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# Optimum Traffic Signal Condition Assessment and Strategic Maintenance Planning

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**16. Abstract**

The objectives of this study include developing condition assessment procedures, condition thresholds, and improvement plans for traffic signals in Illinois. This project first synthesized previous research and current practices of transportation agencies related to the management and lifespan expectations of traffic signals and their components. Interviews were then conducted with personnel familiar with traffic signal management practices in Illinois, and field work was conducted to identify refinements to then-proposed methods and condition thresholds. The project's technical review panel also provided important guidance throughout the development of the assessment methods. The final recommendations included 34 assessments of traffic signal components. Pictures were included to demonstrate condition levels, and hyperlinks were included to guide reviewers to important online resources. The developed procedures support consistent evaluation of traffic signals throughout Illinois, provide a systematic process for public agencies to identify components in critical condition, and create the foundation to including traffic signals into asset management frameworks. Overall, implementing these procedures and standards should improve traffic signal performance due to reduced failures related to poor component conditions. Improved traffic signal performance is expected to reduce traffic signal life-cycle costs to Illinois Department of Transportation and improve traffic signal performance and safety for the traveling public.

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# EXECUTIVE SUMMARY

The objectives of this study include developing condition assessment procedures, condition thresholds, and improvement plans for traffic signals in Illinois. Condition assessment procedures detail which traffic signal components require inspection. The types of traffic signals vary as well as common practices, so the developed procedures provide a uniform approach to evaluating the condition of these important transportation assets. Next, condition thresholds discern between good, fair, poor, and critical conditions for each assessed signal component. These condition descriptions were built upon consensus of Illinois stakeholders familiar with traffic signals and promote consistency in the evaluation process. Last, this study developed improvement plans to guide the implementation of the study findings.

This study first synthesized previous research and current practices of transportation agencies related to the management and lifespan expectations of traffic signals and their components. Interviews were then conducted with personnel familiar with traffic signal management practices in Illinois, and field work was conducted to identify refinements to then-proposed methods and condition thresholds. The project's technical review panel also provided important guidance throughout the development of the assessment methods.

The recommendations included assessment procedures for 34 traffic signal components. Each assessment method was developed based on previous research and practices of other state departments of transportation and was tailored to meet the needs of traffic signal infrastructure in Illinois. In addition, 145 condition levels were developed to discern between categories of conditions. To support these decisions, many condition descriptions are supported by example pictures or hyperlinks to related standards and other documentation.

The developed procedures support consistent evaluation of traffic signals throughout Illinois, provide a systematic process for public agencies to identify components in critical condition, and create the foundation for including traffic signals into asset management frameworks. Traffic signals in Illinois are managed by a litany of public agencies and contractors. In addition, traffic signal expectations differ between urban and rural locations. The recommendations of this study can bring uniformity to the evaluation and management of traffic signals throughout the state.

Overall, implementing these procedures and condition levels can provide both near- and long-term benefits. In the near term, public agencies that operate traffic signals in Illinois will identify the current state of these systems and build inventories of the devices present. This information can be used to prioritize the repair/replacement of traffic signal components in critical condition.

In the long term, implementing these recommendations can support the inclusion of traffic signals into asset management programs, such as those used for bridges and pavement. With more-informed management, traffic signal performance will improve due to reduced failures related to poor component conditions. Improved traffic signal performance is expected to reduce traffic signal life-cycle costs, increase traffic signal performance, and improve safety for the traveling public.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# CHAPTER 1: INTRODUCTION

Approximately 330,000 traffic signals help control intersections throughout the U.S. (Halkias & Schauer, 2004). Maintaining and managing traffic signals is essential to the safe and efficient flow of traffic along roadways but requires notable investment. By identifying optimum methods for assessing traffic signals, the results of this study can provide a cost-effective path toward better performance of signalized intersections throughout Illinois. The strategic maintenance planning tasks of the proposed study will guide the implementation of traffic signal best practices.

The objectives of this study included developing condition assessment procedures, condition thresholds, and improvement plans. The condition assessment procedures established a method for assessing the various components within a traffic signal system. Managing traffic signal assets is more complicated than traditional infrastructure such as pavement because traffic signals include both physical and electrical/computing assets. The proposed condition assessment procedures considered the nature of these different components, their failure modes, and their life cycles. In addition, this study identified thresholds for acceptable traffic signal equipment conditions that will aid in consistent asset management practices. Last, the implementation recommendations provide a practical path for implementing the results of this study.

The next chapter of this report describes previous research and practice related to traffic signal conditions. Chapter 3 describes the recommended assessment methods and condition levels for traffic signal components. These components include foundations, bases, junction boxes and conduits, aerial structural connections, poles, mast arms, span wires, signal heads, power supply, cabinet, controller, malfunction management unit (MMU), communication systems, and detection systems. Next, Chapter 4 presents implementation recommendations, including recommendations for implementing the developed assessments, options for recovering value from end-of-life components, and recommended maintenance practices. This report concludes in Chapter 5, and the appendices provide a wealth of information related to the management of traffic signals and supporting information related to the study.

# CHAPTER 2: LITERATURE REVIEW

At major intersections, traffic signals determine the direction and flow of traffic. This highly technological equipment must operate continuously to ensure vehicles can pass through the crossing safely (Washington State DOT, 2022). Traffic signal assets are the physical infrastructure necessary for traffic signals to work as planned (FHWA, 2017). On occasion, LEDs go out, poles are broken or fall over, control systems fail, and electrical wiring or services short-out or lose power due to an outage (Washington State DOT, 2022). Asset management is an organized plan for performing maintenance, repair, rehabilitation, and replacement tasks to preserve an asset's desired condition of good repair for the duration of its useful life at the lowest reasonable cost (FHWA, 2017). Installing a traffic signal system at an intersection typically costs more than $200,000 (in 2020 dollars). Table 1 provides example installation costs for traffic signal components in 2020 dollars.

**Table 1. Installation Costs for Traffic Signal Components in 2020 Dollars**

| Element | Approximate Installed Unit Prices |
|---|---|
| Mast arms | $10,000 to $20,000/each |
| New controller unit (timer) in existing cabinet | $4,000/each |
| New controller assembly | $12,000/each |
| 3-section, 12-inch LED signal head | $840/each |
| 5-section, 12-inch LED signal head | $1,400/each |
| LED pedestrian signal head with countdown timer | $800/each |
| LED replacement bulb | $130/each |
| Pedestrian pushbutton | $400/each |
| Accessible pedestrian signals | $1,250/each |
| Loop detector | $1,200 to $1,800/each |
| Video detector | $5,500/approach, $22,000/intersection |
| Radar detector | $8,000/approach, $30,000/intersection |
| Junction box | $1,100/each |
| Emergency vehicle preemption (EVP) | $7,000/intersection |
| Signs, post-mounted | $55/square foot |
| Uninterruptible power supply (UPS) | $3,000 to $5,200/intersection |
| External generator panel (hook-up to accommodate a small generator) | $1,200 |
| Stop bar (thermoplastic) | $125/lane |
| Lane uses arrow pavement marking (thermoplastic) | $200 to $300/each |
| Traffic Signal Retiming & Analysis (recommended every 3 to 5 years for every traffic signal) | $1,000 to $8,000/intersection |

***Source: PennDOT (2020)***

After erecting and testing a traffic signal, unless the signal owner has a contract with another organization specifying otherwise, traffic signal maintenance and operation chores typically rest with the signal owner (PennDOT, 2020). In recent years, transportation organizations at many levels of government have investigated and put asset management principles, techniques, and tools to use. The investigations, however, have typically concentrated on pavements and bridges (FHWA, 2017). This literature review aimed to inform the management and assessment of traffic signal components with three objectives:

- To better understand the state of practice for managing traffic signal assets.
- To develop recommended condition assessment procedures for traffic signals in Illinois.
- To develop companion procedures to attain and maintain recommended conditions.

The research team conducted a comprehensive literature review on optimal traffic signal condition assessment and maintenance strategy. The literature review findings are summarized in three sections: traffic signal condition assessment and standards, financial awareness, and asset management practices. This chapter presents the synthesis of the literature review results.

## CONDITION ASSESSMENT AND STANDARDS

Condition assessment of traffic signals is a method of assessing traffic signals' physical and operational integrity and dependability. As a common practice, transportation agencies have developed and used performance metrics to evaluate their traffic signals. Choosing the appropriate performance measures helps agencies better assess, manage, and minimize associated risks of traffic signal systems. The condition standards set by the agencies help them to keep track of their progress and direct the allocation of resources to projects and programs to achieve their performance goals (McKay & Senesi, 2022). Table 2 and Table 3 summarize the performance metrics and condition standards established by transportation agencies in the U.S.

**Table 2. Performance Metrics and Standards Established by U.S. State DOTs**

| Agency | Performance Measure | Performance Metric | Performance Target | Classification | Source |
|---|---|---|---|---|---|
| Connecticut DOT | Age | Percentage of signals that are under 25 years (state of good repair—SOGR) | 80% | Age > 25 years: Poor<br>Age 16–25 years: Fair<br>Age < 16: Good | Connecticut DOT (2019) |
| Utah DOT | Electronics and physical equipment condition obtained through an annual inspection | Percentage above poor condition | 95% | Good, Average, or Poor | Utah DOT (2019) |
| Minnesota DOT | Age | Percentage of signals that were past their 30-year useful life | 2% or less | | Minnesota DOT (2019) |
| Colorado DOT | Physical Condition | Percentage of signal in severe condition | 2% or less | | Colorado DOT (2016) |
| Washington State DOT | Frequency of repair | Number of repairs/years | | A: One / 2 years<br>B: One / year<br>C: Two / year<br>D: Three / year<br>F: Four / year | Thompson et al. (2012) |
| Virginia DOT | Physical Condition | General Condition Rating (GCR) | | Good, Fair, Bad, Critical, and Failing | Virginia DOT (2021) |

**Table 3. Performance Metrics and Standards Established by U.S. City DOTs**

| Agency | Performance Measure | Criteria | Source |
|---|---|---|---|
| City of Columbus, Ohio | Physical condition | Very Good, Good, Fair, and Poor | Minnesota DOT (2020) |
| Portland, Oregon | Age | 30-year life | Portland Bureau of Transportation (2017) |
| Seattle DOT, Washington | Physical and Operational condition | Good, Fair, and Poor | Seattle DOT (2015) |

Agencies frequently base their performance assessments on an asset's age or remaining useful life. However, institutions are moving toward more thorough methods to evaluate the condition of traffic signals, such as condition scores based on visual inspection, asset age, and component assessments, as opposed to just asset age or overall asset assessment (McKay & Senesi, 2022). For instance, while Connecticut DOT (2019) started with an age-based approach to assess the state of traffic signals, the organization intends to switch to a system that considers the traffic signal components' age and condition. For establishing condition standards, it is essential to consider the typical service life of various traffic signal assets. The expected life of specific components varies among different transportation agencies. Table 4 presents a summary of the expected life for signal controllers. Appendix A presents the estimated lifespan of other signal components.

**Table 4. Expected Life of Signal Controller**

| Signal Component | Expected life, years (Source) |
|---|---|
| Signal Controller | 20 (San Jose DOT, 2010) |
| | 15 (PennDOT, 2020; Colorado DOT, 2016; Kloos & Bugas-Schramm, 2005) |
| | 5–10 (Indiana DOT response; Minnesota DOT, 2020) |
| | 7 (Ontario Ministry of Transportation response; Minnesota DOT, 2020) |
| | 4–20, average 13.5 (Markow, 2008) |
| | 8.2 for the state, 9.6 for the County, 9.8 for the City/Municipality, with 9.4 as the national average (National Operations Center of Excellence and Institute of Transportation Engineers, 2019) |

It was noted that other factors could negatively affect the expected life of the components. LEDs tend to get dimmer over time and, even if they work, and they are often replaced in 5 years (Institute of Transportation Engineers and International Municipal Signal Association, 2010). Apart from age, the risk of obsolescence due to rapid technology development is another aspect related to the life cycle of signal controllers (Colorado DOT, 2016). Changes in land use result in a significant shift in traffic patterns that can render signal timing inaccurate before the planned retiming period of 3 to 5 years (MnDOT, 2020).

## FINANCIAL AWARENESS

Financial awareness of signal assets is necessary to develop an effective investment plan for traffic signals (FHWA, 2017). The investment plan is a collection of tactics developed from comparing alternative funding levels with the state DOT's goals for asset condition and system performance effectiveness (FHWA, 2017). It relates to understanding the value of current infrastructure and knowledge of funds required to reach the desired condition standards. Financial awareness also relates to the concept of tort liability.

### Valuation of Existing Infrastructure

The value of an asset can be its replacement value or condition-based value (depreciated replacement cost method). Replacement value reconstructs or replaces the device using current market pricing. Condition-based valuation combines current market value with depreciation to represent the value of the remaining predicted life (McKay & Senesi, 2022). For example, the Colorado DOT applied condition-based valuation to traffic signal assets. The replacement cost was adjusted by an age-based condition evaluation (percent of asset life expectancy). The 2016 value of the traffic signal assets was determined as $520.71 million, a replacement value of $962.52 million with a percent value remaining of 54.1% (Colorado DOT, 2016).

### Funding Needed to Meet the Desired Conditions

The term "performance gap" refers to the discrepancies between present asset conditions and asset condition standards. Gaps in system conditions and performance can be best addressed by upgrading physical assets (FHWA, 2017). Information on funds required to reach the desired condition standard is essential to plan for additional funds compared to current funding. The Minnesota Department of Transportation's (2019) investment strategy for traffic signals called for spending $157 million over 10 years, which is $78 million less than what was required to achieve the desired standard of 2% or less traffic signals beyond their 30-year useful life. The Connecticut DOT (2019) determined that to get 80% of traffic signals in good repair, it would take $45 million per year (in 2019 dollars) to replace and repair traffic signals. Figure 1 presents the projection for the percentage of traffic signals in good repair with different levels of funding, as developed by Connecticut DOT.

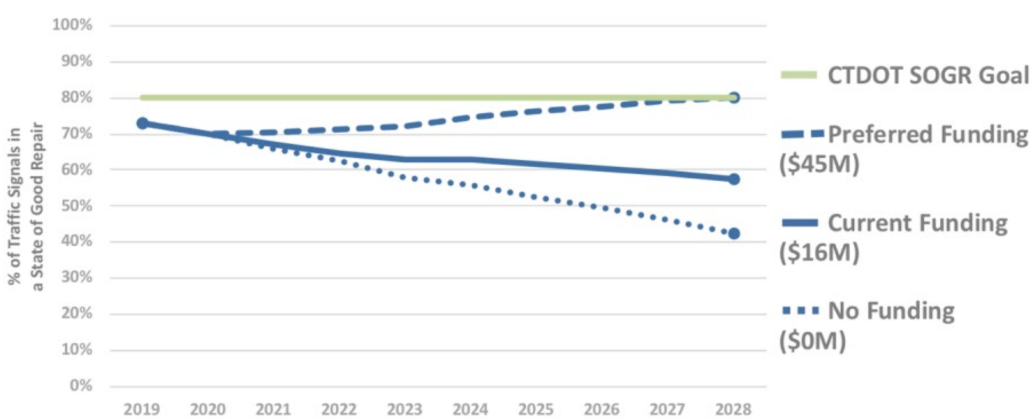



**Figure 1. Chart. Signal performance projections by Connecticut DOT at different funding levels.**

***Source: Connecticut DOT (2019)***

## Concept of Tort Liability

The federal government and nearly all states have approved tort claims legislation allowing them to be held liable for the negligence but not the intentional wrongdoing of government personnel (Institute of Transportation Engineers and International Municipal Signal Association, 2010). If an agency neglects its traffic signal system, it may be subject to tort liability claims. Therefore, planned maintenance is valuable and advantageous to the organizations that apply it (National Operations Center of Excellence and Institute of Transportation Engineers, 2019). Planned maintenance may include both preventive and reactive maintenance. For reactive maintenance, how quickly an agency reacts to maintenance requests and returns traffic lights to regular operation determines an organization's liability risk (Institute of Transportation Engineers and International Municipal Signal Association, 2010). The longer an agency leaves a traffic signal maintenance task unaddressed, the greater the chance of a mishap resulting from a faulty signal system. Appendix B provides information on reactive maintenance standards developed by Pennsylvania DOT and Highways England.

# LIFE-CYCLE RISK MITIGATION THROUGH ASSET MANAGEMENT

Life expectancy can be defined as the period between a particular point in an asset's life and the time when it needs to be replaced or removed. The date of manufacture, the day the asset is put into service, and the current date are commonly utilized as the starting points when determining the asset's remaining life. The objective of the assessment should guide the selection of the starting point. However, agencies should take caution in determining the endpoint. Here are some of the possibilities:

- The failure date for an asset intended to fail suddenly (Figure 2, left side).
- The date on which the obsolescence event occurs for a property intended to lose value at a specific or observable period. It could be the case for equipment whose support ends on a specific date or when a new, stricter standard is approved (Figure 2, right side).
- For items whose obsolescence is directly correlated with age, the end of the predetermined lifespan is the end of life (Figure 3, left side).
- The endpoint is when the usage threshold is met for assets whose life is determined by utilization. It could apply to structural components vulnerable to metal fatigue (Figure 3, right side).
- It is essential to define "end of life" in terms of the replaceable pieces if elements of an asset can be repaired without replacing the complete asset (Figure 4) (Thompson et al., 2012).

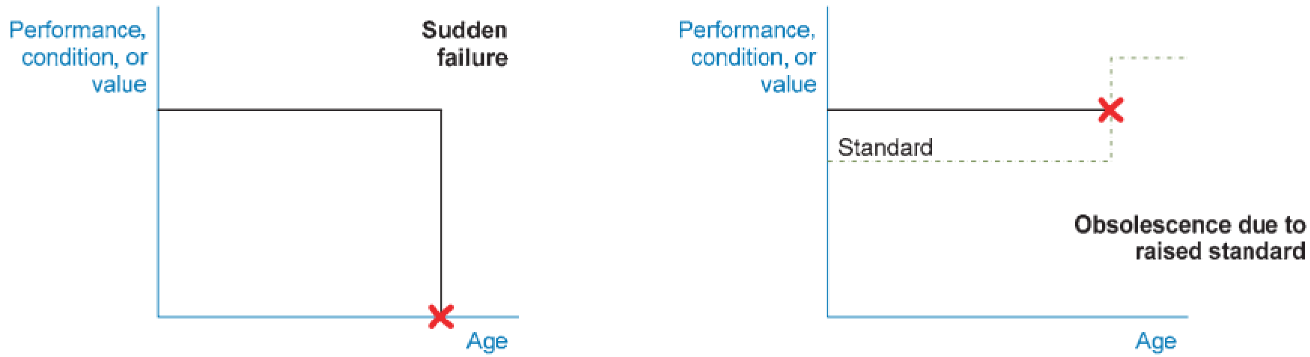



**Figure 2. Chart. End-of-life criteria.**

***Source: Thompson et al. (2012)***

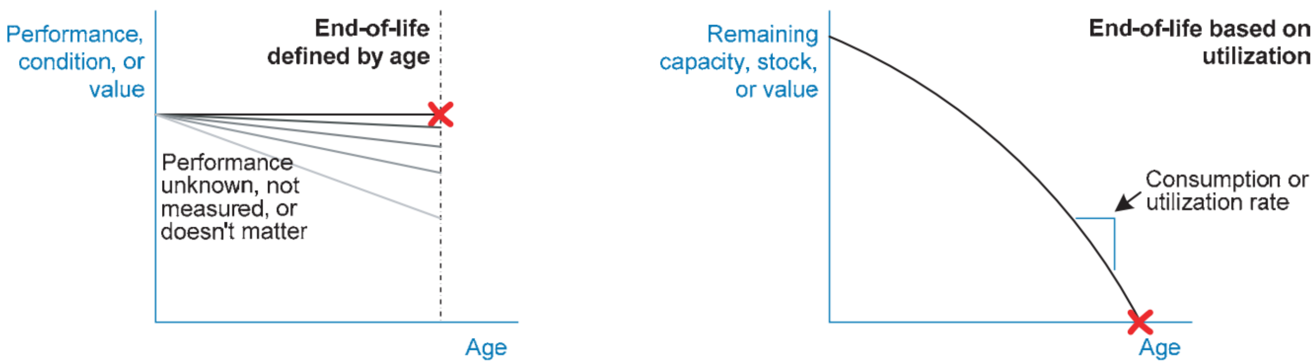



**Figure 3. Chart. Additional end-of-life criteria.**

***Source: Thompson et al. (2012)***

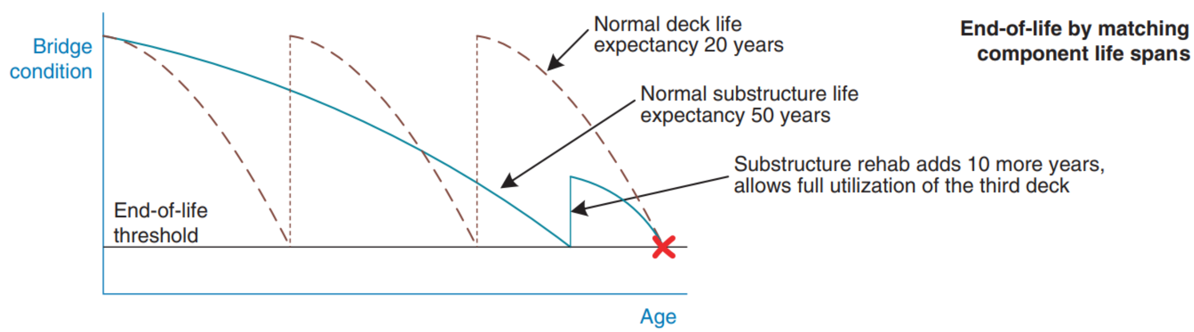



**Figure 4. Chart. Visualizing end of life linking with the lifespans of components.**

***Source: Thompson et al. (2012)***

The term "life-cycle cost" refers to the actual cost associated with managing an asset class or asset sub-group from construction until replacement (FHWA, 2017). Life-cycle planning is estimating the cost of managing an asset class or asset sub-group throughout its life while considering how to keep costs as low as possible while maintaining or enhancing the condition (FHWA, 2017). Some agencies like Connecticut DOT typically replace traffic signal components at certain time intervals. Components could include LED signal displays and cabinet air filters (Connecticut DOT, 2019). However, annualized cost per signal could vary depending on the treatment strategy (Minnesota DOT, 2019). The overall management cost of traffic signals may be kept low through proactive maintenance (McKay & Senesi, 2022). Appendix D provides information on interval-based proactive maintenance practices established by the Pennsylvania DOT for different signal components.

Different signal components deteriorate at various rates and have varying degrees of impact on traffic signal functionality (McKay & Senesi, 2022). Therefore, an asset-specific maintenance strategy is required. Figure 5 presents possibilities for asset deterioration, highlighting that both sudden and gradual failures could occur.

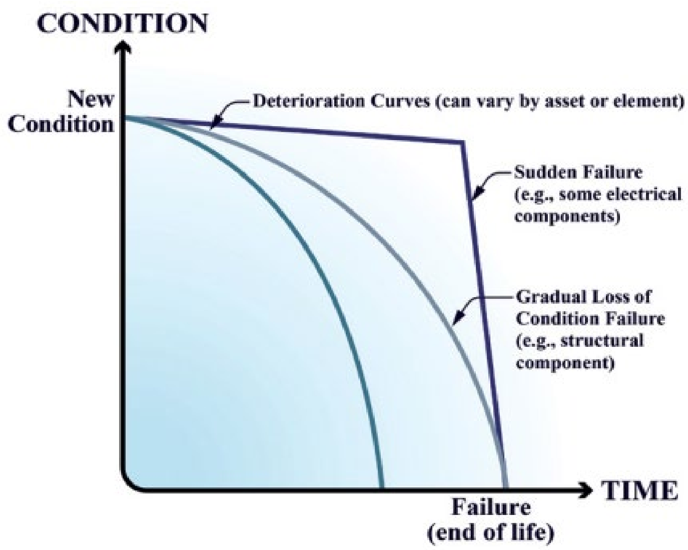



**Figure 5. Chart. Example asset deterioration curves.**

***Source: McKay & Senesi (2022)***

Data collection on traffic signal components (for instance, records on lifespan and interventions for maintenance performed) is essential for proactive maintenance. Traffic Signal Asset Management Systems (TSAMS) can track changes in asset conditions. For example, the traffic signals team in Plymouth, England, updates the Information Management for Traffic Control (IMTRAC) database with information about any new traffic signal infrastructure (Plymouth City Council, 2022). TSAMS' advantages include increased staff awareness of traffic signal system failure, improved asset prioritization, improvements to maintenance procedures, and improvements to monitoring and reaction to failure (Chan et al., 2014). Each TSAMS typically has two modules: inventory and maintenance modules. The inventory module maintains a history of removed components and provides a snapshot of the existing components and subcomponents. The maintenance conducted is detailed in the maintenance module, including what modifications were made, who made them, how they were made, and why they were made (PennDOT, 2020). Figure 6 presents a web-based TSAMS example developed by Pennsylvania DOT.


**Figure 6. Screenshot. Traffic signal asset management system web interface used by PennDOT.**

***Source: Pennsylvania DOT (n.d.)***

A reliability-centered maintenance (RCM) approach, based on each asset within a system, is used to identify critical maintenance assets. The steps of RCM involve defining what an organization wants to achieve with the help of traffic signals, identifying each component that makes up a signal, and defining how and why each asset fails (Institute of Transportation Engineers and International Municipal Signal Association, 2010). An agency may consider three maintenance management strategies for components of traffic signal systems: condition-based maintenance, interval-based maintenance, and reactive maintenance based on the severity of impact resulting from asset failure. Virginia DOT performs condition-based maintenance on the structures of its traffic signal systems (ancillary structure). The agency uses an interval-based strategy for traffic signal heads (McKay & Senesi, 2022). A decision tree for RCM approach maintenance management is presented in Figure 7.

