Poor	Poor	Fair	Good	Good
Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Fair	Good

NOISE WALLS

WOOD PANEL NOISE WALLS

Figure C-41 presents deterioration model for wood panel noise walls. The same model is used for both the current and desired approaches. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-41: Deterioration Model for Wood Panel Noise Walls

TRANSITION STATES	YEARS	GOOD	FAIR	POOR	VERY POOR
Good to Fair	35	98%	2%	N/A	N/A
Fair to Poor	20	N/A	96.6%	3.4%	N/A
Poor to Very Poor	10	N/A	N/A	93.3%	6.7%

Figures C-42 and C-43 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-42: Annual Treatment Distributions for Wood Panel Noise Walls - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN VERY POOR CONDITION	UNIT COST ($ PER ASSET)
Structural Inspection	10%	10%	10%	10%	$500
Reactive Maintenance	2%	2%	2%	2%	$15,000
Out of Cycle Inspection	0%	0%	0%	0%	$500
Re-Planking	0%	0%	16%	16%	$375,000
Splash Zone Sealing	0%	0%	0%	0%	$8,500
Replacement	0%	0%	4%	4%	$800,000

Figure C-43: Annual Treatment Distributions for Wood Panel Noise Walls - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN VERY POOR CONDITION	UNIT COST ($ PER ASSET)
Structural Inspection	10%	10%	10%	10%	$500
Reactive Maintenance	2%	2%	2%	2%	$15,000
Out of Cycle Inspection	0%	0%	10%	10%	$500
Re-Planking	0%	0%	12%	12%	$375,000
Splash Zone Sealing	0%	20%	20%	20%	$8,500
Replacement	0%	0%	8%	8%	$800,000

CONCRETE NOISE WALLS

Figure C-44 presents deterioration models for concrete noise walls. The same model is used for both the current and desired approaches.

Figure C-44: Deterioration Model for Wood Panel Noise Walls

TRANSITION STATES	YEARS	GOOD	FAIR	POOR	VERY POOR
Good to Fair	50	98.6%	1.4%	N/A	N/A
Fair to Poor	20	N/A	96.6%	3.4%	N/A
Poor to Very Poor	10	N/A	N/A	93.3%	6.7%

Figures C-45 and C-46 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-45: Annual Treatment Distributions for Concrete Noise Walls - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN VERY POOR CONDITION	UNIT COST ($ PER ASSET)
Structural Inspection	10%	10%	10%	10%	$500
Reactive Maintenance	0%	0%	0%	0%	$0
Out of Cycle Inspection	0%	0%	0%	0%	$500
Re-Planking	0%	0%	20%	20%	$400,000
Splash Zone Sealing	0%	0%	0%	0%	$15,000
Replacement	0%	0%	0%	0%	$800,000

Figure C-46: Annual Treatment Distributions for Concrete Noise Walls - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN VERY POOR CONDITION	UNIT COST ($ PER ASSET)
Structural Inspection	10%	10%	10%	10%	$500
Reactive Maintenance	2%	2%	2%	2%	$30,000
Out of Cycle Inspection	0%	0%	10%	10%	$500
Re-Planking	0%	0%	12%	12%	$400,000
Splash Zone Sealing	0%	20%	20%	20%	$15,000
Replacement	0%	0%	8%	8%	$800,000

TREATMENT IMPACT MATRIX

Figure C-47 shows the treatment impact matrix for noise walls (both wood panel and concrete). It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:

- Structural inspection, reactive maintenance, out-of-cycle inspection, and splash zone sealing do not have any impact on asset condition.
- Complete replacement is the only treatment action that has a significant impact on asset condition, especially assets in poor and very poor condition.
- Re-planking (for wood panel noise walls) and minor rehabilitation (for concrete noise walls) results in:
  - Significant condition improvement for assets in fair condition.
  - Small condition improvements for assets in poor and very poor condition.

Figure C-47: Treatment Impact Matrix for Noise Walls

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	STRUCTURAL INSPECTION	REACTIVE MAINTENANCE	OUT OF CYCLE INSPECTION	RE-PLANKING (WOOD PANEL) / MINOR REHAB (CONCRETE)	SPLASH ZONE SEALING	REPLACEMENT
Good	Good	Good	Good	N/A	Good	N/A
Fair	Fair	Fair	Fair	90% Good	Fair	N/A
Poor	Poor	Poor	Poor	20% Good/ 80% Fair	Poor	Good
Very Poor	Very Poor	Very Poor	Very Poor	10% Good/ 50% Fair/ 40% Poor	Very Poor	Good

OVERHEAD SIGN STRUCTURES

Figure C-48 presents the deterioration models used for each LCP approach evaluated.