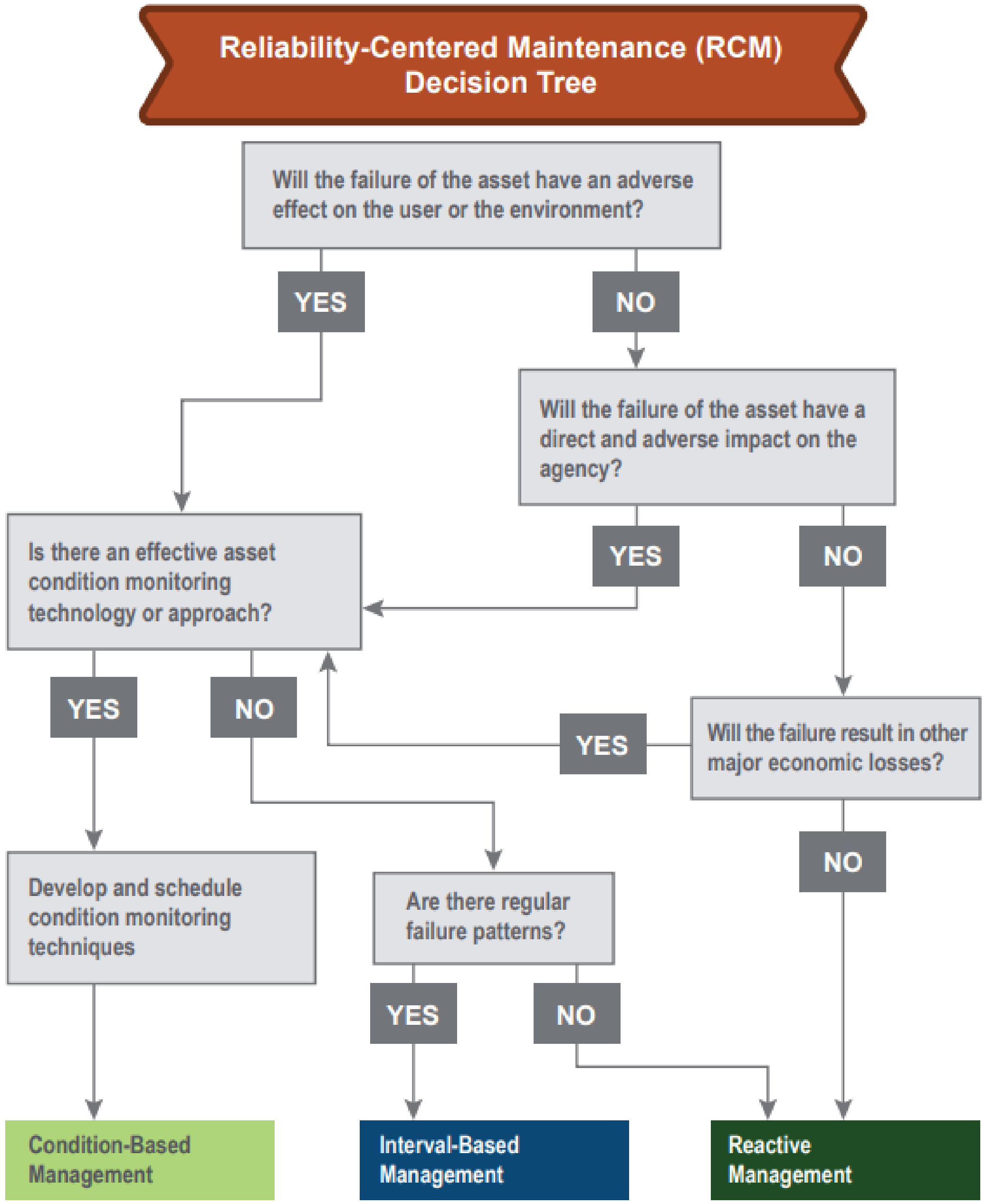



**Figure 7. Chart. Decision tree for RCM approach maintenance management.**

***Source: McKay & Senesi (2022)***

## Condition-Based Maintenance Management

Condition-based maintenance management entails performing maintenance tasks per consistently tracked performance. The City of Columbus, Ohio, estimated a benefit-to-cost ratio of 45:1 for operational inspection of the city's traffic signals (Minnesota DOT, 2020). Figure 8 presents a condition-based maintenance management curve where a maintenance task is carried out as performance reaches X%. Life expectancy models and deterioration models are useful when component condition is based on age.

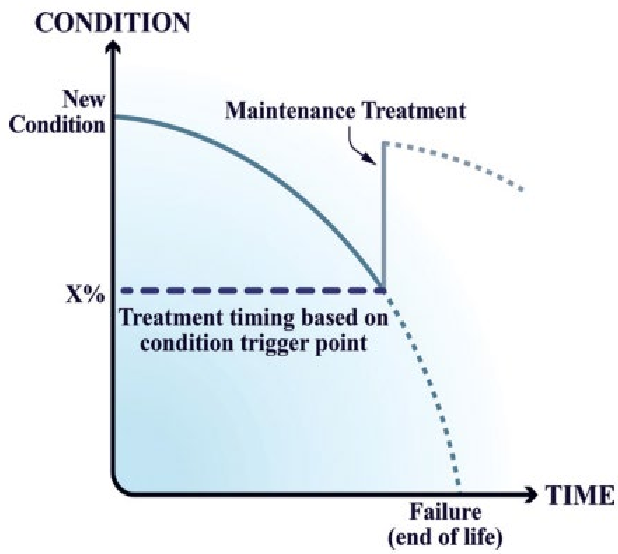



**Figure 8. Chart. Condition-based maintenance management.**

***Source: McKay & Senesi (2022)***

Life expectancy models are used to determine the expected life for an asset without any intervention. A Weibull-distributed survival probability model was created for signal controllers and is presented in Figure 9 and Figure 10.

$$y_{1g} = \exp\left(-1.0 \times (g/\alpha)^{\beta}\right)$$

**Figure 9. Equation. Traffic signal controller survival probability.**

***Source: Thompson et al. (2012)***

where $y_{1g}$ is survival probability as a function of age

g = age, the survival probability is sought for in years

b = the shape parameter, 1.415, and the scaling parameter α is determined as presented below

$$\begin{aligned}\alpha = \exp\big(9.343 &- 0.101 * (\text{average wind speed in mph}) \\ &- 0.108 * (\text{average annual temperature in °F}) \\ &+ 0.139 * (1 \text{ if pre-timed or semi-actuated signal}, 0 \text{ otherwise}) \\ &- 0.288 * (1 \text{ if on a city street}, 0 \text{ otherwise}) \\ &- 0.583 * (1 \text{ if supported by a mast arm}, 0 \text{ otherwise}) \\ &+ 0.352 * (1 \text{ if part of a closed loop or hardwire interconnected}) \\ &- 0.319 * (1 \text{ if fiber-optic cables}, 0 \text{ otherwise})\big)\end{aligned}$$

**Figure 10. Equation. Weibull equation alpha for survival probability of traffic signal controllers.**

***Source: Thompson et al. (2012)***

In accordance with the equation, pre-timed or semi-actuated traffic signals that are hardwire-connected or part of a closed loop have longer service lifespans. On the other hand, signals in warmer climates, places with greater wind speeds, on city streets, supported by a mast arm, or with fiber-optic cables, have lower service lifespans (Thompson et al., 2012).

The approach of generating life expectancy models when no previous model exists depends on the type of data available. There are several factors to consider. It includes the availability of data on previous replacement and life extension actions, the availability of pertinent inventory, condition, and performance data on both existing assets and assets that were replaced and the accessibility of a time series of previous observations of condition and performance. The consistency of data collection definitions over time and the degree to which the available data represent the population are also important. Note that it could be easier to track the life cycle of a component if there is a unique identifier associated with each one (Thompson et al., 2012). Figure 11 presents an example of difficulties in using historical replacement data.

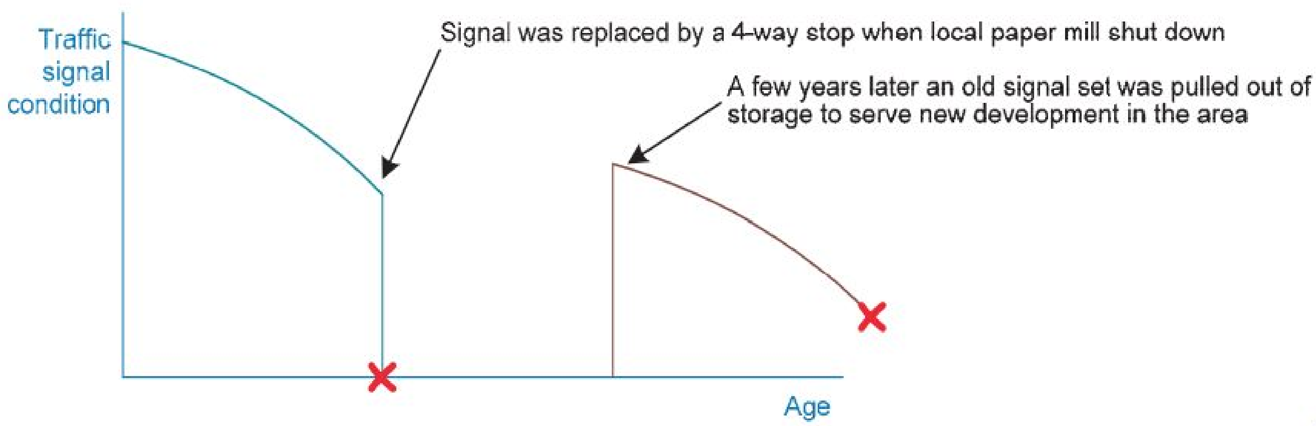



**Figure 11. Chart. Difficulties in using historical replacement data.**

***Source: Thompson et al. (2012)***

Degradation models are employed to predict deterioration in conditions. Unlike life expectancy models, which are more specific, they anticipate not just the end of life but also all other potential condition levels. Appendix B provides details on different methods of developing life expectancy and deterioration models.

## Interval-based Maintenance Management

In interval-based maintenance management, maintenance tasks are planned at predetermined intervals. Figure 12 presents an interval-based maintenance management curve where the maintenance task is carried out after X months.

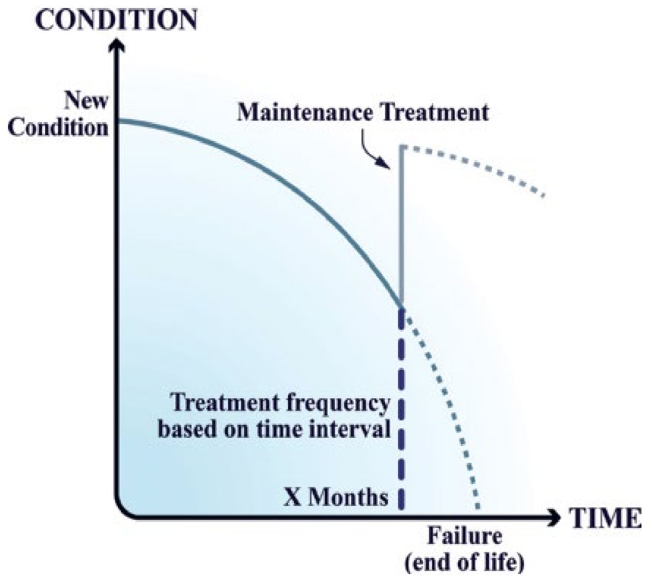



**Figure 12. Chart. Interval-based maintenance management.**

***Source: McKay & Senesi (2022)***

Appendix D provides information on Pennsylvania DOT interval-based maintenance practice for different signal components.

## Reactive Maintenance Management

When using reactive maintenance management, maintenance tasks are carried out in reaction to events or reported asset failures (McKay & Senesi, 2022). The response interval is between receiving notice of a traffic signal malfunction from the signal owner or contractor and when the proper response staff is present to fix the issue(s). In addition to the response interval, the repair interval is the time frame during which temporary or final repairs may be implemented (PennDOT, 2020).

- Temporary repair uses temporary methods/parts to return the traffic signal to safe operation until repairs can be finished. Traffic lights should not be left in an unlit state and should, at the very least, be set to operate in flashing mode (PennDOT, 2020).

- Final repair is the complete replacement or repair of defective parts to bring the traffic signal back to its correct and safe operation. This repair should match the approved traffic signal permit (PennDOT, 2020).

Appendix B provides information on Pennsylvania DOT and Highways England reactive maintenance management practices for different signal components.

# SUMMARY OF LITERATURE REVIEW

Traffic signal asset management is a deliberate and purposeful approach to managing, maintaining, and improving traffic signal physical resources. Transportation agencies understand the need for a component-specific management plan due to the varied deterioration rates of components and the severity of impact on the system. Researchers and practitioners are collecting data continuously and studying changes associated with signal components to develop an effective strategy. The establishment of an asset management system can help with data collection. With the management plan in place, funding will play a vital role in whether the agencies can reach their planned threshold.

# CHAPTER 3: ASSESSMENT PROCEDURE AND CONDITION LEVEL RECOMMENDATIONS

## METHODS

To develop a method for assessing traffic signal components, researchers reviewed available literature, learned from the existing practices of other transportation agencies, interviewed traffic signal technicians, and gathered feedback from engineers and managers in Illinois with expertise in traffic signals. Several state transportation agencies have published detailed guidance on their assessment and maintenance practices related to traffic signals, including Pennsylvania, Minnesota, and Virginia (Minnesota DOT, 2020; VDOT, 2014; PennDOT, 2020). These resources guided the selection of traffic signal components to assess. Next, interviews with traffic signal technicians were conducted in the summer and fall of 2023. The interview questions and research methods were reviewed and approved by the Institutional Review Board (IRB) at Southern Illinois University Edwardsville (Approval #2152), see Appendix E. Findings confirmed the practicality of assessment methods, identified places for clarification or supplemental information, and recommended which components and condition levels require additional information and/or pictures be taken by inspectors. The project's technical review panel (TRP) reviewed multiple versions of the assessment procedures and condition levels. The detailed feedback helped the researchers capture the differing practices and agency needs throughout Illinois.

## INTRODUCTORY QUESTIONS

The traffic signal assessment begins with a statement describing the purpose of the process. Next, questions about the location and inspectors are asked. The following introductory questions are recommended.

- Which intersection are you assessing? Please include traffic signal number and road names as appropriate.
- Which agency is responsible for this traffic signal? (e.g., IDOT, City of Edwardsville)?
- If IDOT is responsible, which district is the traffic signal in?
- Who is/are inspecting the intersection? Please note first and last names and agency/company affiliations.
- What is the date of inspection?
- What is the time of inspection?

The question about IDOT districts should include a link to a district map for reference. To save time during the assessment, it is recommended that the date and time automatically populate with the current date and time.

## SPECIAL-CASE SIGNAL COMPONENTS

Next, information is collected about various intersection equipment. Examples include signal head mounting (Figure 13), signal head features (Figure 14), electrical service type (Figure 15), special operational features (Figure 16), and sight obstructions (Figure 17).

*Q2.1.* How are signal heads mounted at this intersection? Select all that apply.

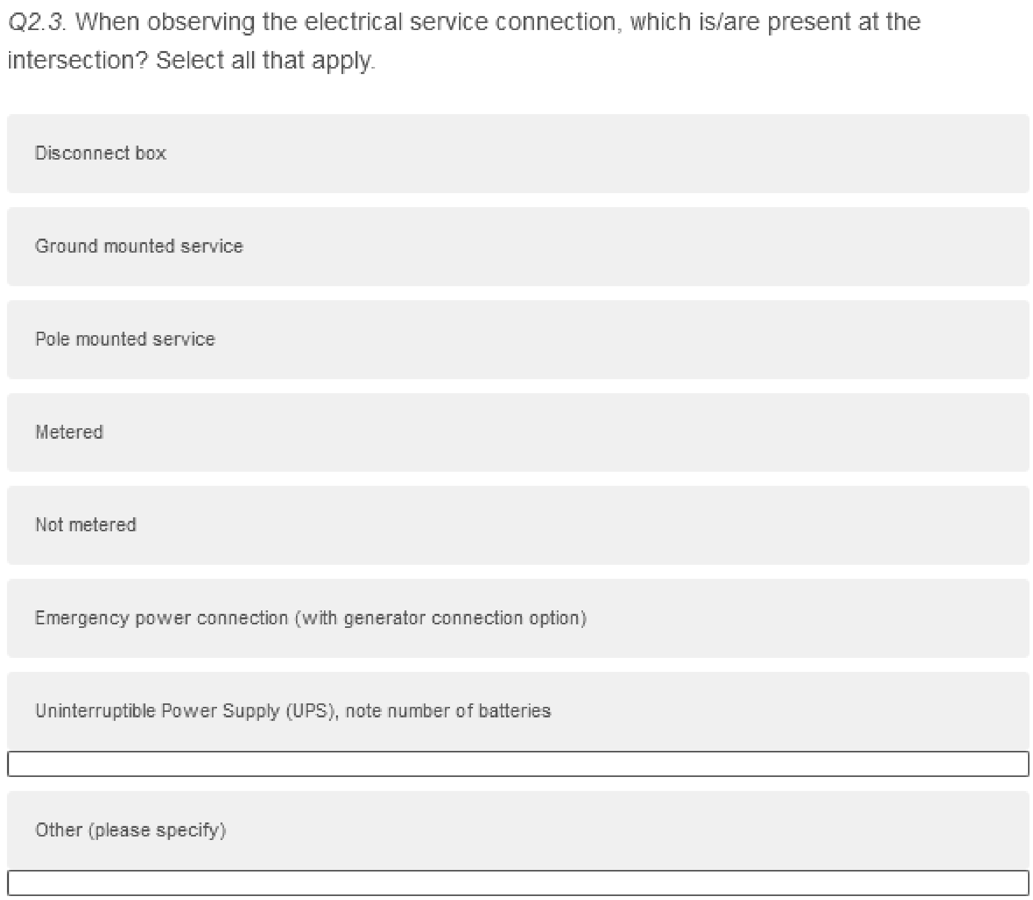
- Posts
- Mast arms
- Span wire
- Poles with mast arms
- signal heads mounted on luminaire/street light pole
- Other (please specify)

**Figure 13. Illustration. Signal head mounting question.**

*Q2.2.* Which of the following signal head features are present at this intersection? Select all that apply.

- Retroreflective backplates
- Flexible backplates
- Louvered backplates
- Directional Louvers
- Heater visors or snow cones lens cover
- Elongated visors or tunnel visors
- Other (please specify)

**Figure 14. Illustration. Signal head features.**


*Q2.3.* When observing the electrical service connection, which is/are present at the intersection? Select all that apply.

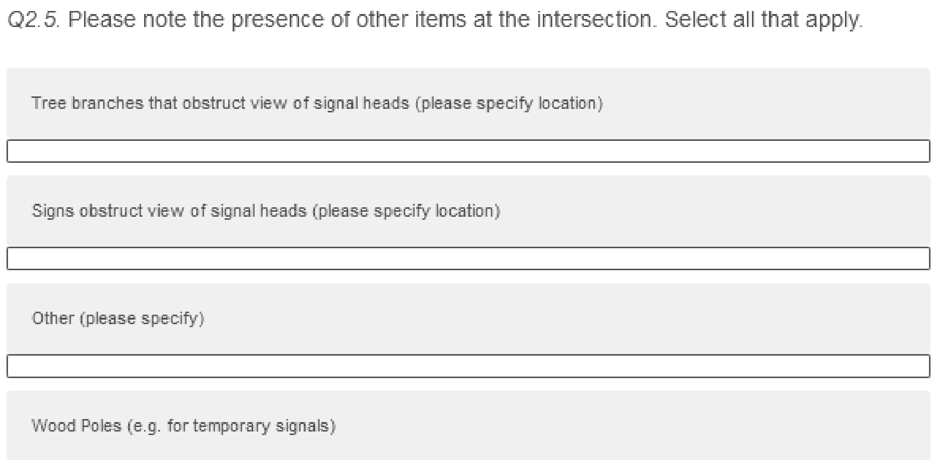
- Disconnect box
- Ground mounted service
- Pole mounted service
- Metered
- Not metered
- Emergency power connection (with generator connection option)
- Uninterruptible Power Supply (UPS), note number of batteries
- Other (please specify)

**Figure 15. Illustration. Electrical service connection.**

Q2.4. Which special operation features are present at the intersection? Select all that apply.

- Cellular modems/routers for communication
- Emergency Vehicle Preemption (EVP) system (functioning)
- Flashing yellow arrow
- License plate recognition camera(s)
- Programmable Visibility (PV) Signal Head
- Accessible Pedestrian Signal (APS) buttons present and functioning
- LED street name signs
- Mast-arm mounted street name signs (please specify location)
- PTZ Camera
- Railroad interconnect
- Red light running enforcement system
- Transit signal priority (TSP) system (functioning)
- Video detection system
- Other (please specify)

**Figure 16. Illustration. Special traffic signal operation features.**


Q2.5. Please note the presence of other items at the intersection. Select all that apply.

Tree branches that obstruct view of signal heads (please specify location)

Signs obstruct view of signal heads (please specify location)

Other (please specify)

Wood Poles (e.g. for temporary signals)

**Figure 17. Illustration. Presence of other conditions.**

## ASSESSMENT OF TRAFFIC SIGNAL COMPONENTS

During the initial stages of the study, researchers categorized signal components as structural, control, or cabinet. When organizing the assessment questions, it was decided to begin with structural components at the ground level, then assess aerial structures and control components, and end by assessing cabinet components. It is recommended that each group of questions includes a place for inspectors to take and upload pictures supporting their observations. The following sections are presented in the recommended order, beginning with structural traffic signal components.

### Foundations

Findings indicated that foundation condition is influenced by cracks in the concrete, rodent prevention, water drainage, and soil movement/erosion. The foundation should be inspected for damage (cracking, spalling, and reinforcement exposure) to prevent pole or cabinet failure (VDOT, 2014). Pennsylvania DOT (2020) recommends inspection of the foundation in general, whereas Virginia DOT recommends documenting cracks that propagate from the anchor bolts and any staining observed along those cracks. Such stains may be a sign of overloaded or significantly corroded anchor bolts. VDOT also recommends sounding the foundation pedestal with a hammer to detect locations of delamination, which can be indicated by a hollow sound (VDOT, 2014). Several agencies recommend documenting corrosion of reinforcement or any section loss that could affect the serviceability of the structure (Garlich & Thorkildsen, 2005; VDOT, 2014). During interviews, traffic signal technicians and managers confirmed the importance of documenting cracks propagating from anchor bolts and added that vertical cracks were the most concerning. Based on these sources of information, the recommended assessment procedure is as follows:

> Inspect pole and post foundations. Document cracks propagating from the anchor bolts (especially vertical cracks) and rust staining. The cracking could indicate the bolts have been overloaded or have appreciable corrosion within the foundation. Use a hammer to sound the pedestal and identify places with delamination. A hollow sound can indicate delaminated areas. Document all spalling, scaling, honeycombing, and exposed reinforcement.

To describe condition levels, damage such as cracking, spalling, and reinforcement exposure were considered, and four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Garlich and Thorkildsen (2005) noted that surface cracks and spalls less than 1/32” are considered fair and above 1/16” are considered poor. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 18.

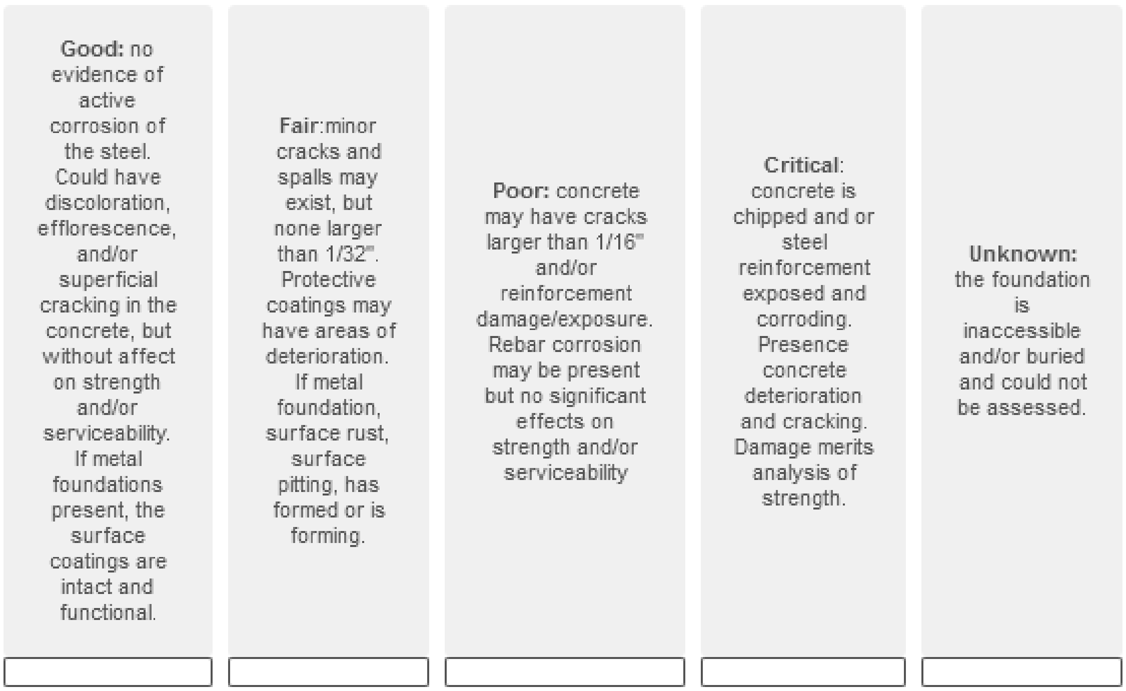



**Figure 18. Illustration. Assessment conditions for foundations.**

## Grout Pads and Rodent Screens

Grout pads and/or rodent screens are important to inspect to prevent water accumulation, corrosion, and infestation. When grout pads are present, VDOT recommends documenting deterioration. Partial deterioration included minor section loss and/or cracking and full section loss including heavy cracking. Assessing this component was considered important because water retention in the grout pad can lead to anchor bolt corrosion. In addition to noting the level of deterioration, VDOT (2014) also asks inspectors to measure the maximum thickness of each grout pad, where thickness is measured between the pedestal top and the base plate bottom.

Both previous research and practitioner feedback suggested that rodent screens are preferred over grout pads. PennDOT (2020) and MnDOT (2020) recommend removing the grout pad if evidence of anchor bolt corrosion is present. Previous research concluded that a poorly functioning grout pad is worse than no grout pad at all (Choi et al., 2015). This perspective was echoed by members of the project TRP and those interviewed by the researchers. Additional feedback suggested including “shrouds” into the assessment method because that component was a precursor to current rodent screens.

To assess the condition of pole bases with a rodent screen, PennDOT recommends checking that the rodent screen is present and functioning. If the screen is missing/broken or if there are signs of bolt corrosion, maintenance is recommended. These maintenance actions could include replacing the rodent screen, removing the rodent screening to observe anchor bolt weathering, bending, or cracking, and/or removing debris (PennDOT, 2020). Based on those sources of information, the following assessment method was recommended.

> Inspect rodent screens, grout pads, and/or shrouds. Rodent screens and shrouds should provide continuous protection without gaps or holes. If grout pads are present, note the deterioration level. Partial deterioration could include minor section loss and/or cracking, and full deterioration could show signs of heavy cracking or section loss. Moisture leaking from under or within the grout pad indicates moisture/water retention and possible corrosion of the partially exposed or unexposed anchor bolts. Document the maximum thickness of each grout pad as measured from the top of the pedestal to the bottom of the pole/post base plate.

For the assessment of grout pads, shrouds, and/or rodent screens, four categories were developed to differentiate between conditions. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 19. Textboxes are included below each condition level to allow inspectors to record comments and details. These condition levels focus on rodent screen because that is the preferred method of protecting the pole-base connection.

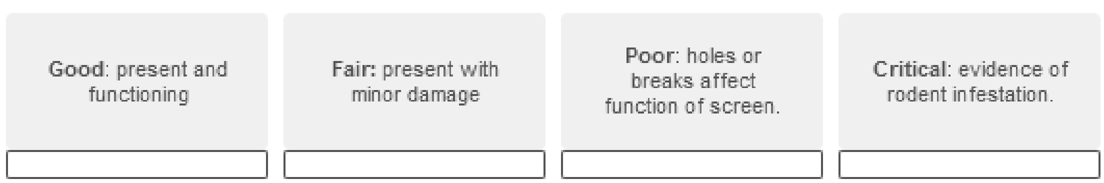



**Figure 19. Illustration. Assessment conditions for grout pads, shrouds, and/or rodent screens.**

## Ground around Foundations

Because subsidence can lead to foundation failure, the ground around the foundation should be observed and any settlement documented (VDOT, 2014). If erosion or undermining is found near bases, the ground should be probed to identify the extent and depth. Any rotation or movement of the pole/post foundation should be measured and documented (VDOT, 2014). This type of assessment was also recommended by the TRP. Based on these established practices and feedback from stakeholders in Illinois, the following assessment method was recommended.

> Inspect the ground around the foundation for washout or erosion. Areas of observed ground movement/undermining should be probed to identify the extent and depth, then documented. Signs of tilt, movement, or rotation of the foundation should be documented. Measure and document the height of the exposed foundation if concerns exist.

For the assessment of the ground around the foundation, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during field work. The final version is presented in Figure 20. Textboxes are recommended to allow details to be entered for fair, poor, and critical conditions.

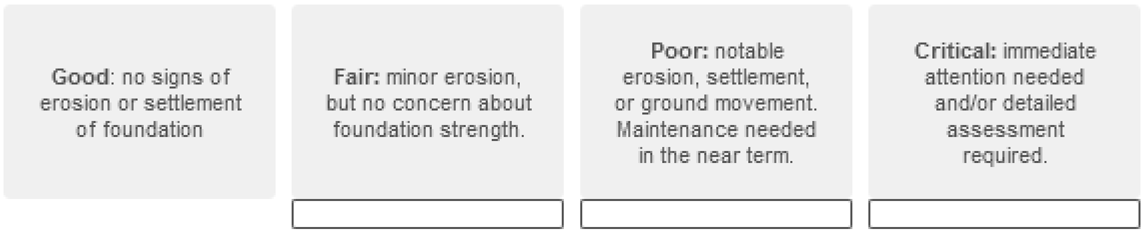



**Figure 20. Illustration. Assessment conditions for ground around foundation.**

## Bases

Findings indicated that base condition is influenced by the coating condition and obstructions in the drain at the pole base. Bases were divided into two general categories, posts and poles, depending on the foundation connection. Within this report, posts are vertical members supporting signal heads/displays, with no masts. Posts are generally smaller in diameter than poles and likely have break-away bolts and transformer bases. In this report, poles are vertical members supporting masts. Poles are generally larger in diameter than posts and are connected to the foundation with a plate and fixed bolted connection. The text in this chapter differentiates the assessment between posts and poles.

Pole bases should be inspected for coating condition (powder-coating, galvanization, paint) to prevent corrosion. This assessment can be done by visually inspecting the protective metal coating of all bases (PennDOT, 2020). Any cracks or areas of missing coating can cause the underlying metal to corrode; therefore, these signs of corrosion must be checked. Based on the available information and feedback from the researchers, the following assessment procedure was recommended.

> Inspect base plates and coating condition. Base plates and pedestals should be inspected both visually and tactilely. Inspect the extent of section loss due to corrosion, distortion of the base plate, and/or distress around anchor bolts holes. When corrosion is present, a rubber mallet should be used to strike the base plate between each set of bolts and listen for a ringing sound. Visually inspect the protective metal coating on all bases. Any cracks or areas of missing coating can cause the underlying metal to corrode. Document any deterioration causing poor or critical conditions.

For the assessment of the base plate and coating condition, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. The good condition must not have corrosion and the surface coating should be intact and performing well. The fair condition may have minimal corrosion, whereas a critical condition has notable section loss and justifies structural analysis.

Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The researchers proposed four condition levels to differentiate between base plate conditions. The final version is presented in Figure 21. To promote consistency in the assessments, a picture of severe corrosion was linked to the question. Throughout the assessment, when “(PICTURE)” is presented, the assessment links to an example of the condition level. These example pictures are included in Appendix F. For base plates, it was recommended to allow text entry for poor and critical conditions so inspectors can write details.

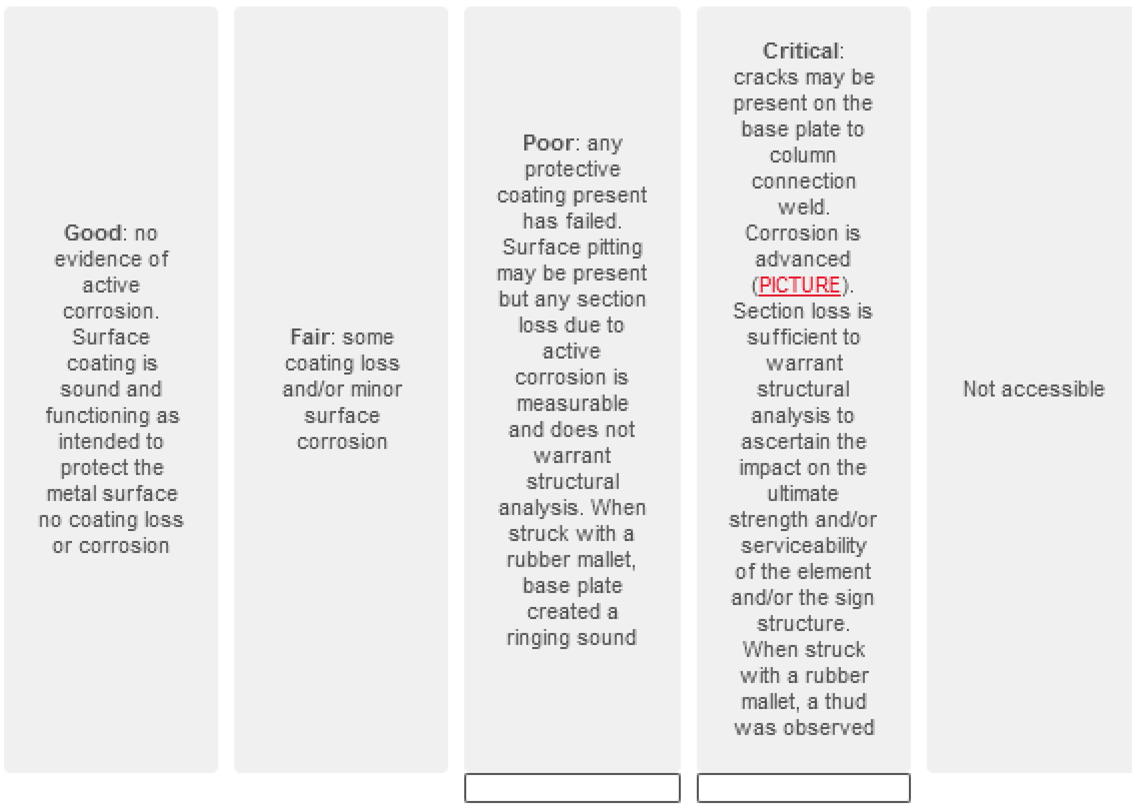



**Figure 21. Illustration. Conditions levels for traffic signal pole base plates.**

Obstructions in the drain at the pole base should also be checked to prevent collection inside the pole. PennDOT (2020) recommends checking for obstructions to drains at the base of poles and clearing debris, as needed. The following procedure was recommended.

> Inspect drain at pole bases. View stormwater drains at pole bases to identify any obstructions. If present, remove and note any standing water.

For the pole drain conditions, five categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 22.

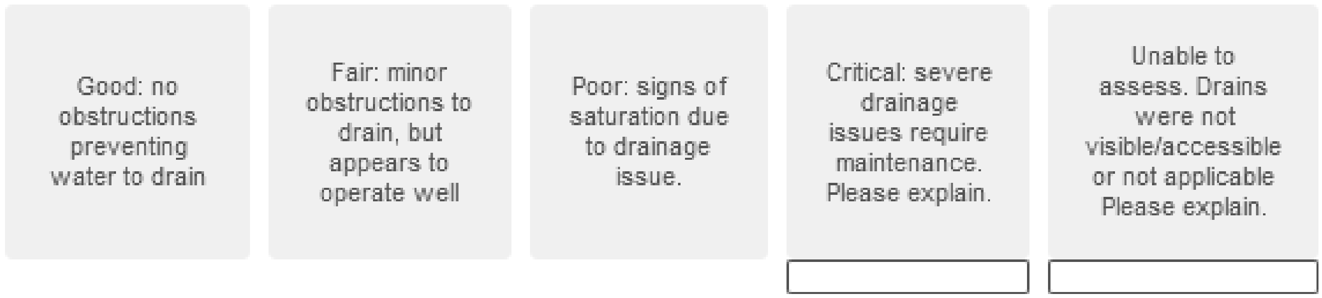



**Figure 22. Illustration. Condition levels for drain obstructions at pole bottom.**

Posts with transformer bases should be inspected to prevent infestation, water intrusion, and tampering. The TRP recommended visually inspecting that transformer bases are free of cracks or damage and the base door is intact and secure. The following assessment procedure was recommended.

> Inspect transformer bases. Visually inspect the transformer base to identify cracks or damage and confirm the base door is intact and secure.

For the conditions of transformer bases, five categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 23. To promote consistency in the assessments, a picture is included to describe the critical condition, as indicated by “(PICTURE).” These example pictures are included in Appendix F.

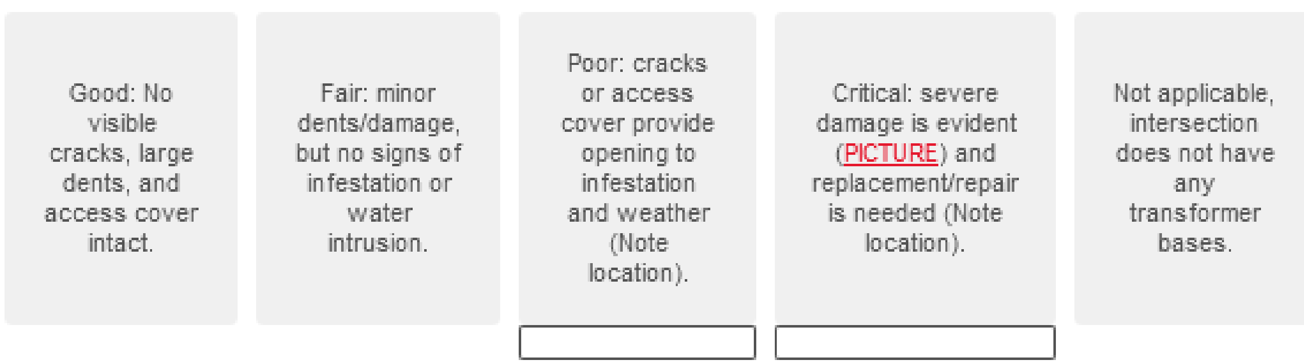



**Figure 23. Illustration. Assessment condition levels for transformer bases.**

Poles with base plates should be inspected to prevent base plate failure. Base plates should be visually and tactilely inspected. The extent of section loss due to corrosion, distortion of the base plate, and distress around anchor bolt holes should all be inspected, and conditions documented (VDOT, 2014). When corrosion is present, a rubber mallet should be used to strike the base plate between each set of bolts and listen for a ringing sound.

The foundation and base plate connection should be inspected to prevent pole failure. Debris should be removed, and the anchor bolts should be assessed for signs of bending and/or cracking (PennDOT, 2020; MnDOT, 2020; VDOT, 2014). VDOT recommends also inspecting for loose nuts and documenting any deviation, excess, or missing components. Example deviations could include non-plumb anchor bolts, improperly seated top nuts, incorrect material type, and additional/missing components (VDOT, 2014).

Several agencies recommend visually verifying that the top nuts are free of corrosion (PennDOT, 2020; MnDOT, 2020). VDOT recommends the top of the bolts be sounded with a hammer to confirm each is securely bonded to the foundation. If a hollow sound is heard, VDOT recommends that an ultrasonic test be done to investigate (VDOT, 2014).

Several agencies recommend inspecting the nuts are in a snug-tight condition. Several agencies consider the full force of a person on a 1-inch wrench should cause no movement to a nut in snug-tight condition (PennDOT, 2020; MnDOT, 2020). Alternatively, VDOT recommends assessing tightness by striking the sides of each nut 2–3 times with consistent force and a 16-ounce hammer in the nut-tightening direction. Any movement of the nut is considered too loose (VDOT, 2014). If a hollow sound is present when bolts are struck with a hammer, advanced inspection techniques are needed. Advanced inspection could include the use of ultrasonic testing, x-ray, etc. Based on these sources of information, the researchers recommended the following assessment procedure. Recall the difference between poles and posts.

> Visually inspect (if not obscured by a grout pad) for loose nuts and damage. Remove any debris, and examine the anchor bolts for signs of bending, cracking, etc. Document components that differ from the typical configuration. Deviations could include anchor bolt plumbness, improperly seated nuts, incorrect bolt/nut material, and/or the presence of incorrect/extra washers. Assess bolts for structural integrity. Visually verify that nuts and washers are free of corrosion. If assessing a post, the connection tightness can be checked by attempting to rock the post. If any motion is suspected, first check the snugness of all nuts using a wrench. If motion is suspected, but bolts are snug, strike bolts with a hammer, and listen for a ringing sound. If the sound is abnormal or lacks ringing (e.g., thud), check for corrosion. If a hollow sound is present, advanced inspection techniques are required. Note any cracks in the base near the bolts.

For the assessment of foundation and base plate connection, five categories were developed. Researchers used each assessed component and described those in multiple condition categories. The good condition has no components missing and no deterioration or misalignment. The fair condition may have minor corrosion present with no missing components. Broken, bent, or missing components or significant corrosion with 30% or greater section loss of one or more anchor bolts leading to questionable strength means the condition is critical. Inspectors are guided to include details if conditions are poor or critical. Those condition level descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 24.

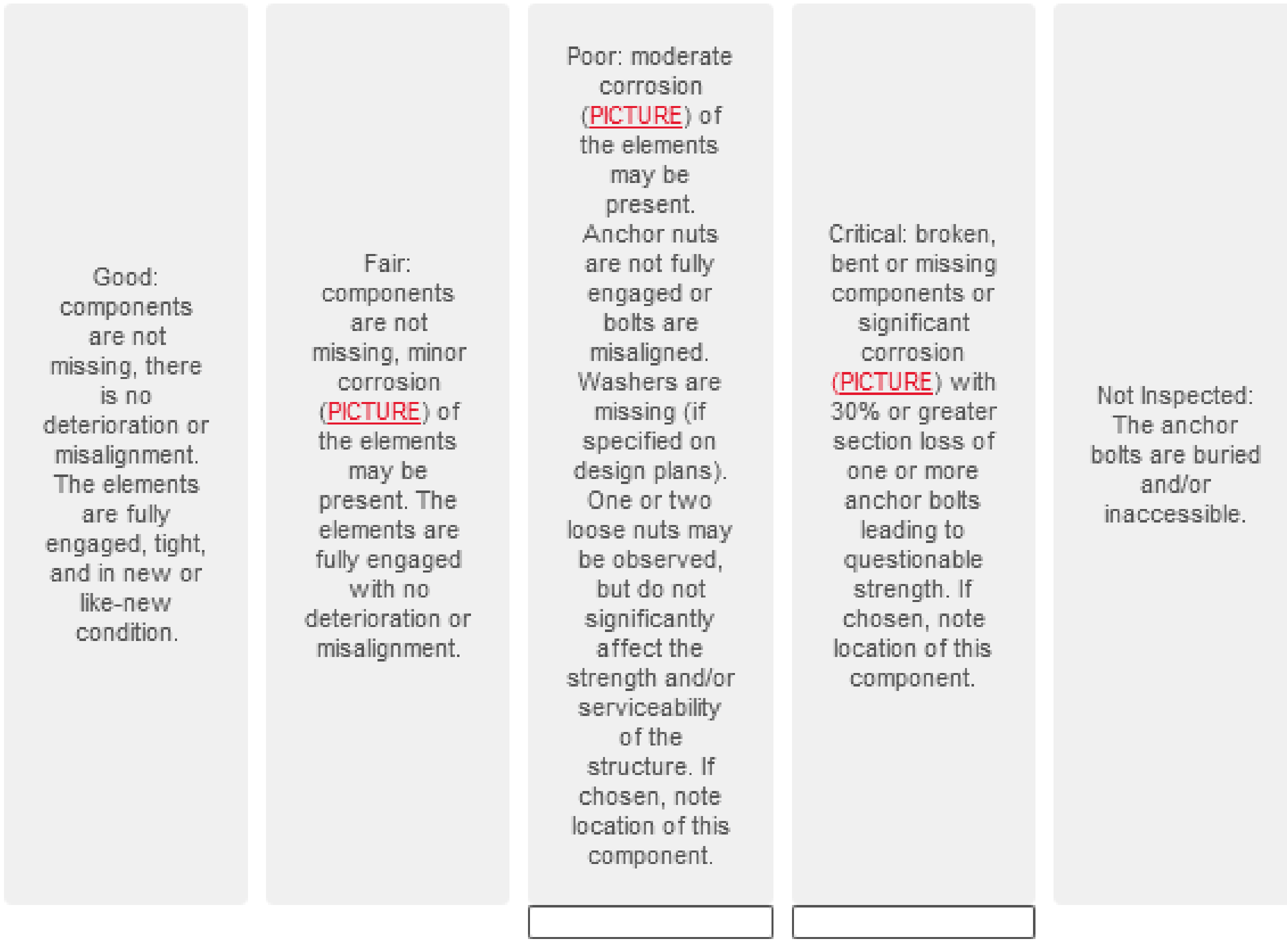



**Figure 24. Illustration. Condition levels for foundation and base plate connections.**

## Junction Boxes and Conduits

Findings indicated that the junction box and conduit condition are influenced by boxes and handholes and the presence of exposed conduits. The inspection of junction boxes and handholes can prevent rodent/insect infestation, identify tampering, and minimize water collection. Several agencies recommend inspecting the junction box for unusual amounts of water or signs of water damage (PennDOT, 2020; MnDOT, 2020). If water is present, maintenance could include installing weep holes to allow drainage. It is also recommended to check for adequately secured handhole covers and replace any missing covers (PennDOT, 2020). These practices were supported by the TRP and ITE (Institute of Transportation Engineers, 2023).

There was less consensus on the need to open and inspect all handholes and junction boxes. Although opening all junction boxes/handholes could help identify issues before they cause a failure, this process would require additional time to assess the intersection. The recommendations are to observe all junction boxes without opening, and if concerns exist, then open and inspect. The following procedure was recommended.

Visually inspect junction boxes and handholes to identify open handholes, damaged lids, rodent nesting, cracks in box walls, or signs of water intrusion. Check if the handhole is heavy duty or standard duty, check the ground around a handhole and note if the handhole needs to be raised or lowered. Open if there are concerns and confirm frame and lids are grounded (see IDOT Highway Standards [2024], include a hyperlink to https://public.powerdms.com/IDOT/documents/2677373).

To describe the condition of junction boxes and handholes, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. A good condition has all covers present and snug with no rodent or water damage. A poor condition may have one or more damaged covers with evidence of water intrusion, settlement, or rodent infestation. This condition level may also have concrete that is cracked/broken/crumbling, but there is no immediate trip hazard to pedestrians and bicyclists. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 25.

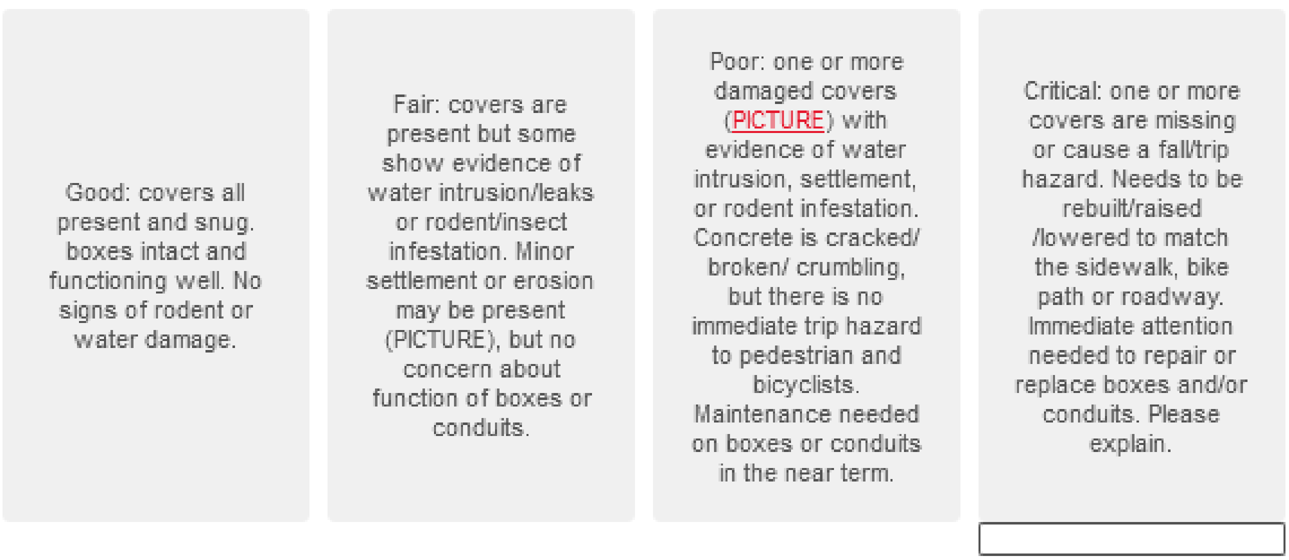



**Figure 25. Illustration. Condition levels for junction boxes and handholes.**

The presence of exposed conduit (that should be buried) is also important to identify and document for the protection of the conduit and wires. PennDOT (2020) recommends checking if any conduit is visible above ground, and if so, checking for damage. Based on these sources of information, the following assessment procedure was recommended.

Identify presence of exposed conduit. Check that no conduit is visible (at or above grade when it should be buried), broken, or damaged.

Four categories were developed, describing likely component conditions. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and applied during fieldwork. The final version is presented in Figure 26.

| | | | |
|---|---|---|---|
| Good: conduits are not visible, broken, or damaged. | Fair: Conduits are visible / exposed but not broken, or damaged. | Poor: conduits are visibly broken / damaged or missing straps. | Critical: broken / damaged conduits with exposed wire. |

**Figure 26. Illustration. Condition levels for traffic signal conduits.**

## Aerial Structural Connections

Findings indicated that the condition of aerial structural connections are influenced by both bolted and welded connections. Bolted connections are inspected to prevent pole and mast arm failure. Several agencies agree that these connections should be visually inspected. The connection should be tight, and there should be no visible gap between the connection plates, nuts, or washers (MnDOT, 2020; PennDOT, 2020).