The desired approach's extended transition state periods are attributed to an increase in out-of-cycle Inspections, which will help identify and monitor issues before they cause structures to deteriorate in condition. The change also increases the frequency of nut tightening, rehabilitation, and replacement, ensuring that more structures will be assigned higher condition states, improving overall inventory health. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-48: Deterioration Models for Overhead Sign Structures

APPROACH	TRANSITION STATES	YEARS	GOOD	FAIR	POOR
Current	Good to Fair	20	96.6%	3.4%	N/A
Current	Fair to Poor	10	N/A	93.3%	6.7%
Desired	Good to Fair	25	97.3%	2.7%	N/A
Desired	Fair to Poor	12	N/A	94.4%	5.6%

Figures C-49 and C-50 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-49: Annual Treatment Distributions for Overhead Sign Structures - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	UNIT COST ($ PER ASSET)
Reactive Maintenance	0.2%	0.2%	0.2%	$90,000
Structural Inspection	20%	20%	20%	$200
Out of cycle inspection	0%	0%	0%	$200
Tighten Nuts	0%	0%	7.5%	$800
Major rehab	0%	0%	5%	$19,000
Replacement	0%	0%	3%	$125,000

Figure C-50: Annual Treatment Distributions for Overhead Sign Structures - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	UNIT COST ($ PER ASSET)
Reactive Maintenance	0.2%	0.2%	0.2%	$90,000
Structural Inspection	20%	20%	20%	$200
Out of cycle inspection	0%	0%	10%	$200
Tighten Nuts	0%	0%	10%	$800
Major rehab	0%	0%	7%	$19,000
Replacement	0%	0%	5%	$125,000

Figure C-51 shows the treatment impact matrix for overhead sign structures. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:.

- Treatments such as reactive maintenance, structural inspection, and out-of-cycle inspection have no impact on condition.
- Treatments such as tightening nuts improve assets in poor condition to either good (75% of the time) or fair (25% of the time) condition.
- Major rehabilitation and replacement treatments completely restore assets in poor condition to good condition.

Figure C-51: Treatment Impact Matrix for Overhead Sign Structures

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	REACTIVE MAINTENANCE	STRUCTURAL INSPECTION	OUT-OF-CYCLE INSPECTION	TIGHTEN NUTS	MAJOR REHAB	REPLACEMENT
Good	Good	Good	Good	N/A	N/A	N/A
Fair	Fair	Fair	Fair	N/A	N/A	N/A
Poor	Poor	Poor	Poor	75% to Good and 25% to Fair	Good	Good

PEDESTRIAN INFRASTRUCTURE

CURB RAMPS

Figure C-52 presents the deterioration model for curb ramps. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-52: Deterioration Model for Curb Ramps

TRANSITION STATES	YEARS	COMPLIANT	NON-COMPLIANT
Compliant to Non-Compliant	10	93.3%	6.7%

Figures C-53 and C-54 present the unit costs and annual maintenance fractions for the current and desired approaches, respectively.

Figure C-53: Annual Maintenance Fractions for Curb Ramps - Current Approach

TREATMENT	% ANNUALLY TREATED IN COMPLIANT CONDITION	% ANNUALLY TREATED IN NON-COMPLIANT CONDITION	UNIT COST ($ PER ASSET)
Inspection	5%	5%	$35
Grinding	7.5%	6%	$150
Slab Jacking	7.5%	6%	$250
Vegetation Removal	7.5%	6%	$50
Replacement	4.5%	10.00%	$5,000

Figure C-54: Annual Maintenance Fractions for Curb Ramps - Desired Approach

TREATMENT	% ANNUALLY TREATED IN COMPLIANT CONDITION	% ANNUALLY TREATED IN NON-COMPLIANT CONDITION	UNIT COST ($ PER ASSET)
Inspection	6%	6%	$35
Grinding	8.5%	7%	$200
Slab Jacking	8.5%	7%	$250
Vegetation Removal	8.5%	7%	$50
Replacement	4.5%	35%	$5,000

Figure C-55 shows the treatment impact matrix for curb ramps. Inspection has no impact on condition. Grinding, slab jacking, and vegetation removal result in fractional condition improvements and replacement restores the asset to a compliant condition state.