Based on these sources of information and input from practitioners in Illinois, the following method was recommended.

> Inspect bolted aerial connections of mast arms. Visually confirm the connection is tight and there is no visible gap between the connection plates, washers, bolts, and/or nuts. Also confirm the bolt has stick out (> 2 threads) past the end of the nut. Binoculars (or similar) should be used to view overhead structures.

For the assessment of aerial bolted connection of mast arms, five categories were developed. Researchers used each assessed component and described those in multiple condition categories. Garlich and Thorkildsen (2005) recommended assessing the threads' stick out where > 2 is considered fair, < 2 is considered poor, and no thread stick out is considered critical. VDOT (2014) notes that a critical condition includes broken, bent, or missing components (e.g., no stick out of bolts) or significant corrosion with 30% or greater section loss of one or more anchor bolts leading to questionable strength. The proposed condition level descriptions were reviewed and commented on by the TRP, discussed during interviews, and tested during field work. The final version is presented in Figure 27.

The welded connections are also inspected to prevent pole and mast arm failure. Both PennDOT and MnDOT recommend checking the welded connections between the mast arm or column connection plates for cracks. These agencies noted that cracks are more common at the top and bottom of welded mast arm connections because of galloping caused by wind loads (PennDOT, 2020; MnDOT, 2020). Fatigue cracking was observed in various crucial sections of the structure, including the welds that connect the tube to the transverse plate in the mast arm and/or the poles, as well as the weld surrounding handhole frames (AASHTO, 2015).

| | | | | |
|---|---|---|---|---|
| Good: components are not missing, there is no deterioration or misalignment. The elements are fully engaged (>2 threads of stick-out), tight, and in new or like-new condition. | Fair: components are not missing, minor corrosion (PICTURE) of the elements may be present. The elements are fully engaged (>2 threads of stick-out) with no deterioration or misalignment. | Poor: moderate corrosion (PICTURE) of the elements may be present. One or more bolts are not fully engaged (<2 threads of stick-out) or are misaligned. Washers are missing (if specified on design plans). One or two loose nuts may be observed, but do not significantly affect the strength and/or serviceability of either the element or the structure. | Critical: broken, bent or missing components (e.g. no stickout of bolts) or significant corrosion (PICTURE) with 30% or greater section loss of one or more anchor bolts leading to questionable strength. | Not Inspected: The bolts are inaccessible. |

**Figure 27. Illustration. Condition levels for aerial bolted connection of mast arm.**

VDOT (2021) recommends that “the welds be closely inspected for cracking, especially at points of intersecting welds and incomplete or excessively ground welds, as they create stress risers. Special attention should be given to the pole-to-base plate weld due to the high stresses at this location. The location and size of any weld crack is to be documented. Suspected cracks should be verified by non-destructive testing.”

Because some municipalities in Illinois have painted signal structures, the researchers sought information about assessing welds with a paint coating. The National Highway Institute’s *Bridge Inspector’s Reference Manual* recommends inspectors search for evidence of cracks, such as rust stains, or broken paint (Ryan et al., 2023). If cracks are suspected, it is recommended to remove the paint before conducting testing, such as magnetic particle testing (Doughty et al., 2021). Agencies with painted signal structures should coordinate their assessment and painting schedules to enable weld inspections prior to repainting.

Aerial welds are difficult to assess from the ground, so researchers sought to identify when more in-depth assessments are warranted. A method was developed to assess the weld connections in detail to find out the threshold age of welds, after which it needs to be assessed more frequently. Three categories were developed, and three condition ratings were developed for each category. Table 5 presents the categories and condition ratings.

**Table 5. In-Service Mast Arm Weld Condition Categories and Condition Ratings**

| Categories | Condition Rating | | |
|---|---|---|---|
| **What to inspect** | **Good (1)** | **Poor (2)** | **Critical (3)** |
| Cracks/Scars/Crater Pit (A) | Shall not have any cracks, scars, or crater pits. | Shall not have any cracks at weld's face or toe. May have small scars or crater pits on weld face. | Has one or more cracks at or near the weld's face or toe. May have scars or crater pits on or near weld. |
| Roughness/Porosity (B) | Should be smooth and clean, no roughness around the weld. | May have the presence of minor roughness around the weld, but not on the weld face. | Has minor roughness around weld toe and on weld face |
| Corrosion/Oxidation (C) | May have minor corrosion/oxidation around the weld. | May have moderate corrosion or oxidation around the weld. | May have severe corrosion or oxidation on or around the weld, causing section loss. |

A limiting state analysis was conducted where each mast arm condition was denoted by combinations, such as A1B1C1 for good conditions across all categories, indicating an overall good quality weld. If the scale read A2B1C1, the entire weld was deemed poor, as the worst rating in any category determined the overall condition. This approach was more conservative and more realistic, ensuring that weaknesses or deficiency in any weld category would limit the overall condition rating.

To find out the age after which the welds are considered critical, a t-test was performed to find the range of age in which 95% of the sample lie. The summary of statistics for the data is presented in Table 6. Figure 28 displays the confidence interval of mast arm welds found to be in critical condition, and it was found to be the age group between 18.65 years and 20.31 years. Figure 29 presents the normal distribution of ages when welds were observed to be critical.

**Table 6. Summary Statistics for Critical Condition**

| Condition | Observations | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|---|
| Critical | 63 | 11.000 | 25.000 | 19.480 | 3.280 |

$$\text{Confidence Interval} = [\mu \pm t_{\text{critical}} * \sigma / n^{1/2}]$$

**Figure 28. Equation. Confidence interval for mast arm critical weld age.**

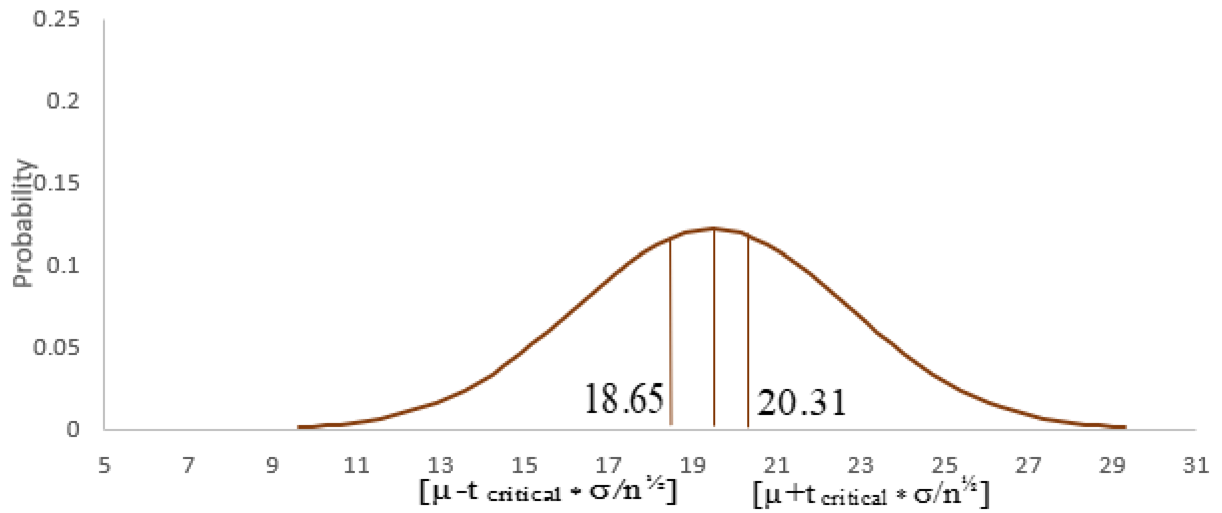



**Figure 29. Graph. 95% confidence interval of age for observed critical welds.**

From the results obtained after the t-test, a conclusion was drawn where the threshold age of the mast arm weld connection after which the welds turn critical and need frequent assessment was 19 years old. To be conservative, a threshold of 18 years is recommended, beyond which aerial welds should be inspected in detail using a camera on a telescoping pole, a drone, or a bucket truck. Further research on the aging of traffic signal mast arm welds (painted and unpainted) throughout Illinois can refine this threshold and better-inform future practice. In addition, research is lacking on the aging of mast arm welds with paint coatings. Based on these sources of information, the following method was proposed.

> Inspect welded aerial connections. Visually confirm there are no cracks in or near welds. Check the top and bottom of vertical connections for cracks. Identify and document any bending or deformation of the welded connection or surrounding structure. Drones, cameras on telescoping poles, and bucket trucks are the preferred methods of observing welded connections in detail. Binoculars are an acceptable substitute for assessment of galvanized, unpainted structures younger than 18 years, or as approved by the area's Traffic Signal Engineer or Electrical Services Supervisor.
>
> - Structures older than 18 years or with welds in critical condition should be assessed in detail (not using binoculars from the ground).
> - Agencies with painted signal structures should always inspect welds in detail. If cracks are suspected, paint should be removed for closer inspection and before conducting any testing (e.g., magnetic particle testing). It is recommended these agencies coordinate their assessment and painting schedules to enable weld inspections prior to each repainting.

To describe the conditions of aerial welded connection of mast arms, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Garlich and Thorkildsen (2005) noted any visible cracks in or near welds were of upmost concern. Notable bending or deformation of the connection or surrounding area is also considered critical. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 30. The proposed condition levels include three example pictures and one text box, allowing details to be added for critical conditions observed.

| | | | |
|---|---|---|---|
| Good: no cracks in or near welds (especially the top and bottom of vertical connections); no bending or deformation of connection or surrounding area. | Fair: minor corrosion (PICTURE) in or near welds. | Poor: moderate corrosion (PICTURE); slight bending or deformation of connection (PICTURE) or surrounding area. | Critical: significant corrosion in/near weld (PICTURE); Any visible cracks in or near welds, notable bending or deformation of connection or surrounding area. Multiple elements warrant ultimate strength and/or serviceability analysis. Please explain. |

**Figure 30. Illustration. Assessment conditions for aerial welded connection of mast arms.**

## Poles and Posts

Findings indicated that the condition of a pole or post is influenced by the plumbness, warping/damage, corrosion, and missing caps. Three separate assessments were developed to capture these conditions. Recall that this report differentiates between posts and poles, as described in the section about bases.

The plumbness of the pole/post is important to inspect because a slanted pole/post can obstruct the lane of traffic and affect the visibility of traffic signals. It can create more pressure on the foundation, leading to uneven settlement. PennDOT (2020) recommends checking a pole for plumbness and adjusting as necessary. Because traffic signal poles are slightly tapered, measuring tilt may be challenging. Instead, it was recommended to assess tilt qualitatively, provide example pictures of traffic signal poles/posts with tilt, and request inspectors to document any notable tilt with either a measurement and/or a picture.

> Inspect poles and posts for plumbness. Visually inspect signal poles and posts for plumbness. Document any notable tilt with a measurement and/or picture.

To describe the condition of pole and post plumbness, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 31.

| | | | |
|---|---|---|---|
| Good: no damage or notable tilt observed. | Fair: minor damage/dent or slight tilt at one or more poles/posts. (PICTURE) | Poor: evidence of moderate damage (e.g. vehicle impact) or noticeable tilt at any pole/post. | Critical: pole/post damage or tilt causes concern for stability (PICTURE); requires immediate structural assessment. |

**Figure 31. Illustration. Assessment conditions for pole and post plumbness.**

To prevent pole failure, inspection should also check for warping, corrosion, or other damage. VDOT recommends visually inspecting poles to identify any dents, vehicle impact damage, or warping and noting any dents/marks deeper than 1/2" or other damage that could affect strength. Their inspection method also recommends visually inspecting the protective metal coating on the pole and checking for signs of corrosion. Any cracks or areas of missing coating can cause the underlying metal to corrode. If corrosion is present on the pole/post, the inspector should use a hammer to sound the metal and identify if any areas appear thin (VDOT, 2014).

Dents can cause a significant reduction in the load-bearing capacity of round hollow structural members. In particular, slender structural members are likely to fail with buckling occurring at the location with the imperfection/dent (Shahbazi et al., 2019). Traffic signal poles are considered slender columns, and caution should be taken when considering dents. The AASHTO (2015) *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* recommends a method for identifying if dents can be safely ignored. Small dents on either posts or poles can be ignored if all of the following items are met:

- "No cracking exists in the steel or sharply folded kinks in the dent.
- The dent is located away from other considerations such as holes and welded-on plates.
- For posts with dents: Under typical dead loads, neither out-of-plumb nor out-of-straightness of a post exceeds 2.5% of post length. (Often owners may want to impose a tighter limit for aesthetic reasons, specialized structural issues, or clearance issues.)
- For mast arms with dents: Under typical dead loads, extra bend in the mast arm does not create unacceptable aesthetic, structural, or clearance issues.
- $\delta \leq t$ where $\delta$ (in.) is depth of the dent measured relative to the original shape and $t$ is thickness of the tube wall (in.).
- $W \leq 0.05C$, where $W$ is width of the dent measured along the original circumference of the tube (in.), which has a total circumference of $C$ (in.).
- $L < 0.1\ C$, where $L$ is the maximum dimension of the dent measured straight across the largest dimension of the dent (in.) and $C$ is the total circumference of the tube (in.)" (AASHTO, 2015).

To aid agencies in determining if dents exceed these thresholds, this effort has developed a spreadsheet that allows the inspector to enter measured field values for immediate results. This tool is separate from this report and the authors can be contacted for a copy. A few spreadsheet notes:

- Use a separate copy for each intersection. The file is "read-only" so save the file with a unique name upon opening.
- There is room to enter up to 5 dents per sheet/intersection. The "Example" column can be over-written.
- Enter a value in the "Pole Location" field to enable the threshold results for that column.
- Pole thickness value may be best acquired through shop drawings.

For any poles whose dents reach a "Non-Negligible" level, agencies should determine the next step in assessment.

To prevent water intrusion, corrosion, or infestation inside signal poles/posts, missing caps should be identified and replaced. Several agencies include this element in their traffic signal assessment procedures, including PennDOT (2020), MnDOT (2020), and VDOT (2014). Based on those sources of information, the following assessment procedure was recommended.

> Note the presence of caps on poles and mast arms. Visually inspect all poles and mast arms (as applicable) to identify missing caps or other sources of water intrusion. Please describe the location of any missing caps.

Feedback from the TRP and interviews suggested inspectors note any damage to poles from hits by vehicles to allow tracking of conditions over time, such as crack formation, corrosion, and/or plumbness. Based on those sources of information, the following assessment procedure was recommended. The pictures and measurements can support appropriate personnel in determining if dents can be ignored.

> Visually inspect poles/posts to identify any dents or vehicle impact damage. Record the following for any notable dents.
>
> Pictures:
>
> - A close-up picture that shows the dent, with a ruler for size reference.
> - A picture showing the location of the dent compared to access holes and/or welded plates.
>
> Measurements:
>
> - The vertical and horizontal distance from the dent to access holes or welded plates (e.g., bottom plate)
> - Depth of dent, relative to the original pole/post shape
> - Width of dent, measured along the circumference of the pole/post

- Length of the dent, "measured straight across the largest dimension of the dent"
- Thickness of pole material
- Circumference of pole adjacent to dent location

For the assessment of pole and post for dents and damage, three categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and applied during fieldwork. The final version is presented in Figure 32.

| | | |
|---|---|---|
| Good: no evidence of damage | Fair: moderate damage/dent identified on one pole/post. | Critical: heavy damage and/or concerning dent on one or more poles/posts (Example picture). Condition may warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of the element. |

**Figure 32. Illustration. Assessment conditions for pole and post.**

## Wood Poles

Findings indicated that the condition of poles are influenced by buckling, cracking, holes, rot, and knots along with the depth of the pole's initial installation/setting (Occupational Safety and Health Administration, 2014). To distinguish between conditions of wooden poles, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 33.

| | | | |
|---|---|---|---|
| Good: no buckling at the ground line. Pole is buried to a sufficient depth. No carks, holes, rots or knots present. | Fair: no buckling at the ground line. Pole is buried to a sufficient depth. May have signs of minor cracks, hole, rot and knots. | Poor: signs of minor buckling or that pole is not buried to sufficient depth. Concerning cracks perpendicular to the wood grain. Could have evidence of moderate rot or knots. | Critical: heavy damage with major cracks perpendicular to the wood grain. Could show signs of rot, cracks, and/or that pole is not buried to sufficient depth. The stability of the pole is questionable. |

**Figure 33. Illustration. Assessment conditions for wooden poles.**

## Mast Arms

Findings indicated that the condition of mast arms is influenced by the mast arm structure and missing mast arm end caps. Missing mast arm end caps are inspected to prevent water intrusion and collection inside the mast arm, which leads to corrosion. PennDOT (2020) and ITE (2023) recommend checking for missing caps on poles and the end of mast arms, replacing as required.

The mast arm structure should also be inspected to prevent unexpected failure. Several agencies recommend assessing the horizontal and vertical components of mast arms to identify warping or other damage and documenting any deficiencies. Feedback from the TRP and interviewees generally agreed with these methods. Based on these sources of information, the following assessment method was recommended.

> Visually inspect the protective metal coating on the mast arm with binoculars (or similar devices). Any cracks or areas of missing coating can cause the underlying metal to corrode. Check for signs of corrosion. If corrosion is suspected inside the mast arm, sound the outside with a hammer and listen for a ringing sound. Check for warping or other damage.

To differentiate between mast arm conditions, five categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and applied during fieldwork. The final version is presented in Figure 34.

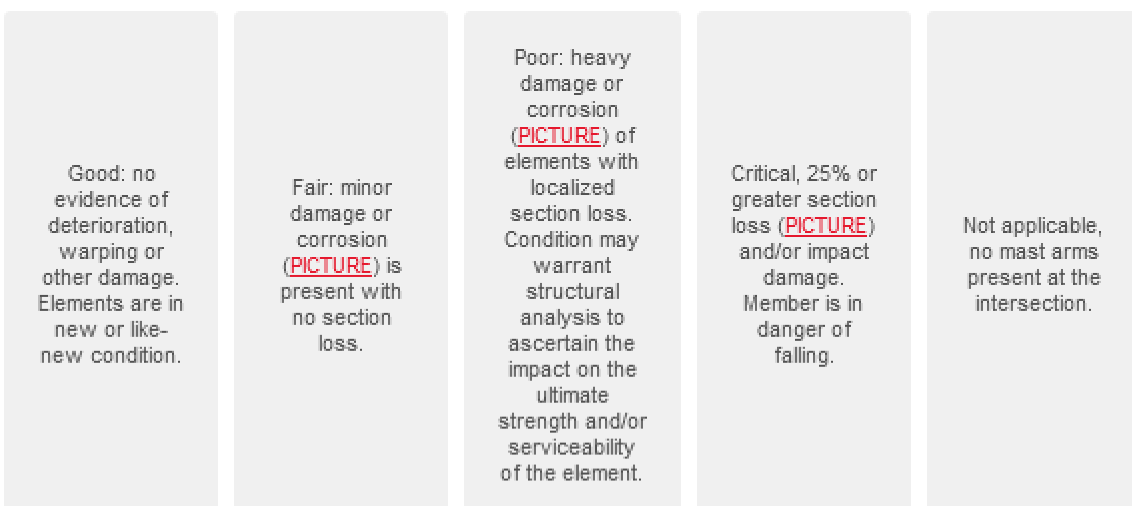



**Figure 34. Illustration. Assessment conditions for mast arms.**

## Span Wires

Because IDOT prefers mounting signal heads/displays with mast arms instead of span wires, this method relied heavily on the experience of other agencies. Findings indicated that the span wire condition is influenced by the span wire connection to the pole, span wire tension and condition, and span wire hardware.

The span wire connection to the pole should be inspected to prevent span wire failure. Several agencies agree that the span wire and tether wire connections to the pole should be assessed (PennDOT, 2020; MnDOT, 2020). Span wire hardware should also be inspected. These components could include support brackets, anchors, guards, and cable lashing (PennDOT, 2020; MnDOT, 2020). If these components are found loose, tightening or replacing is the recommended maintenance (ITE, 2023). These practices were supported by the TRP. Based on these sources of information, the following assessment procedure was proposed.

> Using binoculars (or similar devices), visually inspect each span wire connection for deterioration; inspect wires for deterioration and broken strands at connection. Inspect the eyebolt connecting the span wire and sway wire to the pole. Search the eyebolt for evidence of over-loading, such as cracking or bending. Check the nut (securing the eyebolt) is tight, crack-free, and fully engaged. Confirm that washers are present and all hardware is proper size.

For the condition of span wires, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during field work. The final version is presented in Figure 35.

| | | | |
|---|---|---|---|
| Good: Connection of tether wire is visibly tight and in new or like-new condition. | Fair: connection appears tight, but with minor corrosion. | Poor: one or more connections have small visible gaps; and/or moderate signs of corrosion. | Critical: connection shows significant damage or corrosion; requires immediate structural assessment. |

**Figure 35. Illustration. Assessment conditions for span wire.**

The span wire tension and condition are also important to inspect to prevent unexpected failure. Both PennDOT (2020) and MnDOT (2020) recommend visually inspecting every span wire for excessive sagging and adjusting as necessary. This type of visual inspection was also supported by the project's TRP. Based on these sources of information, the following procedure was recommended.

> Inspect span wire tension and condition. Using binoculars, visually inspect spans holding signal heads for excess sag. Visually check for damage, deterioration, or corrosion. Confirm that no signal heads have questionable clearance above the roadway.

For the span wire tension and condition, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during field work. The final version is presented in Figure 36. Because span wire traffic signals are less common in Illinois, it was challenging for the researchers to collect pictures describing all condition levels of these components. Instead, Appendix D includes only pictures of fair span wire tension.

| | | | |
|---|---|---|---|
| Good: normal sag of span wire, no damage, deterioration or corrosion. Signal heads appear at acceptable heights and no issues observed. | Fair: moderate sag, signal heads have less clearance than ideal, but no concerns with traffic interference; or signs of minor damage or corrosion. | Poor: significant sag in one or more span wires that requires maintenance or span wire has moderate corrosion; signal heads have questionable clearance/evidence of vehicle contact. Request clearance be measured with proper traffic control in place. | Critical: span wire sag endangers one or more signal heads; requires immediate attention. Request clearance be measured with proper traffic control. |

**Figure 36. Illustration. Condition levels for traffic signal span wire tension and condition.**

## Traffic Signal Head/Display Assessment

Findings indicated that the condition of signal head structural components is influenced by cracks and damage in the signal head housing, their secure assembly, clearance above the roadway from the bottom of the signal head, and the secure mounting of the signal heads. Three questions were developed to assess these conditions.

Signal heads should be inspected for damage and cracks to the housing and the presence and condition of attachments such as visors, backplates, and louvers (MnDOT, 2020). If metal housings, coating condition (power-coating, galvanization, paint) should be checked to prevent water intrusion and corrosion. Several agencies recommend inspecting lenses and mounting hardware, cleaning and tightening as necessary (PennDOT, 2020; MnDOT, 2020). The clearance between the roadway surface and the bottom of the signal should also be inspected for signal heads over travel lanes, to avoid vehicle obstructions (PennDOT, 2020; MnDOT, 2020). These practices were also supported by the project TRP. Based on these sources of information, the following procedure was recommended.

> Visually, with binoculars, observe all signal heads to identify cracks, breaks, or other damage. This step includes signal housing, backplates, visors, and louvers, as necessary. For displays made of metal, use binoculars (or similar devices) to visually inspect the protective coating for signs of rust.

To describe the conditions of signal heads, four categories were developed. Researchers used each assessed component and described those in multiple condition categories. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during field work. The final version is presented in Figure 37.

| | | | |
|---|---|---|---|
| Good: No cracks, breaks, or other damage are visible in the signal heads. If metal, no coating loss or corrosion visible. | Fair: One or more signal heads has coating loss, but not more than minor corrosion. | Poor: One or more signal heads has a visible crack or missing/damaged gasket, moderate corrosion, and/or degraded retroreflectivity on backplate. | Critical: Several signal heads have cracks or broken attachments and/or significant corrosion is present. |

**Figure 37. Illustration. Conditions levels for traffic signal heads/displays.**

For the assessment of signal head mounting, the following procedure was recommended, and several categories were developed. After review, the fair condition was removed, leaving only good, poor, and critical, as presented in Figure 38.

> Inspect mounting of signal heads. Observe mounting hardware that is visible from the ground to identify changes in alignment or signs of looseness/movement. Identify any components that might be missing or heads that are not aligned to traffic.

| | | |
|---|---|---|
| Good: Signal heads appear secure, mounting hardware are present and correctly aligned. | Poor: Signal heads show slight movement in response to wind, but acceptably aligned and not in danger of falling. | Critical. One or more signal heads show notable movement and alignment is concerning/mounting unsecure. |

**Figure 38. Illustration. Condition levels for traffic signal head mounting.**

For the assessment of vehicular signal head alignment, the following procedure was developed, and four categories were developed. Similar to other questions, inspectors have a text box to describe certain conditions in more detail. The final condition categories are presented in Figure 39.

> Inspect vehicular signal head alignment. View signal heads from approximately 150 feet from stop bar and confirm visibility is clear. Note if any displays have rotated or shifted. Notify the agency immediately of any twisted and/or conflicting signals. If rated critical, poor, or fair, please describe the locations of these issues.

| | | | |
|---|---|---|---|
| Good: Signal heads are aligned relative to the crossing they serve; no issues observed. | Fair: Some signal heads have shifted, but no effect on safety or operation. | Poor: One or more signal heads require redirectioning, but cause no safety concerns (Please explain). | Critical: Signal heads require immediate attention for traffic safety (Please explain). |

**Figure 39. Illustration. Condition levels for vehicular signal head alignment.**

For the assessment of pedestrian signal head alignment, a similar assessment procedure was developed with five condition levels. Because not all signalized intersections have pedestrian accommodations, the fifth option allows inspectors to report that information, as presented in Figure 40.

> Inspect pedestrian signal head alignment. View pedestrian signal heads to confirm they are visible from the opposite side of the crosswalk. Observe performance by activating pedestrian crossing, watching character display, and confirming call ends.

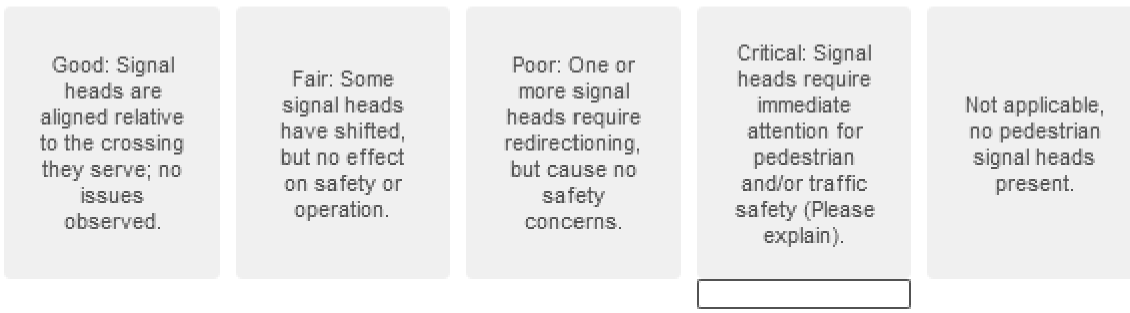



**Figure 40. Illustration. Condition levels for pedestrian signal head alignment.**

For the assessment of signal lights and lenses, they are visually inspected for cracks or any other damage. Three categories were developed, and if the poor or critical condition is chosen, a box is provided to mention further details, as presented in Figure 41.

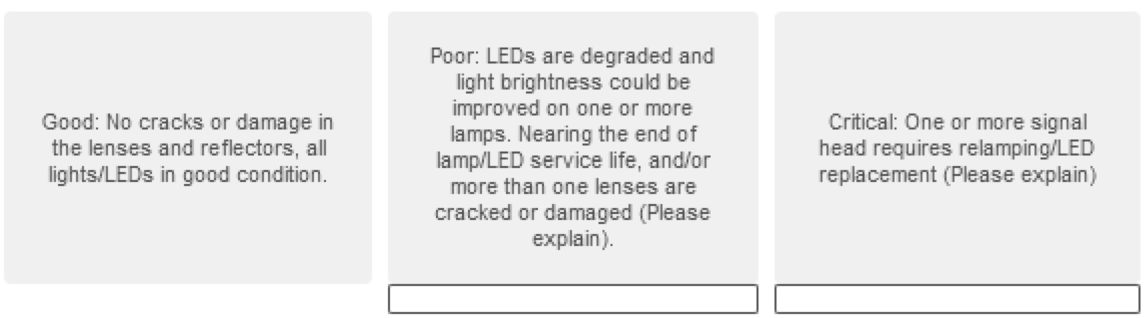



**Figure 41. Illustration. Condition levels for traffic signal lights and lenses.**

## Power Supply and Wiring

Findings indicated that the power supply and wiring condition is influenced by the wire wear at key locations and by the condition of the grounding system. When assessing the wear on signal wires, key locations include the wire's entrance to poles, heads/displays, mounting brackets, and where a cable is secured to a span wire. The focus of assessing these locations is to prevent electrical short circuits. Associated maintenance could include installing or replacing rubber grommets as needed (PennDOT, 2020; MnDOT, 2020). The grounding rod, clamp connections, conduit bonding, and conduit bushings should also be inspected to ensure proper grounding (PennDOT, 2020; MnDOT, 2020).

The condition of the electrical service disconnect box enclosure and meter should be inspected to identify the physical condition. Inspection should identify the presence of corrosion and a proper lock (PennDOT, 2020; MnDOT, 2020). In addition, the surge protection, transfer switch, and connector cable assembly can be inspected (MnDOT, 2020; PennDOT, 2020).

Based on this information, assessment procedures were recommended for signal cable bushings, grounding systems, and electrical service disconnect. These procedures are described as follows and the condition levels are presented in Figure 42, Figure 43, and Figure 44, respectively.

Inspect the conduit bushings (if used). Visually check that signal cables have bushings at cable outlets and there is no evidence of insulation wear.

| | | | |
|---|---|---|---|
| Good: Signal cables have bushings at cable outlet, no evidence of insulation wear. | Poor: One or more bushings are missing, but only minor wear. | Critical: Bare wire is exposed due to insulation damage/wear. | Not applicable |

**Figure 42. Illustration. Condition levels for traffic signal cable bushings.**

Inspect the grounding system. Visually check that all straps, rod connections, and grounding bushings on rigid metallic conduit are tight and secure.

| | | |
|---|---|---|
| Good: All straps and rod connections are tight and secure. Grounding bushing(s) is/are present. | Poor: One or more grounding rods, and/or bushings are disconnected/missing. | Unable to assess |

**Figure 43. Illustration. Condition levels for traffic signal grounding system.**

Inspect the condition of the power connection. Confirm that the disconnect box is visible, clearly labeled, and free of corrosion and the conduit is not damaged.

| | | | |
|---|---|---|---|
| Good: Disconnect box is present and corrosion free. | Fair: Disconnect box is visible, but could have moderate rust (PICTURE) or lack identification/label. | Poor: Disconnect is not visible or not labelled; or severe rust is present (PICTURE). | Critical: Disconnect box is damaged or severely corroded (PICTURE). Replacement is needed. |

**Figure 44. Illustration. Condition levels for traffic signal electrical service disconnect.**

## Traffic Signal Cabinet Assessment

Findings indicated that cabinet exterior condition is influenced by dents, holes, rips, or corrosions. MnDOT (2020) recommends that all traffic signal cabinets be inspected annually for exterior damage. Damage could result from vehicle impact, vandalism, fallen tree limbs, etc.

For painted steel cabinets, PennDOT (2020) recommends evaluating the condition of paint and any indications of corrosion. Although multiple types of signal cabinets are present in the U.S., feedback from the project TRP and during interviews indicated there were few painted cabinets in Illinois and the majority were unpainted aluminum. Further, corrosion of a signal cabinet was not reported as a common cause of signal failure. Input suggested that corrosion can be included in comments when present.

Four categories were developed for the cabinet exterior assessment. A good cabinet has no coating loss or corrosion, whereas a fair cabinet may have some coating loss and minor corrosion or dents. Anything with significant coating loss and presence of holes and rips requiring maintenance is considered poor. The proposed assessment method is described below, and the condition levels are presented in Figure 45.

> Inspect the cabinet exterior. Visually inspect for dents, holes, rips, or corrosion (as applicable).

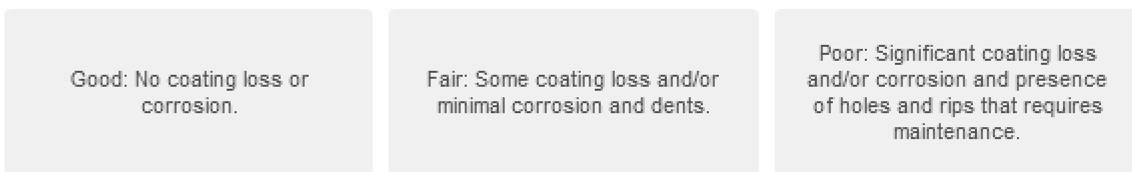



**Figure 45. Illustration. Condition levels for traffic signal cabinet exterior.**

Cabinet anchoring can be assessed several ways. Similar to pole foundations, the bolts can be tested with a wrench or by sounding with a hammer (VDOT, 2014; MnDOT, 2020; PennDOT, n.d.). Feedback collected during interviews suggested that cabinet anchoring could be assessed more simply by attempting to rock the cabinet with moderate pressure.

ODOT recommends assessing cabinet hinges and lubricating as necessary (MnDOT, 2020). TRP members supported this type of assessment and recommended a check of the lock and police access door also. The recommended assessment method is described as follows.

> Inspect cabinet anchoring and doors. Assess the operation of doors, locks, and police access, when applicable. Gently rock the cabinet to identify signs of looseness. If the cabinet connection to the foundation is questionable, strike bolts gently with a hammer and listen for a ringing sound (not a thud).

For the assessment of cabinet anchoring and door operation, four categories were developed. A good cabinet anchoring is where there is no evidence of corrosion, bending, or cracks, and the cabinet is securely attached to the foundation. If corrosion is evident, or there is a minor bend or crack in a bolt even though the cabinet is securely attached to the foundation, it is considered poor. When the connection becomes questionable and one or more bolts do not produce a ringing sound when struck by a hammer, the condition is considered critical. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 46.

| | | | |
|---|---|---|---|
| Good: Cabinet remains securely attached to the foundation and no issues observed with doors. | Fair: Cabinet remains securely attached, no bending in bolts or concerning foundation cracks. Minor corrosion may exist and doors may require moderate pressure to open. | Poor: Cabinet remains securely attached, but corrosion stains are evident, or one or more bolts have a minor bend or crack. Doors may open poorly and require repair. | Critical: Cabinet connection to foundation is questionable and moves with moderate force. Broken, missing, or severely corroded bolts are present. One or more bolts do not produce a ringing sound when struck with a hammer. Doors not operable without tools. |

**Figure 46. Illustration. Condition levels for traffic signal cabinet anchoring.**

Findings indicated that cabinet weatherproofing and base/foundation conditions are influenced by water intrusions or standing water. Ohio recommends checking cabinet door seals and that the cabinet is sealed to the foundation (MnDOT, 2020). The TRP supported an assessment of the sealant between the cabinet and its base. For common practices inspecting concrete bases, refer to Chapter 2.

> Inspect cabinet base and weatherproofing. Observe floor/base of cabinet to identify signs of water intrusion and/or standing water. Check the exterior of the base for visible cracks and document the number and approximate size, width, and position of the crack(s). Check condition of the caulk around the base of the cabinet.

For the assessment of cabinet weatherproofing and base or foundation, three categories were developed. Researchers used each assessed component and described those in multiple condition categories. A good condition has no obstructions, while a fair condition may have minor obstructions, so long as it operates well. If there are signs of saturation due to drainage issues, it was considered poor, and a textbox is provided to gather details. Those descriptions were reviewed and commented on by the TRP, discussed with interviewees, and tested during fieldwork. The final version is presented in Figure 47.

| | | |
|---|---|---|
| Good: no water intrusion observed. | Fair: Minor obstructions to drain, but not water issues observed. | Poor: Signs of saturation due to drainage issue (PICTURE). |

**Figure 47. Illustration. Assessment conditions for cabinet base and weatherproofing.**

## Traffic Signal Controller Assessment

Other transportation agencies recommend assessing signal controller timings, firmware version, and obsolescence. The basic controller timing of the controller should be inspected to identify severe issues with signal timing. Input from the TRP recommended reducing the detail for this assessment because evaluating the timing is more related to traffic operations, better to be evaluated by a traffic engineer, and not appropriate for condition assessment.

Pennsylvania DOT (2020) recommends noting the serial number, firmware version, make, and model for controllers, conflict monitors, and other major components. This was recommended to identify and assess safety and operational efficiency. Their procedure indicated it was acceptable to place the signal in flashing operation to update software/firmware, as needed.

Transportation agencies were also found to inspect signal controllers for obsolescence to avoid issues like reliability and difficulty of maintenance. If a controller is coordinated with other signals, Pennsylvania DOT (2020) recommends disconnecting controller communication and checking if the signal continues operating independently.

Several transportation agencies used age as a gauge for the condition of a signal controller. For example, PennDOT (2020) and CDOT (2016) assumed an average signal controller lifespan of 15 years, and INDOT assumed 5–10 years (Minnesota DOT, 2020).

The researchers aimed to differentiate between maintenance activities and assessments of the controller's overall condition. One TRP member's feedback guided this differentiation, "The traffic signal engineer/supervisor should be responsible for developing these timings and ensuring they are correct or approving any modifications. This applies to yellow and all-red times as well. Most agencies should be able to remotely monitor their signals and can check timing operations in this manner. This would also apply to other controller settings such as vehicle extension times, min greens, etc." Other TRP feedback suggested that signal controller settings are not representative of its overall condition. For example, a signal controller can reach its full lifespan even if the timings do not serve traffic demand well. Based on these factors, the researchers recommended assessing the condition of the overall controller based on its age.

### *Lifespan Estimation*

To estimate the lifespan of traffic signal controllers, the researchers first sought maintenance records from IDOT districts and their maintenance contractors. Unfortunately, signal controller installation, repair, and replacement information were not available. Instead, researchers applied two methods to estimate controller lifespan in Illinois. The first method included a Weibull model calibrated to estimate signal controller lifespan by previous research. The second method sought to identify and estimate the different ways a signal controller could fail over time.

#### NCHRP Survival Probability Model

A life expectancy model, which can be used to determine the lifespan of signal controllers, was obtained from the literature review. The model uses Weibull's survival probability curve. The functional form of the Weibull curve was presented earlier in this report, see Figure 9.

Higher shaping parameters slow the pace of degradation, but eventually, degradation accelerates as the facility ages. To estimate the shape parameter, maximum likelihood estimation, a systematic trial-and-error approach that involves experimenting with multiple beta values until the best fit to the data is attained, can be utilized (Thompson et al., 2012). To determine $\alpha$, note that the model requires temperature and wind speed data. The model also requires information on the traffic signal's features to determine the signal controllers' lifespan.

Please also note that pre-timed or semi-actuated traffic signals that were hardwired, or part of a closed loop, had a longer service life. Signal controllers that run pre-timed or semi-actuated may last longer, as the required computation level is less than a fully actuated signal. A fiber-optic connected signal may not last as long for the same reason. Similarly, signal controllers on city streets may not last as long due to higher computational demand. A more significant number of pedestrian actuations on city streets may result in a higher need for computation on the signal controllers. Signal controllers on intersections that use mast arms may not last as long as span wire intersections, as mast arms may be more susceptible to lightning strikes.

A few assumptions were made for calculating lifespan with the Weibull model. These assumptions were necessitated by the type of data available from IDOT. Although IDOT districts reported the number of signals with each attribute, data about each signal were not available during this study. For example, the data confirmed the number of signals using mast arms and the number using fiber-optic communication but did not include how many had both. These assumptions are described below:

- All signalized intersections with span wires were assumed to be on city-managed streets and not connected with fiber. This assumption was based on IDOT current practice. Because IDOT prefers mast arms instead of span wire to mount traffic signals, it was assumed signals with span wires were designed and constructed by local municipalities for lower-volume intersections, therefore; these intersections were classified as serving city streets.

- Fiber-connected signals were assumed to be on city streets. The assumption is based on practice that signals on city streets are more likely to serve actuated-coordinated intersections, which require communications between the signal controllers, normally with fiber-optic cable.

- Fiber-connected signals were assumed to be in closed-loop or hardwire-connected systems, and other signals work independently. This assumption is based on practice that fiber-optic communication is used to link intersections with the master controller or central system.

### *Fault Tree Analysis with Return Period Probabilities*

To fill the research gap in understanding the root causes for replacing a traffic signal controller, this study used fault tree analysis (FTA) to investigate how failure mechanisms can interact, leading to traffic signal controller replacement. Not many studies have used FTA to model failure modes related to transportation engineering (Xu et al., 2018). Furthermore, FTA has not been used previously for associating the causes for signal controller replacement. A fault tree was created for traffic signal controller failure, presented in Figure 48.

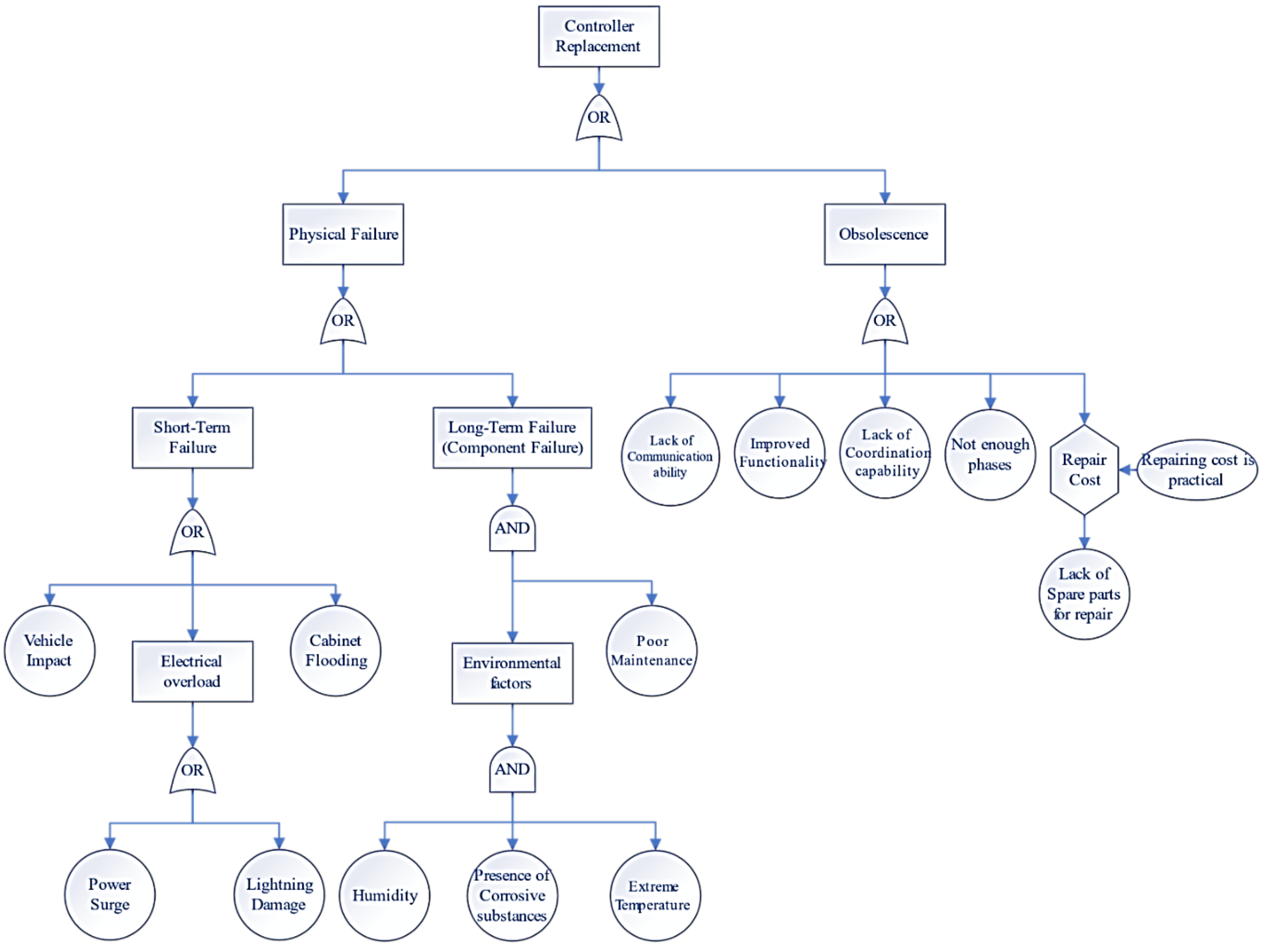



**Figure 48. Chart. Fault tree diagram for traffic signal controller replacement.**

***Source: Sah (2023)***

The initial goal of the research was to determine the variation in probabilities of all the basic events presented in the fault tree to determine the probability of signal controller replacement (i.e., end of life). However, during the data collection process, it was determined that minimal records were available for the replacement of the traffic signal controller, and interviewees could not narrow down the probabilities of basic events. Therefore, it was decided to use probability distributions for the fault tree model's physical failure and obsolescence rates.

### *Data Collection*

Data from the literature provided multiple estimates of the lifespan of the signal controllers. Expected lifespan data obtained from the literature on the lifespan of traffic signal components were presented earlier in this document, see Table 4. Unfortunately, these lifespans did not differentiate between types of failure (e.g., vehicle collision, lightning, became obsolete).

### Weather Data Preparation

Weather information about Illinois was collected from the National Centers for Environmental Information (NCEI, part of the National Oceanographic and Atmospheric Administration) database. A few key locations in Illinois were selected to represent different weather conditions throughout the state.

The data collection process for temperature and wind speed is described below. It was assumed that the annual average temperature and wind speed for the IDOT district headquarters is representative of the annual average temperature and wind speed for the whole IDOT district it represents. If data were not available for district headquarters, then the average locations in the district and other nearby locations were used to substitute for the data.

### Atmospheric Data Collection

Temperature data for different IDOT districts were collected from different locations in the NCEI database. Average temperature data from 1991 to 2020 were obtained for all IDOT districts from the Comparative Climatic Data Climate Normals section (National Oceanographic and Atmospheric Administration, n.d. -b). The obtained data are presented in Table 7. For Districts 1 and 8, average temperature data were not available for the city of the headquarters. In those cases, data from the nearest station (≤ 14 mi.) were used. For IDOT District 1, weather data were taken from Elgin, Illinois, instead of Schaumburg (~14 miles apart). For IDOT District 8, weather data were taken from Belleville, Illinois, instead of Collinsville (~11 miles apart).

**Table 7. Average Annual Temperature and Wind Speed for Locations in Illinois**

| IDOT District | IDOT District Headquarters | Average Annual Temperature (F) | Average Annual Wind Speed (mph) |
|---|---|---|---|
| 1 | Schaumburg (Chicago metro) | 49 | 9.9 |
| 2 | Dixon | 49.4 | 8.85 |
| 3 | Ottawa | 50.2 | 8.9 |
| 4 | Peoria | 52.7 | 8.3 |
| 5 | Paris | 51.4 | 9.4 |
| 6 | Springfield | 54 | 9.3 |
| 7 | Effingham | 54.4 | 9.25 |
| 8 | Collinsville | 57.7 | 9 |
| 9 | Carbondale | 56.4 | 7.6 |

***Source: National Oceanographic and Atmospheric Administration (n.d.-a, n.d. -b)***

Wind speed data for different IDOT districts were collected from different locations in the NCEI database. Average wind speed data from 1984 to 2020 was obtained from the Comparative Climatic

Data Climate Normals section (National Oceanographic and Atmospheric Administration, n.d. -a) for five locations. This dataset was chosen because it was the most recent dataset with at least 30 years of data.

The average annual wind speed data were not as comprehensive as the temperature data, and only three district headquarters had data from their city: District 1, Chicago metro; District 4, Peoria; and District 6, Springfield. To overcome this lack of data, the researchers used a weighted average to estimate wind speeds for the other districts. The wind speed was weighted based on proximity, where a closer city's wind had a stronger weight than a farther city.

- District 2—Dixon: wind speeds from Rockford and Moline, Illinois, were used.
- District 3—Ottawa: wind speeds from Moline, Chicago, and Peoria, Illinois, were used.
- District 5—Paris: wind speeds from Indianapolis, Indiana, and Springfield, Illinois, were used.
- District 7—Effingham: wind speeds from Indianapolis, Indiana, and St. Louis, Missouri, were used.
- District 8—Collinsville: wind speeds from St. Louis, Missouri, were used.
- District 9—Carbondale: wind speeds from Paducah, Kentucky; Evansville, Indiana; and St. Louis, Missouri, were used.

The last dataset included the number of traffic signals with specific characteristics (e.g., mast arms and pre-timed). This information was provided by IDOT district offices. Details included the number of span wires supported and fiber-optic connected signals. It is important to note that traffic signals owned and operated by local municipalities were not included in this data. The responses obtained are presented in Table 8.

**Table 8. Information on Signals Managed by IDOT Districts, 2023**

| SN. | Parameter / IDOT District | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Signals Operated by the District | 2,814 | 460 | 435 | 265 | 283 | 300 | 206 | 450 | 151 | 5,364 |
| 2 | No. of Span Wire Signals | 30 | 1 | 1 | 2 | 0 | 0 | 0 | 5 | 0 | 39 |
| | No. of Signals with Mast Arm and Pole System | 2,784 | 459 | 434 | 263 | 283 | 300 | 206 | 445 | 151 | 5,325 |
| 3 | No. of Fiber Optic Connected Signals | 2,400 | 78 | 161 | 27 | 206 | 255 | 21 | 90 | 23 | 3,261 |
| | No. of Mast-arm Fiber Connected | 2,370 | 77 | 160 | 25 | 206 | 255 | 21 | 85 | 23 | 3,222 |

## Expert Opinion Data Collection

Personal experience data were obtained by interviewing signal controller manufacturers, distributors, and state department of transportation (DOT) personnel. This effort was initiated after multiple attempts to obtain maintenance records documenting service life. Although state and local agencies have records about when controllers are replaced, many are repaired and returned to service. In addition, sometimes controllers are removed from service for software updates, retiming, or other reasons. Due to these factors, no records were available to track the life of signal controllers in Illinois. Instead, the researchers chose to collect expert opinions on service life through interviews.

The interview questions and research methods were reviewed and approved by the Institutional Review Board (IRB) at Southern Illinois University Edwardsville (Approval #1944). The survey questions used for the study are attached in Appendix E. The interviewees were chosen because of their professional experience with traffic signal controllers and their willingness to participate in an interview. Four individuals participated in interviews, representing one traffic signal controller vendor, two traffic signal controller manufacturers, and one DOT personnel.