Figure C-55: Treatment Impact Matrix for Curb Ramps

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	INSPECTION	GRINDING	SLAB JACKING	VEGETATION REMOVAL	REPLACEMENT
Compliant	Compliant	Compliant	Compliant	Compliant	Compliant
Non - Compliant	Non - Compliant	75% Compliant	75% Compliant	85% Compliant	Compliant

SIDEWALKS

Key Assumption:

A significant assumption for sidewalks is that the network growth rate is 1% annually instead of 3% (used for all other assets). This difference is because sidewalk investments are targeted at existing infrastructure. Therefore, the 1% growth rate means fewer sidewalks are added to the inventory over time.

Figure C-56 presents the deterioration model for sidewalks. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-56: Deterioration Model for Sidewalks

TRANSITION STATES	YEARS	COMPLIANT	NON-COMPLIANT
Compliant to Non-Compliant	10	93.3%	6.7%

Figures C-57 and C-58 present the unit costs and annual maintenance fractions for the current and desired approaches, respectively.

Figure C-57: Annual Maintenance Fractions for Sidewalks - Current Approach

TREATMENT	% ANNUALLY TREATED IN COMPLIANT CONDITION	% ANNUALLY TREATED IN NON-COMPLIANT CONDITION	UNIT COST ($ PER ASSET)
Inspection	0%	0.1%	$0.64
Grinding	0%	0.2%	$2.73
Slab Jacking	0%	0.2%	$4.55
Vegetation Removal	0%	0.2%	$0.91
Major Rehabilitation (Panel Replacement)	0%	2.5%	$8.00
Replacement	0%	10.3%	$8.00

Figure C-58: Annual Maintenance Fractions for Sidewalks - Desired Approach

TREATMENT	% ANNUALLY TREATED IN COMPLIANT CONDITION	% ANNUALLY TREATED IN NON-COMPLIANT CONDITION	UNIT COST ($ PER ASSET)
Inspection	1%	1%	$0.64
Grinding	1%	1%	$2.73
Slab Jacking	1%	1%	$4.55
Vegetation Removal	1%	1%	$0.91
Major Rehabilitation (Panel Replacement)	1%	15%	$8.00
Replacement	1%	37%	$8.00

Figure C-59 shows the treatment impact matrix for sidewalks. Inspection has no impact on the condition. Grinding, slab jacking, and vegetation removal result in fractional condition improvements, and replacement restores the asset to a compliant condition state.

Figure C-59: Treatment Impact Matrix for Curb Ramps

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	INSPECTION	GRINDING	SLAB JACKING	VEGETATION REMOVAL	MAJOR REHAB	REPLACEMENT
Compliant	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant
Non - Compliant	Non - Compliant	75% compliant	90% compliant	80% Compliant	Compliant	Compliant

TRAFFIC SIGNALS

The deterioration model for signals is shown in figure C-60. The same model is used for each LCP approach evaluated. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-60: Deterioration Model for Traffic Signals

TRANSITION STATES	YEARS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Good to Fair	13	79.4%	20.6%	N/A	N/A
Fair to Poor	11	N/A	76.2%	23.8%	N/A
Poor to Beyond Useful Service Life	6	N/A	N/A	60.7%	39.3%

Figures C-61 and C-62 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-61: Annual Maintenance Fractions for Traffic Signals - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN BEYOND USEFUL SERVICE LIFE CONDITION	UNIT COST ($ PER ASSET COUNT)
Structural Inspection	2%	10%	10%	5%	$1,000
Reactive Maintenance	25%	25%	25%	25%	$400
Operations Check	90%	90%	90%	90%	$100
Electrician Preventive Maintenance	30%	20%	20%	20%	$150
Electronic Preventive Maintenance	50%	50%	50%	50%	$200
Replace LED Indications	0%	10%	10%	2%	$1,400
Replace Electronics	0%	30%	30%	5%	$12,000
Complete Replacement	0%	0%	0%	5%	$450,000
PM Treatment (Transformer, bracketing, ped heads)	0%	10%	15%	5%	$1,000

Figure C-62: Annual Maintenance Fractions for Traffic Signals - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN BEYOND USEFUL SERVICE LIFE CONDITION	UNIT COST ($ PER ASSET COUNT)
Structural Inspection	2%	10%	10%	5%	$1,000
Reactive Maintenance	25%	25%	25%	25%	$400
Operations Check	100%	100%	100%	100%	$100
Electrician Preventive Maintenance	50%	50%	50%	50%	$150
Electronic Preventive Maintenance	100%	100%	100%	100%	$200
Replace LED Indications	10%	10%	10%	10%	$1,400
Replace Electronics	0%	30%	30%	5%	$12,000
Complete Replacement	0%	0%	2%	7%	$450,000
PM Treatment (Transformer, bracketing, ped heads)	0%	10%	15%	2%	$1,000