The response data from participants helped the researchers identify different modes of failure. This data were analyzed to obtain time ranges for obsolescence and physical failure of signal controllers. Both sources of information are essential for predicting the overall lifespan of a signal controller. The response range noted that the average time after a company launches a new controller is approximately 14 years. If signal controllers are purchased/installed randomly over time, the mean service time for a signal controller before the company stops producing the model will be around 7 years. The manufacturer and independent technicians provide support for the signal controller even after the controller is stopped from production for between 3 and 15 years. Therefore, the range for obsolescence of a signal controller would be 10 to 22 years, with a mean life of 16 years.

The interview responses also provided input about the lifespan of signal controllers concerning physical failure. These include vehicle collisions, lightning strikes, and others presented in Figure 48. Interviewees shared that when significant repair of a signal controller is needed, it may be at the end of its life.

## NCHRP Survival Probability Model

The lifespan of the signal controller without repair with a 50% probability of failure was calculated using the Weibull survival probability equation for Illinois. Weibull’s equation was used independently for mast arm with and without fiber-optic connection and span wire–supported signals. Then, a weighted average with respect to the number of signals with each support type was calculated for the district. The average life of signal controllers for each district and other calculated values is presented in Table 9.

**Table 9. NCHRP Method Predicted Lifespan of Signal Controller without Repair**

| District | Total Number of Signals | Support Type | Number of Signals by Support | Number by Fiber Optic Connected or Not | Weibull Model Alpha | Predicted Life | Average Life |
|---|---|---|---|---|---|---|---|
| 1 | 2814 | Mast Arm | 2784 | 2370 | 9.144 | 7.06 | 7.63 |
| | | | | 414 | 13.560 | 10.47 | |
| | | Span Wire | 30 | 30 | 18.212 | 14.06 | |
| 2 | 460 | Mast Arm | 459 | 77 | 9.737 | 7.52 | 10.55 |
| | | | | 382 | 14.439 | 11.14 | |
| | | Span Wire | 1 | 1 | 19.394 | 14.97 | |
| 3 | 435 | Mast Arm | 434 | 160 | 8.886 | 6.86 | 8.96 |
| | | | | 274 | 13.177 | 10.17 | |
| | | Span Wire | 1 | 1 | 17.699 | 13.66 | |
| 4 | 265 | Mast Arm | 263 | 25 | 7.207 | 5.56 | 8.02 |
| | | | | 238 | 10.688 | 8.25 | |
| | | Span Wire | 2 | 2 | 14.355 | 11.08 | |
| 5 | 283 | Mast Arm | 283 | 206 | 7.422 | 5.73 | 6.48 |
| | | | | 77 | 11.006 | 8.49 | |
| | | Span Wire | 0 | 0 | 14.782 | 11.41 | |
| 6 | 300 | Mast Arm | 300 | 255 | 5.662 | 4.37 | 4.69 |
| | | | | 45 | 8.396 | 6.48 | |
| | | Span Wire | 0 | 0 | 11.276 | 8.70 | |
| 7 | 206 | Mast Arm | 206 | 21 | 5.450 | 4.21 | 6.03 |
| | | | | 185 | 8.081 | 6.24 | |
| | | Span Wire | 0 | 0 | 10.854 | 8.38 | |
| 8 | 450 | Mast Arm | 445 | 90 | 3.913 | 3.02 | 4.20 |
| | | | | 355 | 5.803 | 4.48 | |
| | | Span Wire | 5 | 5 | 7.794 | 6.02 | |
| 9 | 151 | Mast Arm | 151 | 23 | 5.187 | 4.00 | 5.64 |
| | | | | 128 | 7.692 | 5.94 | |
| | | Span Wire | 0 | 0 | 10.332 | 7.97 | |

To predict the average signal controller lifespan throughout Illinois, a weighted average was used. Districts with more signals had a larger influence on the overall average. Considering all signals in this dataset, the average lifespan was predicted to be 6.9 years. Figure 49 presents the failure probability over time, by district, and on average.

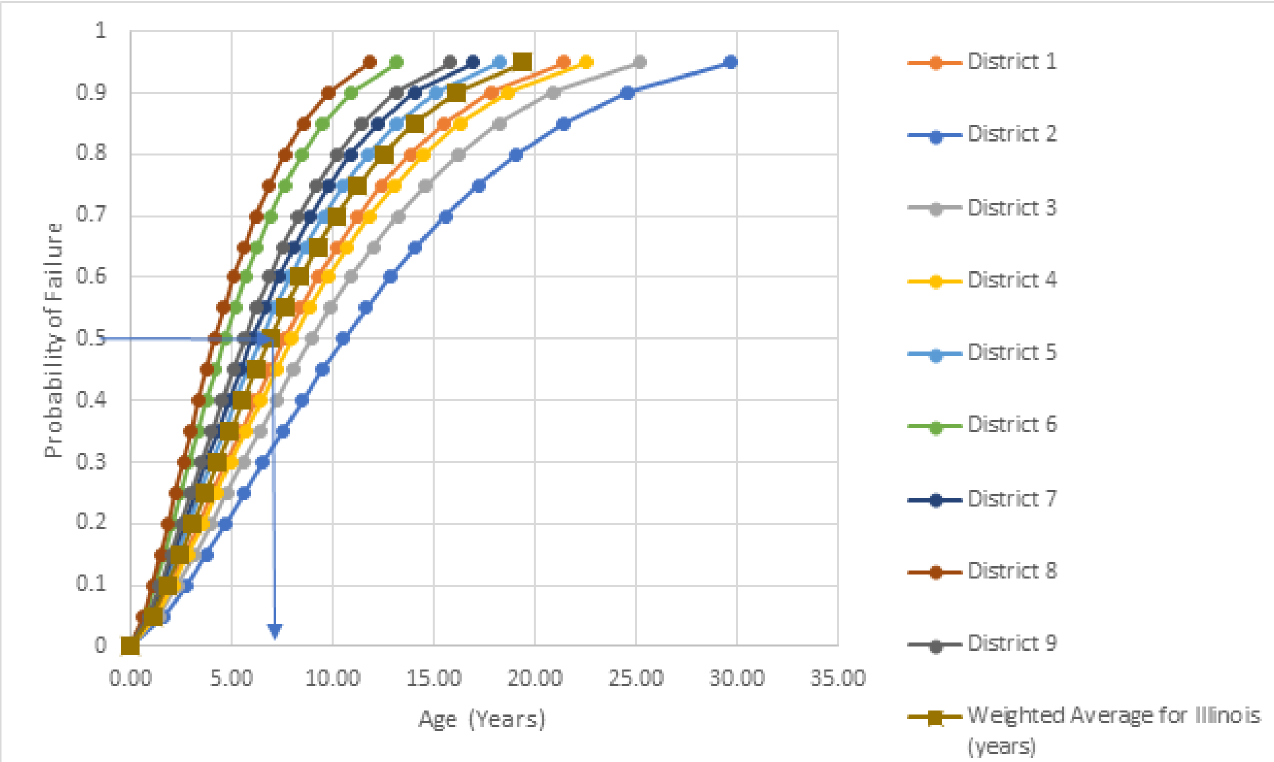



**Figure 49. Chart. Signal controller failure probability estimated with the NCHRP method.**

<u>Fault Tree Analysis with Return Period Probabilities</u>

The study focuses on two primary causes for the failure of traffic signal controllers for lifespan prediction—physical failure and obsolescence. Both failure mechanisms are based on return period probabilities. The average time elapsed between two subsequent observations of a particular event is known as the return period. Alternatively, the return level is the value that is predicted to be exceeded once every return period on average (World Meteorological Organization, 2009). Each failure mechanism was evaluated independently to determine the probability of failure throughout the lifespan and then combined to portray the combined effect.

If an event occurs randomly over time, independently of other events, and a consistent occurrence rate, then the Poisson distribution is appropriate to represent the number of occurrences in a given period of time (Siegel & Wagner, 2022). The probability mass function for the Poisson distribution is presented in Figure 50.

$$P(r) = \frac{(\mu t)^r}{r!} e^{-\mu t} = \frac{\left(\frac{t}{T}\right)^r}{r!} e^{-\frac{t}{T}}$$

**Figure 50. Equation. Probability mass function of the Poisson distribution.**

Where *r* is the number of occurrences for which the probability is computed, *t* denotes the time of interest, *T* denotes the return period, and $\mu = 1/T$ is the counting rate. Evaluating the situation for r = 0 yields the probability of no occurrence. The formula is presented in Figure 51.

$$P(no - occurrence: r = 0, t) = e^{-\mu t} = e^{-\frac{t}{T}}$$

**Figure 51. Equation. Probability mass function of the Poisson distribution for no occurrence.**

Consequently, the probability of occurrence is presented in Figure 52.

$$P(occurrence, t) = 1 - e^{-\mu t} = 1 - e^{-\frac{t}{T}}$$

**Figure 52. Equation. Probability mass function of the Poisson distribution for occurrence.**

The interview responses provided several helpful estimates about when signal controllers become obsolete. First, respondents estimated that new signal controllers are introduced every 14 years. Assuming signal controllers are purchased/installed randomly over time, the mean service time for a signal controller before the company stops producing the model will be around 7 years. The manufacturer and independent technicians provide support for another 3–15 years after a signal controller model production is discontinued. Therefore, the range for obsolescence of a signal controller would be 10 to 22 years, with a mean of 16 years. This information was used to calibrate a Poisson distribution to represent the likelihood of obsolescence over time. This distribution was chosen because of its memoryless property. As presented in Figure 53, 50% of signal controllers are estimated to be obsolete in approximately 15 years.

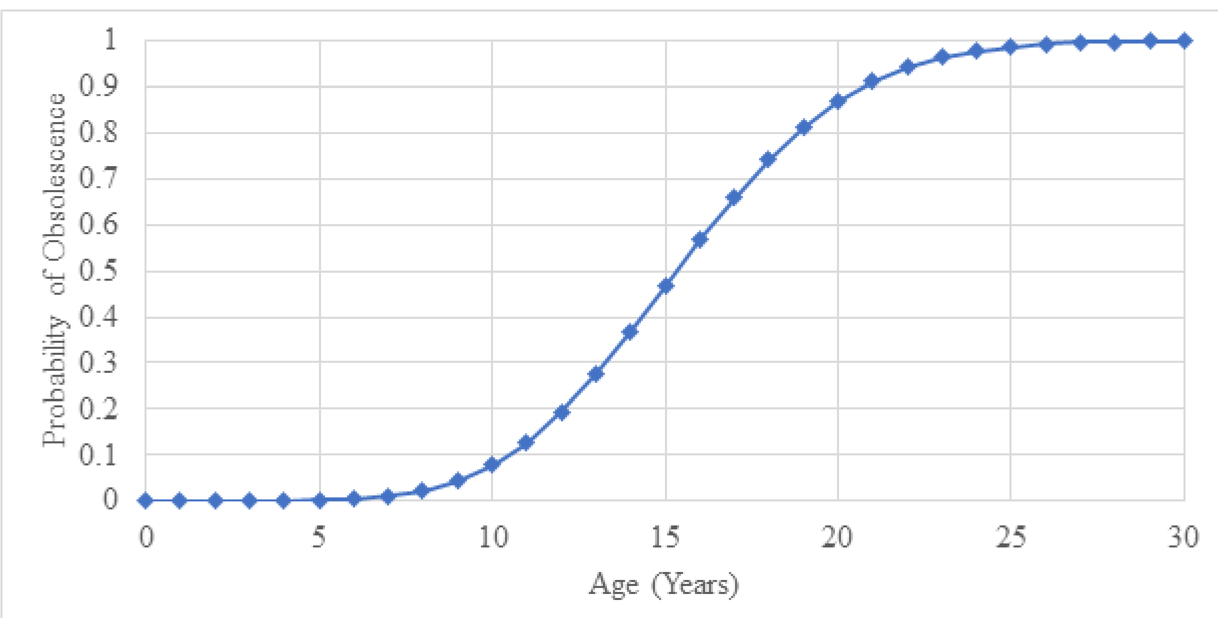



**Figure 53. Chart. Likelihood of signal controller obsolescence over time.**

***Source: Fries et al. (2024)***

The interview responses also provided input about the lifespan of signal controllers concerning physical failure. It was noted that approximately 10% of signal controllers are damaged each year. Initial assessment by signal technicians deems 20% of those damaged controllers unrepairable and the other 80% are sent for repair. Of those sent for repair, approximately 7% of the signal controllers are deemed irreparable for a variety of reasons including availability of parts. The remaining controllers are repaired and placed in service again. These estimates suggest that 2.5% of signal controllers reach the end of their life for physical reasons each year. The researchers recognize that declaring a signal irreparable in the physical sense is commonly based on the maintenance technician's judgment that repairing the controller at its current stage in life is economical. Overall, this information suggests that 50% of signal controllers will reach the end of their physical life in 19.5 years.

The researchers combined estimates from the literature and interviews to calibrate a Weibull equation representing the likelihood of physical failure over time. The probability distribution is presented in Figure 54.

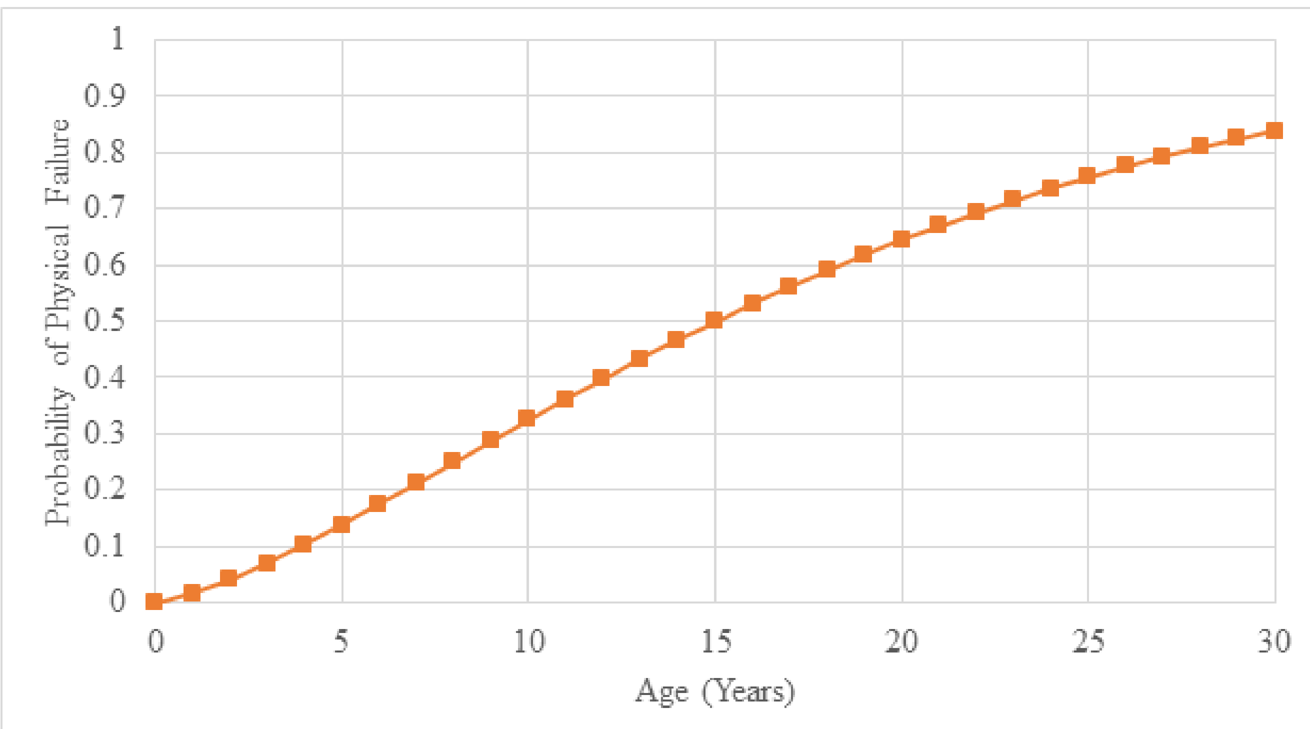



**Figure 54. Chart. Likelihood of signal controller physical failure over time.**

***Source: Fries et al. (2024)***

The overall failure probability curves are presented in Figure 55. As presented, a variation of 20% in the average lifespan will result in a change in the average lifespan of approximately 3 years (~25%), from 9 to 15 years. These findings suggest that traffic signal controller lifespan estimates are sensitive to changes in the mean, supporting the need for better data and additional research on this topic.

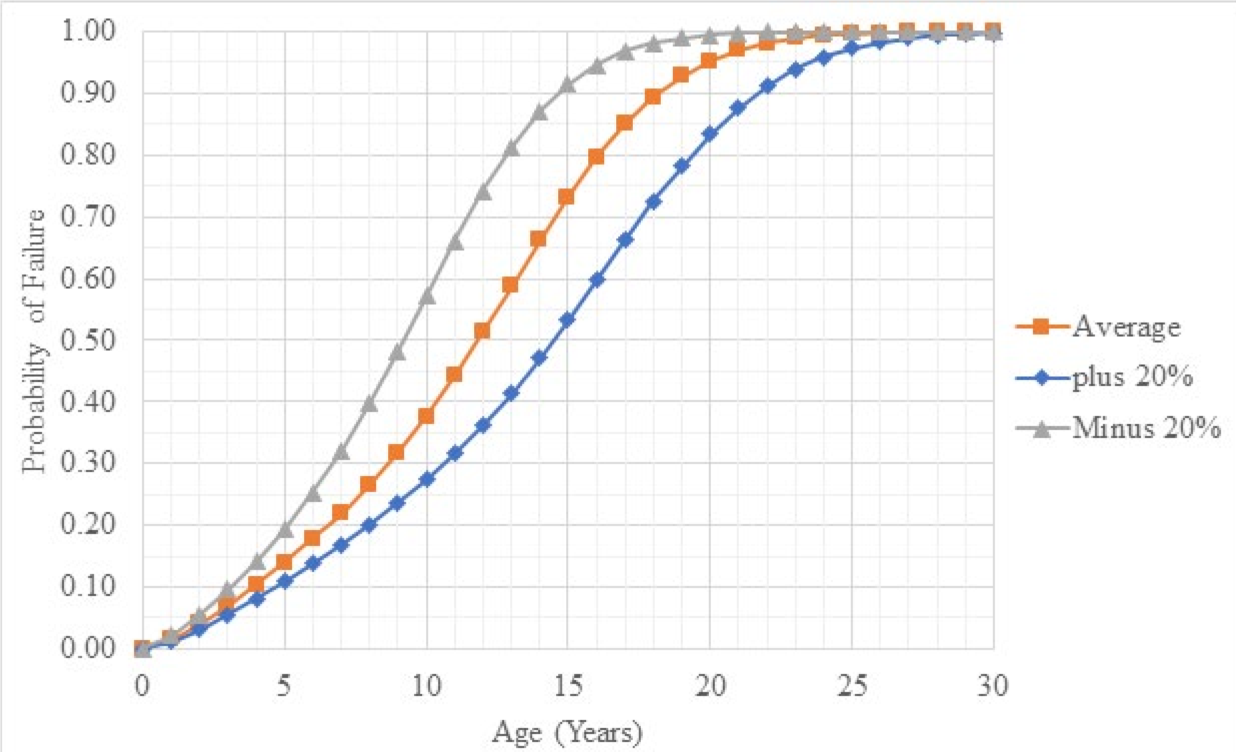



**Figure 55. Chart. Probability of a traffic signal controller by fault tree analysis.**

***Source: Fries et al. (2024)***

Comparing these findings to other studies suggests general agreement. Markow (2008) was most similar, estimating an average life of 13.5 years. Several other studies predicted shorter lifespans (Minnesota DOT, 2020; National Operations Center of Excellence and Institute of Transportation Engineers, 2019) and longer lifespans (Colorado DOT, 2016; Kloos & Bugas-Schramm, 2005; San Jose DOT, 2010; PennDOT, 2020).

Based on these different sources of information, the researchers recommended that signal controllers be assessed based on their age. Controllers that are less than 5 years old can be considered in good condition because the likelihood of failure was estimated low (≤ 0.35). To indicate the effects of aging, controllers from 5 years and less than 8 years can be considered in fair condition. Controllers in this category had an estimated failure rate between 0.15 and 0.57. Signal controllers with an age from 8 years and less than 12 years can be considered in poor condition. Controllers in this category had an estimated failure rate between 0.27 and 0.78. It is important to note that a failure rate > 0.5 indicates half of controllers fail by this age. Controllers that are 12 years or older can be considered in critical condition. Although several controllers may function properly with advanced age, an assessment of "critical" denotes the higher likelihood of failure through either physical or functional (e.g., obsolescence) reasons. Figure 56 presents these categories with the predicted failure probabilities from the two analysis methods. The NCHRP method considers atmospheric conditions and signal types throughout Illinois but does not include repair and reuse of controllers. The fault tree method considers expert opinion and reusing repaired controllers. The true average controller failure rate is likely between these two estimates.

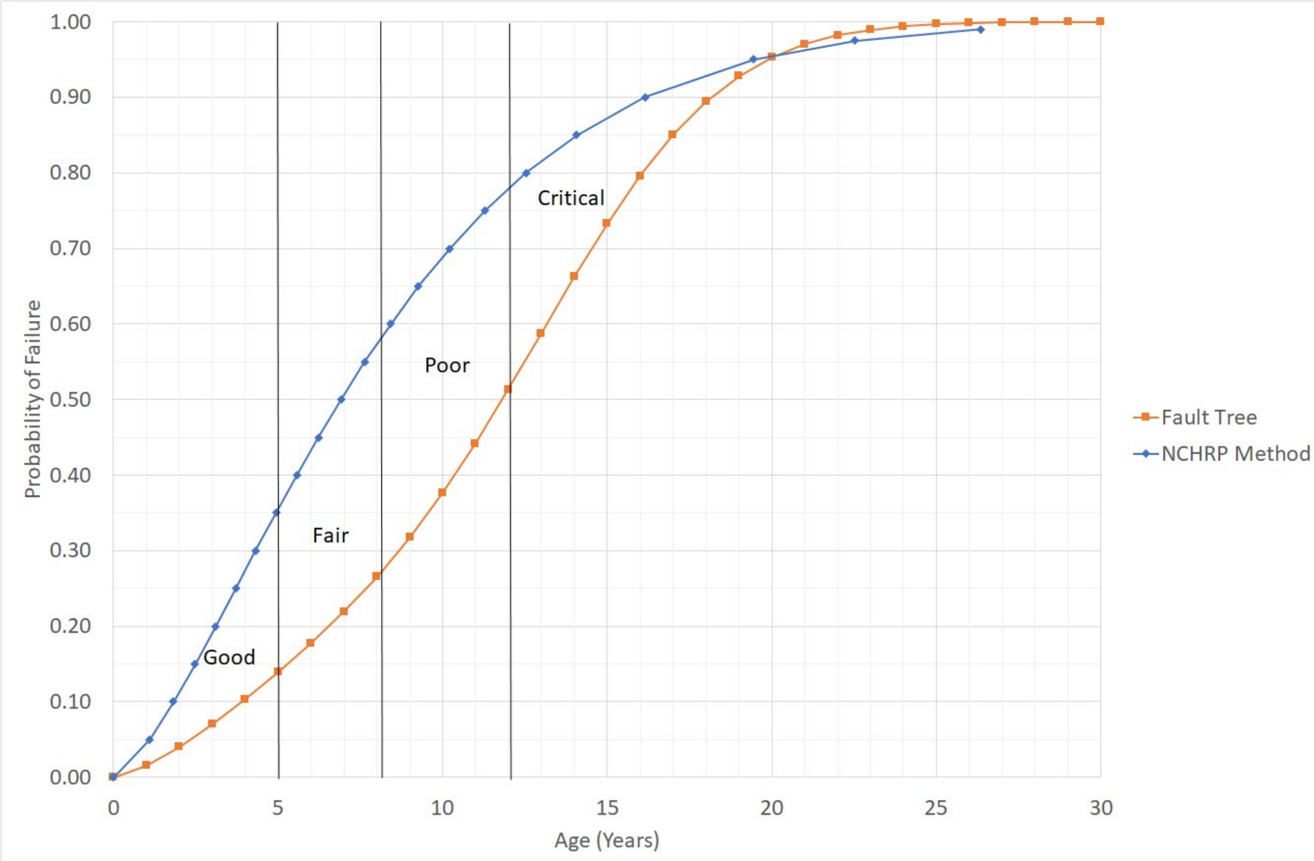



**Figure 56. Chart. Signal controller failure probabilities and assessment categories.**

## Malfunction Management Unit/Conflict Monitor Assessment

Pennsylvania DOT (2020) recommends that malfunction management units (MMUs)/conflict monitors be rotated/tested annually, replacing devices that fail. The project TRP also recommends this practice, and several IDOT districts already use this best practice.

During field assessments, PennDOT also recommended scanning MMUs/conflict monitors for logged events, verifying all indications are sensed, and noting any logged errors. In addition, the make, model, firmware version, and serial number should be recorded (PennDOT, 2020). The project TRP supported these recommendations. Based on these sources of information, the following three assessment methods were recommended, with associated condition levels for each. See Figure 57 to Figure 59.

> Document MMU updates. Document make and model of equipment. Document firmware installed and last date tested (see sticker).

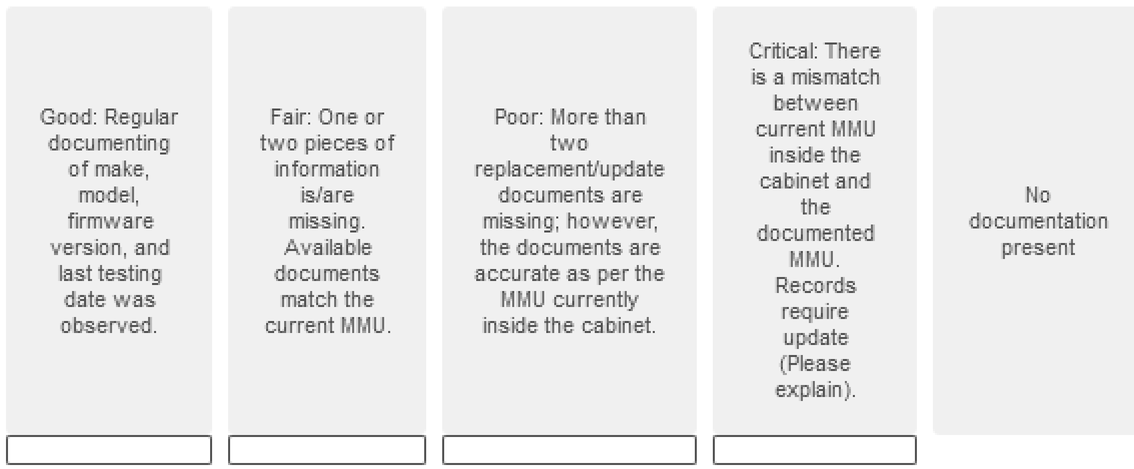



**Figure 57. Illustration. Condition levels for MMUs/conflict monitor documentation.**

Rotate MMU. Document MMU rotation/replacement schedule as appropriate.

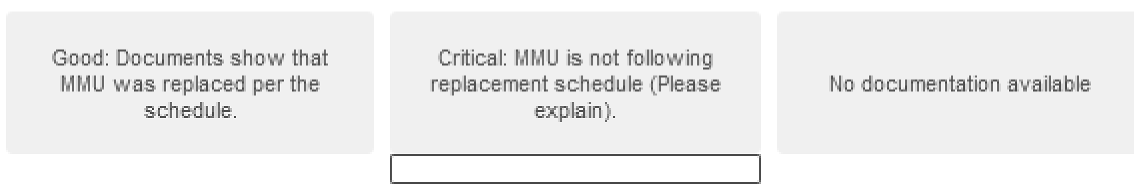



**Figure 58. Illustration. Condition levels of MMU/conflict monitor rotation.**

Inspect operation of MMU. Observe MMU display screen and associated signal phases to verify integration.

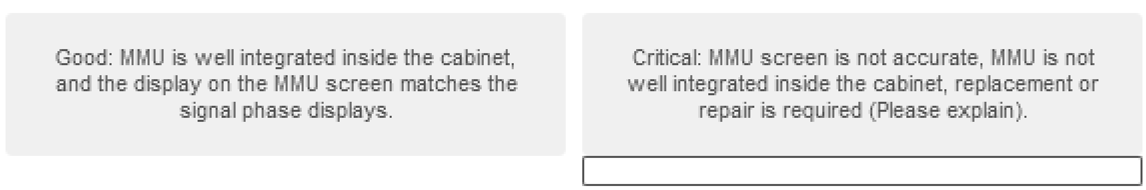



**Figure 59. Illustration. Condition levels for MMU/conflict monitor operation.**

## Signal Head Traffic Control Components

Signal heads/displays are an essential component of the systems because they share information with drivers. When considering the condition of vehicular and pedestrian signal heads, visibility, alignment, lenses, and reflectors should all be assessed.

Pennsylvania DOT (2020) recommends checking the alignment of vehicular signal heads. Assessment includes viewing signals from approximately 150 feet upstream of the stop bar. Signal heads should be angled toward the center of the approach. Similarly, pedestrian signal heads should also be evaluated to ensure good visibility of signal heads (PennDOT, 2020). The project TRP and those interviewed supported these recommendations.

Lamps/LEDs, lenses, and reflectors should be inspected to confirm strong indication to drivers and protective lenses are intact. These components can be visually inspected to identify cracks or other damage. Based on this information, the following assessment method and condition thresholds were recommended for vehicular traffic signal heads (Figure 60), mounting (Figure 61), alignment (Figure 62), pedestrian signal heads (Figure 63), and signal lights and lenses (Figure 64).

Inspect signal heads for cracks or damage**.** Visually, with binoculars, observe all signal heads to identify cracks, breaks, or other damage. This step includes signal housing, backplates, visors, and louvers, as necessary. For displays made of metal, use binoculars (or similar devices) to visually inspect the protective coating for signs of rust.

| | | | |
|---|---|---|---|
| Good, no cracks, breaks, or other damage are visible in the signal heads. If metal, no coating loss or corrosion visible. | Fair, one or more signal heads has coating loss, but not more than minor corrosion. | Poor, one or more signal heads has a visible crack or missing/damaged gasket, moderate corrosion, and/or degraded retroreflectivity on backplate | Critical, several signal heads have cracks or broken attachments and/or significant corrosion is present. |

**Figure 60. Illustration. Condition thresholds for traffic signal heads.**

Inspect mounting of signal heads. Observe mounting hardware that is visible from the ground to identify changes in alignment or signs of looseness/movement. Identify any components that might be missing or heads that are not aligned to traffic.

| | | |
|---|---|---|
| Good, signal heads appear secure, mounting hardware are present and correctly aligned. | Poor, signal heads show slight movement in response to wind, but acceptably aligned and not in danger of falling. | Critical, one or more signal heads show notable movement and alignment is concerning/mounting unsecure. |

**Figure 61. Illustration. Condition thresholds for signal head mounting.**

Inspect vehicular signal head alignment. View signal heads from approximately 150 feet from the stop bar and confirm visibility is clear. Note if any displays have rotated or shifted. Notify the agency immediately of any twisted and/or conflicting signals. If rated critical, poor, or fair, please describe the locations of these issues.

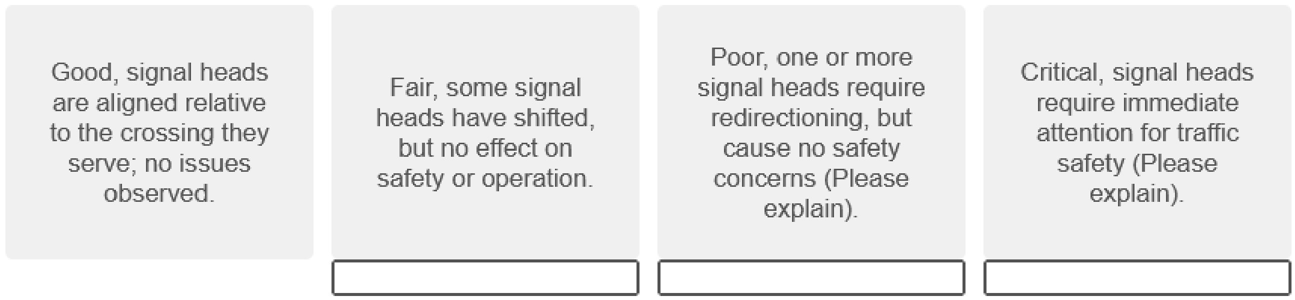



**Figure 62. Illustration. Condition thresholds for signal head alignment.**

Inspect pedestrian signal head alignment. View pedestrian signal heads to confirm they are visible from the opposite side of the crosswalk. Observe performance by activating pedestrian crossing, watching character display, and confirming call ends.

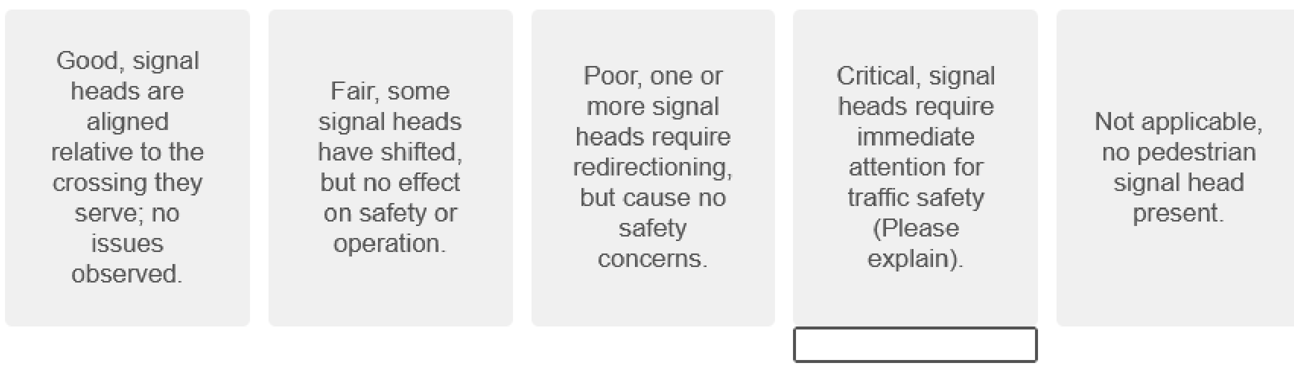



**Figure 63. Illustration. Condition thresholds for pedestrian signal heads.**

Inspect signal lights and lenses. Visually inspect all signal lenses for cracks or other damage.

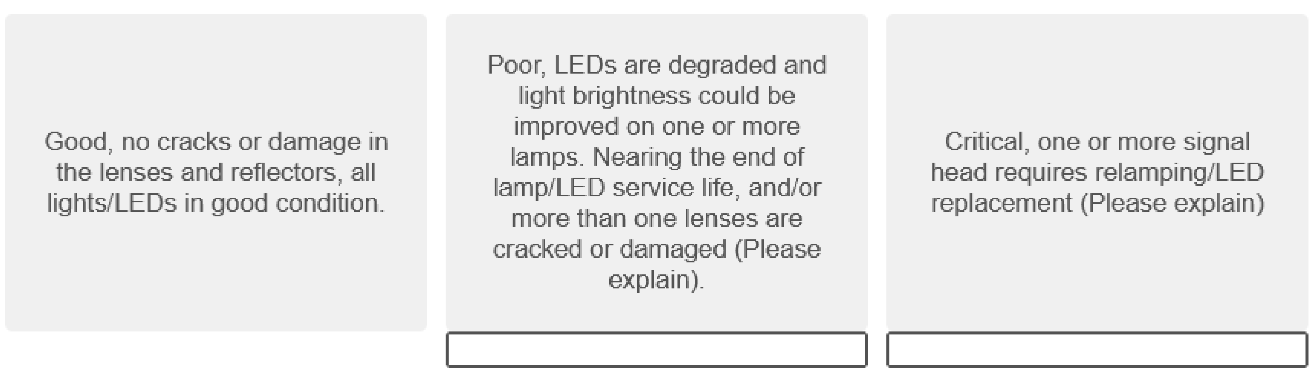



**Figure 64. Illustration. Condition thresholds for signal lights and lenses.**

## Traffic Signal Communication and Detection Assessment

The operation of the signal communication system should be inspected to ensure proper coordination. PennDOT (2020) recommends disconnecting the controller from the master (if applicable) and checking that the signal operates independently. Comments from the TRP indicated this process may create issues if the signal does not reconnect successfully. Based on these different sources of information, the following procedure is recommended with associated condition levels presented in Figure 65.

> Confirm signal coordination. Document type of communication installed. Confirm operation via signal observation.

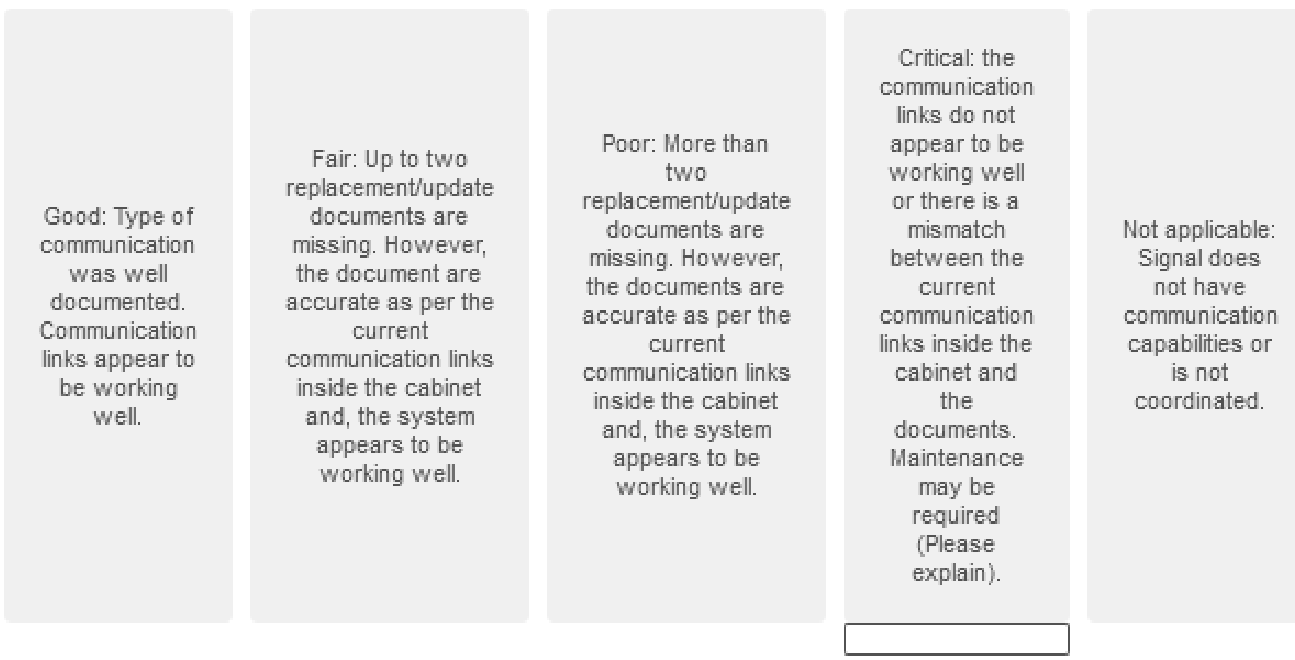



**Figure 65. Illustration. Condition levels for traffic signal communication systems.**

Vehicle detection equipment should be inspected for current operation. Pennsylvania DOT (2020) recommends checking the detector alignment and verifying detection zones are aligned with the lane(s). Based on TRP recommendations, assessment of detection zones was removed to keep the focus on general observation of the signal and traffic detections. The following assessment methods are recommended, with condition levels presented in Figure 66. Note that no condition levels were included for documenting vehicle detection hardware because a textbox is used to collect that information.

> Inspect vehicle detection. Verify actuation of detectors by observing intersection operation and cabinet indications. Update signal documentation as necessary. Consider settings such as sensitivity, pulse/presence, extend/delay, and call holds.

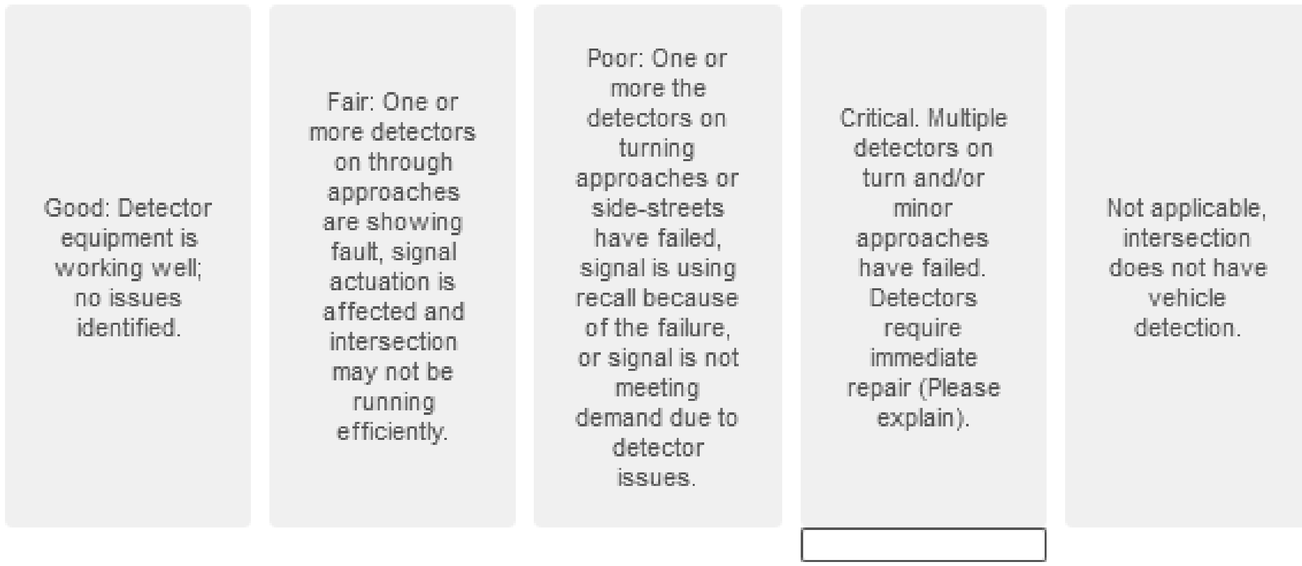



**Figure 66. Illustration. Condition levels for traffic signal vehicle detection.**

Document vehicle detection system hardware, if applicable.

Pennsylvania DOT (2020) recommends verifying the operation of each push button and visually verifying pedestrian signal operation. Input from the TRP and interviewees supported these assessments, and they also recommended checking buttons for tightness and checking pedestrian detector housing for damage or signs of vandalism. The recommended assessment method is described as follows and the condition levels are presented in Figure 67.

> Inspect pedestrian detection. Verify pedestrian signal operations by actuating push buttons and observing signal response. Check each button for tightness, correct audio/visual message, presence of signs, and damage/vandalism that affects operation.

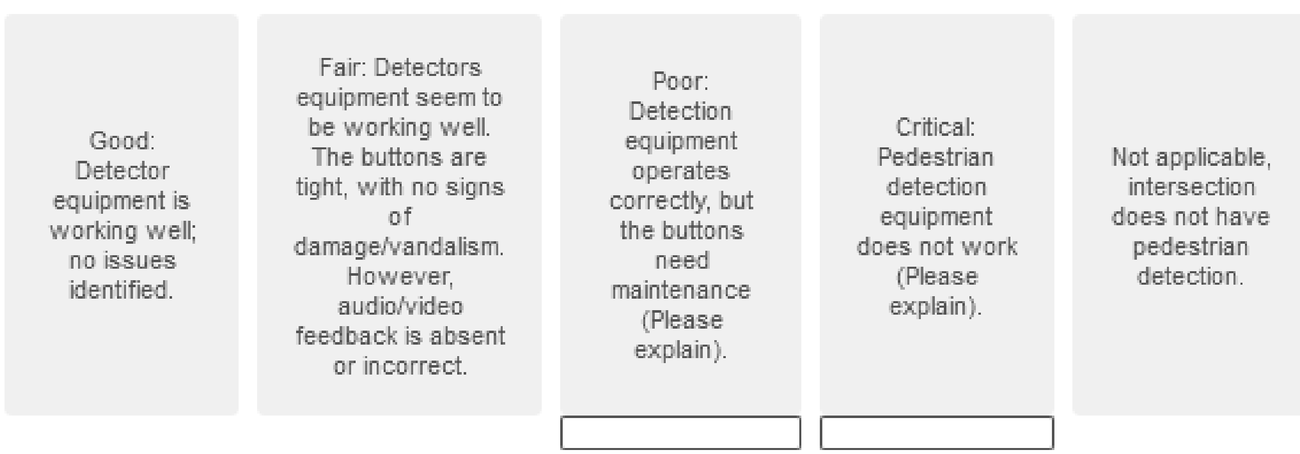



**Figure 67. Illustration. Condition levels for traffic signal pedestrian detection systems.**

## SCORING OF SIGNAL CONDITIONS

Not all traffic signal components have equal importance to the lifespan of the system. The researchers proposed three categories: non-critical, dedicated repairable, and critical. Non-critical traffic signal components are easily repaired, and their failure does not cause safety concerns for travelers. Dedicated repairable traffic signal components are those whose repair is outside the duties of routine maintenance staff, if broken. These components require some planning and scheduling for their repair/replacement and include controller or cabinet changeout. Critical components require lane/intersection closure for replacement and/or require notable in-ground work. These categories of traffic signal components should be scored differently, where critical components have more weight than non-critical components, as presented in Figure 68. The total score for each traffic signal can be used to rank traffic signals relative to the conditions of others. It is expected this ranking can assist in identifying traffic signals whose conditions are more critical to prioritize funding.

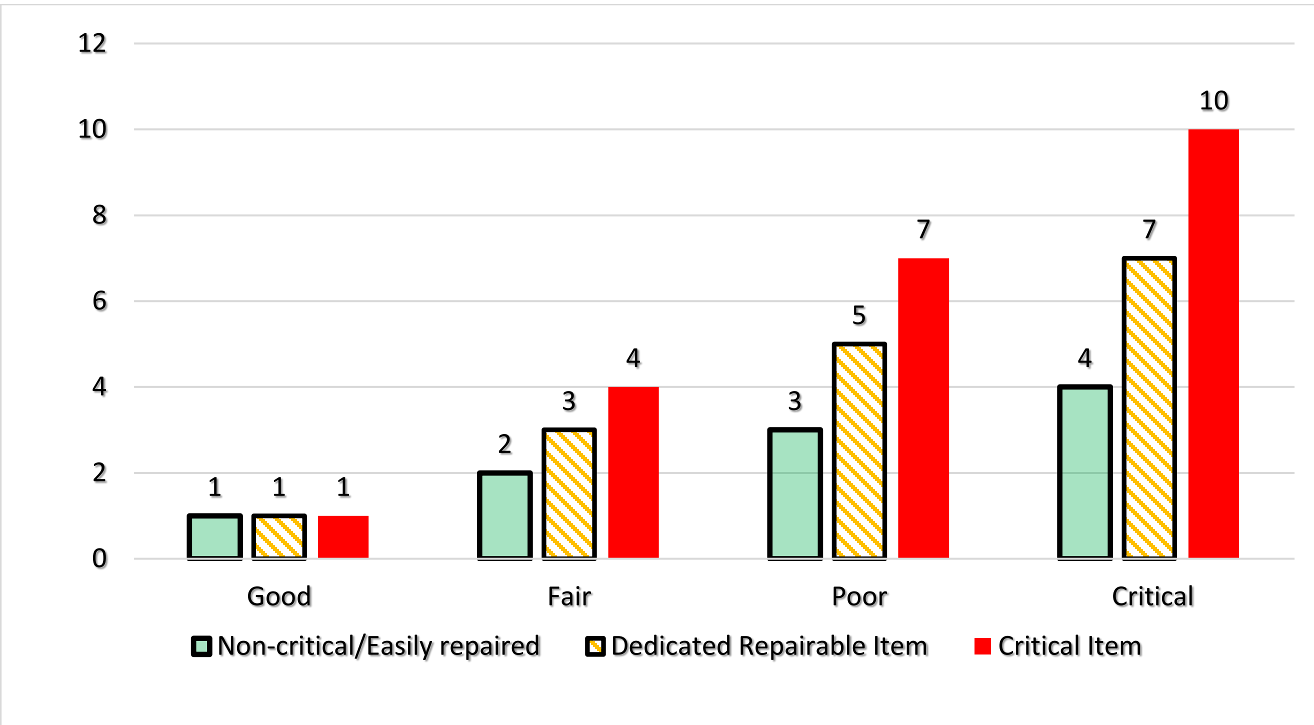



**Figure 68. Chart. Recommended condition scoring.**

The researchers evaluated each traffic signal component and categorized each as non-critical, dedicated-repairable, or critical. Some components were omitted from this categorization because information was collected for inventory or documentation purposes. For example, scoring is not recommended for introductory questions, special operations features present, or for MMU documentation. Table 10 shows the recommended category for each assessed component.

**Table 10. Traffic Signal Component Categories**

| Traffic Signal Component | Category |
|---|---|
| Inspect grout pads, shrouds and/or rodent screens | Non-critical |
| Inspect signal heads for cracks or damage | Non-critical |
| Inspect signal lights and lenses | Non-critical |
| Inspect conduit bushings (if used) | Non-critical |
| Inspect cabinet base and weatherproofing | Non-critical |
| Inspect drain at pole bases | Dedicated repairable |
| Inspect transformer bases | Dedicated repairable |
| Inspect junction boxes and handholes | Dedicated repairable |
| Identify presence of exposed conduit | Dedicated repairable |
| Inspect mounting of signal heads | Dedicated repairable |
| Inspect vehicular signal head alignment | Dedicated repairable |
| Inspect pedestrian signal head alignment | Dedicated repairable |
| Inspect grounding system | Dedicated repairable |
| Inspect condition of power connection | Dedicated repairable |
| Inspect cabinet exterior | Dedicated repairable |
| Inspect cabinet anchoring and doors | Dedicated repairable |
| Note age of controller | Dedicated repairable |
| Rotate MMU | Dedicated repairable |
| Inspect operation of MMU | Dedicated repairable |
| Confirm signal coordination | Dedicated repairable |
| Inspect vehicle detection | Dedicated repairable |
| Inspect pedestrian detection | Dedicated repairable |
| Inspect pole and post foundations | Critical |
| Inspect ground around foundation | Critical |
| Inspect base plates and coating condition | Critical |
| Inspect the connection between the foundation and base plate | Critical |
| Inspect bolted aerial connections of mast arms | Critical |
| Inspect welded aerial connections | Critical |
| Inspect poles and posts for plumbness | Critical |
| Inspect poles and posts for dents/damage | Critical |
| What is the condition of the wood pole? | Critical |
| Inspect mast arms | Critical |
| Inspect span wire connection to pole | Critical |
| Inspect span wire tension and condition | Critical |

# CHAPTER 4: IMPLEMENTATION RECOMMENDATIONS

This chapter describes three key recommendations. These include how to implement the proposed condition assessment procedures and options for recovering value from used traffic signal equipment. This chapter also summarizes traffic signal maintenance and management practices identified during the study.