Figure C-62 shows the treatment impact matrix for signals. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:

- Structural inspection, reactive maintenance, operations check, electrical and electronic preventive maintenance, LED indication and electronic replacements do not have any impact on asset condition.
- Complete replacement is the only treatment action that has a significant impact on asset condition, especially assets in poor and beyond useful service life condition.
- The generic Preventive Maintenance treatments result in small condition improvements for assets in poor and beyond useful service life condition states. For assets in fair condition, the Preventive Maintenance treatments restore the condition to good condition.

Figure C-62: Treatment Impact Matrix for Traffic Signals

(Treatments and Resulting Asset Condition after Treatment Application)

Note: The treatments are structural inspection, reactive maintenance, operations check, electrical preventive maintenance, electronic preventive maintenance, replace LED indications, replace electronics, complete replacement, PM treatment.

CURRENT CONDITION	STRUCTURAL INSPECTION	REACTIVE MAINTENANCE	OPS. CHECK	ELECTRICAL AND ELECTRONIC PM	REPLACE LED AND ELECTRONICS	TOTAL REPLACE	PM TREAT
Good	Good	Good	Good	Good	Good	N/A	N/A
Fair	Fair	Fair	Fair	Fair	Fair	N/A	Good
Poor	Poor	Poor	Poor	Poor	Poor	Good	20% Good /30% Fair
Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Good	10% Good /5% Fair /85% Poor

LIGHTING

The deterioration model for signals is shown in figure C-63. The same model is used for each LCP approach evaluated. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-63: Deterioration Model for Lighting

TRANSITION STATES	YEARS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Good to Fair	13	79.4%	20.6%	N/A	N/A
Fair to Poor	11	N/A	76.2%	23.8%	N/A
Poor to Beyond Useful Service Life	6	N/A	N/A	60.7%	39.3%

Figures C-64 and C-65 present the unit costs and annual treatment distributions for the current and desired approaches, respectively.

Figure C-64: Annual Maintenance Fractions for Lighting - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN BEYOND USEFUL SERVICE LIFE CONDITION	UNIT COST ($ PER ASSET COUNT)
Knockdowns and Replacements	1.5%	1.5%	1.5%	1.5%	$4,000
Reactive Maintenance	2%	2.5%	3%	3.5%	$1,000
Electrical Inspection	1%	1%	1%	1%	$55
Replace Luminaires	10%	10%	10%	10%	$500
Structural Inspection	1%	10%	10%	0%	$140
PM Treatment	0%	1%	1%	0%	$2,480
Complete Replacement	0%	0%	0%	11%	$6,500

Figure C-65: Annual Maintenance Fractions for Lighting - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN BEYOND USEFUL SERVICE LIFE CONDITION	UNIT COST ($ PER ASSET COUNT)
Knockdowns and Replacements	1.5%	1.5%	1.5%	1.5%	$4,000
Reactive Maintenance	2%	2.5%	3%	3.5%	$1,000
Electrical Inspection	20%	20%	20%	50%	$55
Replace Luminaires	10%	10%	10%	10%	$500
Structural Inspection	10%	10%	10%	50%	$140
PM Treatment	0%	1%	1%	0%	$2,480
Complete Replacement	0%	0%	0%	80%	$6,500

Figure C-66 shows the treatment impact matrix for lighting. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:

- For assets in poor or beyond useful service life conditions, knockdowns improve the conditions one level and for assets in a fair condition, 50% of the assets are improved to good condition.
- Reactive maintenance, electrical inspection, replacing luminaries and structural inspection have no impact on asset conditions.
- Preventive maintenance treatment (a generic maintenance treatment) is assumed to improve assets from fair to good conditions and also results in small condition improvements for assets in poor or beyond useful service life conditions.
- Complete replacement restores the assets to an as-built condition.

Figure C-66: Treatment Impact Matrix for Lighting

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	KNOCK-DOWNS	REACTIVE MAINTENANCE	ELECTRICAL INSPECTION	REPLACE LUMINAIRES	STRUCTURAL INSPECTION	PM TREATMENT	COMPLETE REPLACEMENT
Good	Good	Good	Good	Good	Good	N/A	N/A
Fair	50% Good	Fair	Fair	Fair	Fair	Good	Good
Poor	Fair	Poor	Poor	Poor	Poor	20% Good/ 30% Fair	Good
Beyond Useful Service Life	Poor	Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	Beyond Useful Service Life	10% Good/ 5% Fair/85% Poor	Good

HIGH-MAST LIGHT TOWERS

Figure C-67 shows the deterioration model for high-mast light towers. An explanation of the Markov transition matrix and deterioration from one condition state to another is in Figure C-3.

Figure C-67: Deterioration Model for High- Mast Light Towers

TRANSITION STATES	YEARS	GOOD	FAIR	POOR	BEYOND USEFUL SERVICE LIFE
Good to Fair	40	98.3%	1.7%	N/A	N/A
Fair to Poor	10	N/A	93.3%	6.7%	N/A
Poor to Beyond useful service life	10	N/A	N/A	93.3%	6.7%

Figures C-68 and C-69 present the unit costs and annual treatment distributions for the current approach and desired approaches, respectively.

Figure C-68: Annual Maintenance Fractions for High-Mast Light Towers - Current Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN BEYOND USEFUL SERVICE LIFE CONDITION	UNIT COST ($ PER ASSET COUNT)
Structural Inspection	0%	10%	10%	0%	$200
Tighten Nuts and Winch replacement	0%	2%	2%	0%	$250
Out of Cycle Inspection I (excluding Removal and Replacement)	0%	5%	0%	0%	$200
Out of Cycle Inspection II (including Removal and Replacement)	0%	0%	5%	0%	$110,000
Replace LED Luminaires	8.3%	8.3%	8.3%	8.3%	$2,400
Exercise Lowering Mechanism	0%	2%	3%	0%	$100
Removal and Replacement	0%	0%	2%	2%	$110,000

Figure C-69: Annual Maintenance Fractions for High-Mast Light Towers - Desired Approach

TREATMENT	% ANNUALLY TREATED IN GOOD CONDITION	% ANNUALLY TREATED IN FAIR CONDITION	% ANNUALLY TREATED IN POOR CONDITION	% ANNUALLY TREATED IN BEYOND USEFUL SERVICE LIFE CONDITION	UNIT COST ($ PER ASSET COUNT)
Structural Inspection	0%	10%	10%	0%	$200
Tighten Nuts and Winch replacement	0%	2%	2%	0%	$250
Out of Cycle Inspection I (excluding Removal and Replacement)	0%	5%	0%	0%	$200
Out of Cycle Inspection II (including Removal and Replacement)	0%	0%	5%	0%	$110,000
Replace LED Luminaires	8.3%	8.3%	8.3%	8.3%	$2,400
Exercise Lowering Mechanism	0%	2%	3%	0%	$100
Removal and Replacement	0%	0%	5%	5%	$110,000

Figure C-70 shows the treatment impact matrix for high-mast light towers. It reflects the change in conditions expected after each treatment has been applied. Key assumptions are listed below:

- Treatments such as structural inspection, replacement of LED luminaries, and exercise lowering mechanism have no impact on condition.
- Nut tightening and winch replacement restore the asset to a good condition.
- Out-of-cycle inspections:
  - Out of cycle inspection I does not include removal and replacement. This treatment is applied to assets in fair or better condition. When performed on assets in fair condition, most of the assets are expected to return to a good condition.
  - Out of cycle inspection II treatment includes removal and replacement. This treatment is applied to assets in poor or worse condition. This treatment restores the asset to a good condition.
- Removal and replacement restores assets in poor or worse condition to good condition.

Figure C-70: Treatment Impact Matrix for High-Mast Light Towers

(Treatments and Resulting Asset Condition after Treatment Application)

CURRENT CONDITION	STRUCTURAL INSPECTION	TIGHTEN NUTS AND WINCH REPLACEMENT	OUT OF CYCLE INSPECTION I	OUT OF CYCLE INSPECTION II	REPLACE LED	EXERCISE LOWERING MECHANISM	REMOVAL AND REPLACEMENT
Good	Good	N/A	Good	N/A	Good	Good	N/A
Fair	Good	Good	95% Good	N/A	Fair	Fair	N/A
Poor	Poor	Good	N/A	Good	Poor	Poor	Good
Beyond Useful Service Life	Beyond Useful Service Life	Good	N/A	Good	Beyond Useful Service Life	Beyond Useful Service Life	Good