## IMPLEMENTING CONDITION ASSESSMENT

It is recommended that the traffic signal assessment procedures presented in the previous chapter are completed annually. Scheduling the assessments should be done in coordination with regular maintenance activities. If a location has painted structures, scheduling should also coordinate with painting activities. Each IDOT district can create their own plan for these annual assessments on state-owned traffic signals. Signal Maintenance Provisions should be used to encourage annual assessment of traffic signals owned by local municipalities. Recommended changes to the current maintenance provisions template are included in Appendix G.

It is recommended that IDOT create an enterprise-based system to collect the data from traffic signal condition assessments. The user interface should be simple and similar to an online survey. The collected information and pictures should be stored and organized using a database format. A database would enable sorting and manipulation of the collected data. Consideration should also be given to integrating traffic signal condition assessments with other asset management systems used by the agency.

Personnel conducting the traffic signal condition assessment should have a cursory understanding of the components, maintenance, and operation of these systems. Training needs are minimal, but should include reviewing the assessment tool, watching the introduction video, viewing the pictures of example condition levels, and asking questions. It is recommended that personnel complete the assessment using a wirelessly connected tablet that can record pictures. A hard copy of the assessment can also be completed, but condition levels and pictures should be submitted electronically afterwards, in a timely manner. A list of tools recommended for traffic signal condition assessment is described in Table 11.

To guide the use of in-depth inspection of aerial welds, the researchers have proposed procedures for using drones and cameras on telescoping poles. Those recommendations are included in Appendix H.

**Table 11. Recommended Assessment Tools**

| Recommended Tool | Purpose |
|---|---|
| Binoculars | Observing aerial structures and signal heads |
| Rubber mallet | Testing bolts |
| 16-oz hammer | Sounding metal components |
| Small rebar/metal bar | Probing ground around foundations as needed |
| Tablet (with internet connectivity and ability to take pictures) or clipboard (with assessment questions and a camera) | Recording signal conditions |
| Wrench | Testing anchor bolts |
| Hay hook | Opening hand holes/junction boxes |
| Camera on telescoping pole/drone/bucket truck | Assessing older welds on aerial structures |
| Tape measure | Measuring dents |
| Surveying pole | Measuring clearance, as-needed |
| Drill bits | Enable removal of pole bolt covers |

## COST-RECOVERY OPTIONS

The ITE *Traffic Signal Maintenance Handbook* recommends inventory guided by "accurate documentation of field configurations, accurate inventory of field deployed components, and up-to-date stock room inventory listing." Such a method can enable tracking of a component's life cycle (ITE, 2023). Toward that end, PennDOT created an internet-accessible database to collect and maintain traffic signal asset records statewide. Instead of each district/municipality keeping independent and isolated records, the new statewide system will aid municipal budgeting and planning, help identify trends in asset needs, and support performance tracking of signal components (PennDOT, 2020).

One specific example of coordinated salvage recovery is Missouri DOT's (MoDOT's) St. Louis District "Reuse or Recycle" practice with recovered signal equipment. In cases of a project that will remove a signal installation, signal maintenance will work with the project team to identify any items they can reuse. Components with useful service life remaining such as cabinets, controllers, and MMUs are itemized in the contract to be delivered by the contractor to the signal maintenance facility. Those components are then reused in regular maintenance operations. In some cases where structural items are in recent condition and there is room at the facility to store the items, mast arms and poles will be tagged for delivery. These items are used for emergency structural repairs, but given the large space required and rare usage, only a limited amount is ever reclaimed. Any other items not identified for reuse are left for contractor disposal. Structural items and cabinets are frequently "recycled," along with any other items with significant dollar value such as copper cables.

The practice of reclaiming every valuable component for resale in a secondary market (such as govdeals.com) has not been found economically feasible. Although some items may have resale value, the overall cost of storage, packaging, and advertising usually exceeds the item's value and is no longer a typical practice in MoDOT. An example of contractual language for reclaiming items is shown as follows:

DISPOSITION OF EXISTING SIGNAL/LIGHTING EQUIPMENT

**Description.** The existing signal/lighting equipment located at Station _____________ and listed below shall be removed by the contractor and transported to the District's maintenance lot located at 123 Example St., Springfield, IL 62703. The contractor shall notify the District's representative 24 hours prior to each delivery by calling ___________ at 217-_______ or call 309-_______ and ask for the field traffic supervisor. The contractor shall exercise reasonable care in the handling of the equipment during removal and transportation. Should any of the equipment be damaged by the contractor's negligence, it shall be replaced at the contractor's expense. The contractor shall dispose of any other equipment not listed below. Delivery of the listed items shall be within 2 working days of removal. All items returned shall be tagged with the date removed, project number and location/intersection.

| Item | Location | Serial No. (if available) |
| --- | --- | --- |

**Basis of Payment.** This work will be considered included in the contract unit price for Removal of Improvements.

## TRAFFIC SIGNAL MANAGEMENT BEST PRACTICES

Throughout the study, researchers have been identifying and documenting best practices for traffic signal maintenance and management. The following text summarizes these recommendations.

Operating a MMU testing and rotation program was a best practice used by several districts and agencies. The MMU is responsible for identifying malfunctions in traffic control systems and changing signal operation to flash when danger exists. It is recommended to test the conflict monitor using a computerized conflict monitor tester and replace the monitor if it fails. A MMU rotation program can be established to allow testing off-site. When assessing a traffic signal's condition, the MMU rotation should be completed or confirmed, then the conflict monitor's indications can be observed to verify all indications are sensed properly.

Findings indicate that bolt covers/shrouds should be removed from the bases of traffic signal mast arm poles. These covers can trap moisture, accelerate corrosion, and prevent clear condition assessment. Instead, it was recommended these connections be uncovered, cleaned, and treated with corrosion protection and/or anti-seize. When removing shrouds, installation of rodent screen may be required.

Each traffic signal should be assessed and maintained at least once per year. Although most interviewed agencies already meet or exceed this practice, some only visit traffic signals if there are reported issues, and others do not have a consistent time frame. Signal structures that are assessed frequently by DOTs can better ensure safe and effective performance. Signal structure inspection intervals vary from every four years (VDOT, 2014) to five years (Minnesota DOT, 2020). The interval for overall traffic signal inspection varied widely, from weekly to every four years. One-year intervals are used by MnDOT; the City of Ontario, California; Utah DOT; and the City of Columbus, Ohio (Minnesota DOT, 2020).

Cleaning and inspecting the traffic signal cabinet was a recommended practice of several agencies. Some recommended using a leaf blower to remove dust, leaves, and other debris collected inside the traffic signal cabinet. During this maintenance, it was recommended that the conduits terminating in the cabinet be sealed to prevent water, dust, and other materials entering the cabinet that might contaminate the conduits. Sealing these conduits can help in maintaining the functionality of the cabinet components, prevent rodent access, and limit water intrusion from any uphill conduit.

# CHAPTER 5: CONCLUSIONS

This study analyzed traffic signal systems and identified which components should be assessed or documented. The recommendations included assessment procedures for 34 traffic signal components. Each assessment method was developed based on previous research, practices of other state departments of transportation, and tailored to meet the needs of traffic signal infrastructure in Illinois. In addition, 145 condition levels were created to describe different stages of decay expected for each component. When condition descriptions included subjective terms (e.g., moderate corrosion), example pictures were included.

The developed procedures and condition levels support consistent evaluation of traffic signals throughout Illinois, provide a systematic process for public agencies to identify components in critical condition, and create the foundation for including traffic signals into asset management frameworks. First, consistent evaluation is important because districts and local municipalities followed differing traffic signal management practices, had varying levels of institutional knowledge about traffic signals, and operating environments ranged from dense urban to rural. Second, it is essential for Illinois transportation agencies to share a common definition of signal condition levels. This study found notable differences in acceptable component conditions. Applying common condition levels will promote consistent and accurate assessment of traffic signal existing conditions throughout the state. Last, the recommendations of this study are foundational to better management of traffic signals. Public agencies that operate traffic signals in Illinois can apply the recommended methods to identify the current state of these systems and build inventories of the devices present. This information can be used to prioritize the repair/replacement of traffic signal components in critical and poor condition.

In the long term, implementing these recommendations can support the inclusion of traffic signals into asset management programs, such as those used for bridges and pavement. With more-informed management, traffic signal performance can improve due to reduced failures related to poor component conditions. Improved traffic signal performance is expected to reduce traffic signal life-cycle costs, increase traffic signal performance, and improve safety for the traveling public.

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# APPENDIX A: EXPECTED LIFESPANS OF SIGNAL COMPONENTS

**Table 12. Expected Life of Pole, Mast Arm, and Span Wire Assembly**

| Signal Component | Expected life, years (Source) |
|---|---|
| Pole and Mast Arm | 20 (PennDOT, 2020) |
| | 25 (Indiana DOT response, (Minnesota DOT, 2020), (Kloos & Bugas-Schramm, 2005) |
| | 30 (Ontario Ministry of Transportation response, (Minnesota DOT, 2020), (Colorado DOT, 2016) |
| | Tubular Steel: 10-50, average 24.6<br>Tubular Aluminum: 20-35, average 24.3 (Markow, 2008) |
| Span Wire | with a wooden pole: 2-30, average 15.1 (Markow, 2008) |
| | With steel pole:<br>2-30, average 15.1 (Markow, 2008)<br>20 (PennDOT, 2020) |
| | with Concrete pole: 2-30, average 15.1 (Markow, 2008) |

**Table 13. Expected Life of Signal Cabinet**

| Signal Component | Expected life, years (Source) |
|---|---|
| Cabinet | 20 (Colorado DOT, 2016), (Ontario Ministry of Transportation response, (Minnesota DOT, 2020)) |
| | 15 (Indiana DOT response; Minnesota DOT, 2020) |
| | 10-30, average 18 (Markow, 2008) |

**Table 14. Expected Life of Light-Emitting Diodes**

| Signal Component | Expected life, years (Source) |
|---|---|
| Lamps (Light Emitting Diodes – LED) | 8-9 (Connecticut DOT, 2019) |
| | 5 (Ontario Ministry of Transportation response (Minnesota DOT, 2020)), (Institute of Transportation Engineers and International Municipal Signal Association, 2010) |
| | 5-10, average 7.2 (Markow, 2008) |

**Table 15. Expected Life of Signal Heads**

| Signal Component | Expected life, years (Source) |
|---|---|
| Traffic Signal Head | 7-30, average 18.8 (Markow, 2008) |
| | 10 (Ontario Ministry of Transportation response, (Minnesota DOT, 2020)) |
| Pedestrian Signal Head | 15 (Markow, 2008) |

**Table 16. Expected Life of Other Signal Components**

| Signal Component | Expected life, years (Source) |
|---|---|
| Signal Timing | 3-5 (Remias et al., 2018) |
| Traffic Loop Detector | 14 (Minnesota DOT, 2019) |
| | 7.5 (PennDOT, 2020) |
| | 3-20, average 8.6 (Markow, 2008) |
| Communication Cable | Fiber Optic, 20-30, average 23.6<br>Twisted Copper, 10-30, average 17.5 (Markow, 2008) |
| | Fiber Optic, 20; Twisted Copper, 20 (PennDOT, 2020) |
| Cabinet Filter | 1 (Minnesota DOT, 2019) |

# APPENDIX B: EXAMPLE REACTIVE TRAFFIC SIGNAL MAINTENANCE

**Table 17. Reactive Maintenance for Traffic Signal Supports**

| Component | Business Hours Response Intervals (hours) | Non-Business Hours Response Intervals (units) | Temporary Repair Intervals (units) | Final Repair Intervals (units) |
|---|---|---|---|---|
| Support Structures (Mast Arm, Strain Poles, Pedestals, or Wood Poles) | 2 | 4 (hours) | 24 (hours) | 30 (days) |
| Span Wire | 2 | 4 (hours) | – | 24 (hours) |
| Foundation | 2 | 4 (hours) | 24 (hours) | 30 (days) |
| Anchor Bolts | 2 | 4 (hours) | 24 (hours) | 30 (days) |
| Guy Wire | 2 | 4 (hours) | 24 (hours) | 30 (days) |
| Grounding/Bonding | 2 | 4 (hours) | 24 (hours) | 30 (days) |
| Pedestrian Stub Pole | 24 | 72 (hours) | 24 (hours) | 30 (days) |
| Mounting Hardware | 24 | 72 (hours) | 24 (hours) | 30 (days) |
| Tether Wire | 24 | 72 (hours) | 24 (hours) | 30 (days) |
| Hand Hole Covers | 24 | 72 (hours) | 24 (hours) | 30 (days) |

***Source: PennDOT (2020)***

**Table 18. Reactive Maintenance for Controller Assembly**

| Component | Business Hours Response Intervals (hours) | Non-Business Hours Response Intervals (hours) | Temporary Repair Intervals (hours) | Final Repair Intervals (units) |
|---|---|---|---|---|
| Local Controller | 2 | 4 | 24 | 30 (days) |
| Conflict Monitor | 2 | 4 | – | 24 (hours) |
| Flasher Unit | 2 | 4 | 24 | 30 (days) |
| Load Switches | 2 | 4 | 24 | 30 (days) |
| Power Supply | 2 | 4 | 24 | 30 (days) |
| Relays | 2 | 4 | 24 | 30 (days) |
| Radio Frequency Interference (RFI) | 2 | 4 | 24 | 30 (days) |
| Surge Protection | 2 | 4 | 24 | 30 (days) |
| Grounding | 2 | 4 | 24 | 30 (days) |
| Traffic Optimization Processor (adaptive) | 2 | 4 | 24 | 30 (days) |
| Cabinet | 48 | 72 | 24 | 30 (days) |
| Time Clock | 48 | 72 | 24 | 30 (days) |

***Source: PennDOT (2020)***

**Table 19. Reactive Maintenance for Systems and Communication**

| Component | Business Hours Response Intervals (hours) | Non-Business Hours Response Intervals (hours) | Temporary Repair Intervals (hours) | Final Repair Intervals (days) |
|---|---|---|---|---|
| Master Controller | 24 | 72 | 24 | 30 |
| Time-Based Coordinator Unit | 24 | 72 | 24 | 30 |
| Modem | 24 | 72 | 24 | 30 |
| Ethernet/Ethernet Bridge | 24 | 72 | 24 | 30 |
| Managed Network Switch | 24 | 72 | 24 | 30 |
| Transmitter/Receiver | 24 | 72 | 24 | 30 |
| Antennas | 24 | 72 | 24 | 30 |
| Cables/Connections | 24 | 72 | 24 | 30 |
| Mounting Hardware | 24 | 72 | 24 | 30 |
| Server | 24 | 72 | 24 | 30 |
| Systems Software | 24 | 72 | 24 | 30 |
| Communications System | 24 | 72 | 24 | 30 |

***Source: PennDOT (2020)***

**Table 20. Reactive Maintenance for Electrical Distribution**

| Component | Business Hours Response Intervals (hours) | Non-Business Hours Response Intervals (hours) | Temporary Repair Intervals (hours) | Final Repair Intervals (units) |
|---|---|---|---|---|
| Wire and Cable | 2 | 4 | - | 24 (hours) |
| Electrical Service | 2 | 4 | 24 | 30 (days) |
| Wire Connectors | 2 | 4 | - | 24 (hours) |
| Ground Bushings and Lugs | 2 | 4 | 24 | 30 (days) |
| Ground Rods | 2 | 4 | - | 24 (hours) |
| Generator Adaptor Kit | 2 | 4 | 24 | 30 (days) |
| Battery Back-up/UPS | 2 | 4 | 24 | 30 (days) |
| Conduit | 48 | 72 | 24 | 30 (days) |
| Junction Boxes | 48 | 72 | 24 | 30 (days) |
| Service Receptacle | 72 | 72 | 24 | 30 (days) |

***Source: PennDOT (2020)***

**Table 21. Reactive Maintenance for Traffic Signal Heads**

| Component | Business Hours Response Intervals (hours) | Non-Business Hours Response Intervals (hours) | Temporary Repair Intervals (hours) | Final Repair Intervals (units) |
|---|---|---|---|---|
| Signal Housings | 2 | 4 | – | 24 (hours) |
| Vehicle and Pedestrian Indications | 2 | 4 | – | 24 (hours) |
| LED Indication Visibility – caused by snow buildup in housing | 2 | 4 | – | 24 (hours) |
| Optically Programmed Signal Heads | 2 | 4 | – | 24 (hours) |
| Lane Use Control Signal Heads | 2 | 4 | – | 24 (hours) |
| Backplates | 48 | 72 | 24 | 30 (days) |
| Mounting Hardware | 24 | 72 | 24 | 30 (days) |

***Source: PennDOT (2020)***

**Table 22. Reactive Maintenance for Traffic Detectors**

| Component | Business Hours Response Intervals (hours) | Non-Business Hours Response Intervals (hours) | Temporary Repair Intervals (hours) | Final Repair Intervals (days) |
|---|---|---|---|---|
| Sensor Amplifier | 2 | 4 | 24 | 30 |
| Vehicle Detection System (Loop, Video) | 2 | 4 | 24 | 30 |
| Pedestrian Push Buttons | 48 | 72 | 24 | 30 |
| Accessible Pedestrian Signals (APS) | 48 | 72 | 24 | 30 |
| Emergency Vehicle Preemption Systems | 48 | 72 | 24 | 30 |
| Railroad Preemption System | 2 | 4 | 24 | 30 |
| Ramp and Queue Preemption System | 2 | 4 | 24 | 30 |
| Transit Priority Systems | 48 | 72 | 24 | 30 |
| Adaptive System – response to automated trigger alarm (for the failure of an adaptive system component: detectors, communications, hardware, or software) | 2 | 4 | 24 | 30 |

***Source: PennDOT (2020)***

**Table 23. Highways England Maintainability Metrics**

| No. | Metric Description | Performance Category 1 - Urgent Resolution Faults | Performance Category 2 - Service Affecting Faults | Performance Category 3 - Other Faults |
|---|---|---|---|---|
| 1 | Percentage of faults restored within 56 days. | 100% | 100% | 100% |
| 2 | Percentage of faults restored within 168 hours. | 100% | 100% | – |
| 3 | Percentage of faults restored within 48 hours. | 100% | 100% | – |
| 4 | Percentage of faults restored within 24 hours. | 100% | 80% | – |
| 5 | Percentage of faults restored within 12 hours. | 100% | 60% | – |
| 8 | Number of Assessment Periods where no more than 4 faults can occur against any individual asset. | 1 Assessment Period | 1 Assessment Period | 2 Assessment Periods |
| 10 | Average availability for all assets in the Performance Category within an Assessment Period. | 99.99% | 99.9% | 97.5% |

***Source: McKay & Senesi (2022)***

# APPENDIX C: ESTIMATING REPLACEMENT AGE

The development of a regression model using age at replacement as the dependent variable is one strategy if the objective is a direct model of age at replacement. A contract management system or maintenance management system that provides the age or year of construction of the asset that was taken out of service, records of asset demolition combined with archived inventory records for the demolished assets, archived inventory records that specifically state the date the asset was taken out of service and new assets that have the exact location tag or identification number as the assets they replace are all potential sources of data.

The potential for bias brought on by an effect known as "censoring" is one of the drawbacks of using regression models for life expectancy. The regression model calculates the average age at replacement based on previous replacements. However, given that some of the assets that should be in the dataset have uncertain future replacement dates, the analyst is "censored" from seeing these substitute dates.

The left side of Figure 69 presents a list of assets with varying dates for their acquisition and disposal. Since several of these assets will still be in use at the time of the research, their eventual disposal dates will be unclear. A normal probability distribution of replacement age is seen on the right side. There will be an imbalance between early and late replacements in a data collection that includes all previous replacements from this group. As a result, the normal probability distribution's right side is omitted. The average calculated from this dataset will be skewed toward a lower life expectancy than the actual value.

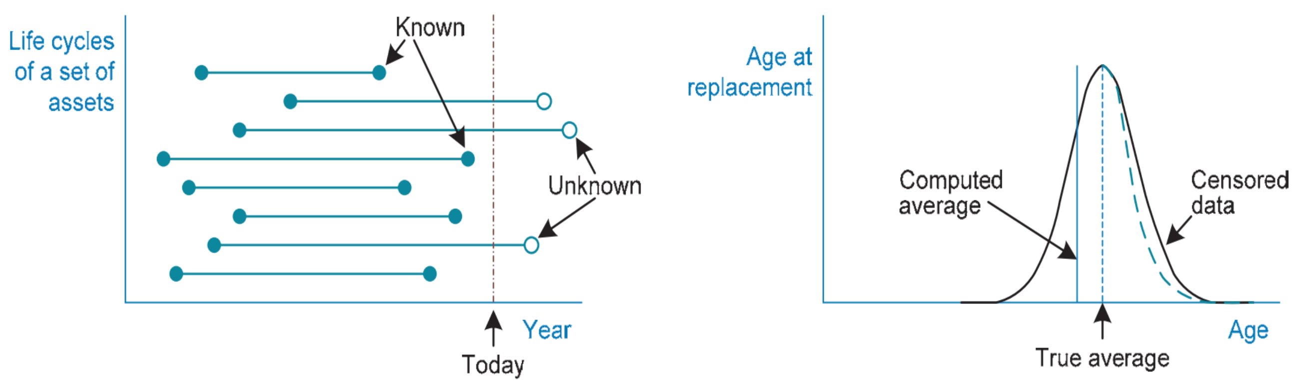


**Figure 69. Graph. Problems with regression models.**

***Source: Thompson et al. (2012)***

One of the first methods for modeling degradation is deterministic models. These models explicitly predict the condition measure's most probable value as a function of age and other explanatory factors using a straight or curved line determined by a regression procedure. Figure 70 presents an example of a non-linear regression curve for deterioration.

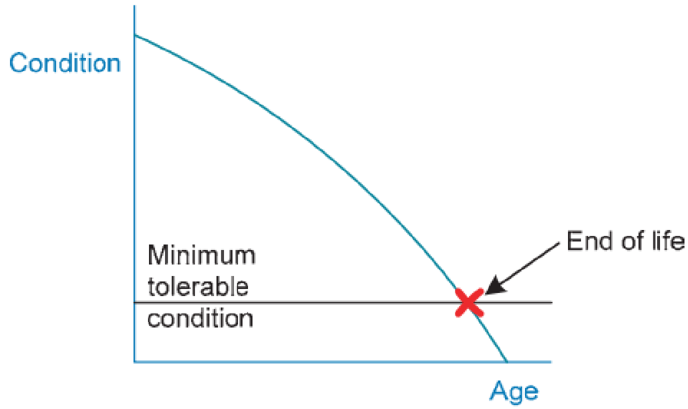


**Figure 70. Chart. Regression-based deterioration model.**

***Source: Thompson et al. (2012)***

A standard equation for the deterioration curve is presented in Figure 71, where $p_t$ is the performance at time t; $p_0$ is initial performance; $p_f$ is terminal performance; t is the year of the forecast; ρ is lifespan, and α is the shaping parameter.

$$p_t = p_0 - (p_0 - p_f)\left(\frac{t}{\rho}\right)^{\alpha}$$

**Figure 71. Equation. Performance-based equation for deterioration curve.**

***Source: Thompson et al. (2012)***

The basic model is simple to design because it has no explanatory variables. Any life expectancy model may yield an estimate of lifespan, which may depend on independent variables. The shaping parameter may be calculated using linear regression if the lifespan is known.

## MARKOV MODEL

In contrast to regression models, the Markov model takes an entirely different approach. A Markov model defines end-of-life in terms of the condition rather than action. A few condition states describe the whole spectrum of potential asset circumstances.

To apply a condition state rating method, define "failed" as the worst possible condition state in a Markov life expectancy model. It is important to note that this only sometimes implies that a structure has collapsed or that its condition obstructs traffic. It can indicate that an asset in the poorest possible condition is a good candidate for replacement. A life-extension strategy like rehabilitation might also be a good fit for it. In addition to "failed," there may be a variety of other condition states. There might be one more state, "not-failed," in the simplest scenario. Identifying more than three or four states may be challenging when condition data are acquired using visual inspection approaches.

The Markov model adds a few extra assumptions based on the discrete condition state idea:

- The state is assessed regularly, such as once a year.
- A unit of the asset either stays in the same condition state for a single interval or changes to one of the other defined states. There are no intermediate states seen.
- The likelihood of moving from one state to another is always the same.

Steps for determining median life expectancy:

- Consolidate the states into only two categories—failed and not failed—starting with a list of prior condition state inspections. When a junction was inspected in 2007 with 25% of the signal heads in state 1, 25% in state 2, 25% in state 3, and 25% in state 4 (the "failed" state), for example, if traffic signals are assessed on a four-state scale, then consider this inspection to be 75% not-failed and 25% failed.
- Pair the facility inspections, each with a one-year gap between them. Each pair, therefore, compares the state before and after a year.
- Any pairs suspected of having received life extension work should be removed from the list of pairs. If maintenance records are available, they may be used to make this conclusion, or it may be based on an improvement in condition (i.e., where the percentage not-failed increased from before to after). Most likely, some form of replacement or life extension work was done on these signal installations.
- Calculate the average percent failed and not failed for the before case and once more for the after case for the whole list of inspection pairings. The inventory condition before and after the one year when no action was taken is compared to provide a measure of condition.
- Using the non-failed percent after and the non-failed percent before, calculate the likelihood of remaining in the non-failed state. Call this the "same-state" probability. The same-state probability is one minus the degradation probability.
- The median life expectancy is readily computed as presented in Figure 72*,* where t is the median life expectancy and $p_{jj}$ is the same-state probability.
- The inspection interval can be represented in terms of intervals and converted to years if not one year (it must be of some consistent length). For instance, multiplying t by 2 indicates life expectancy in years if the examination interval is every two years. Substitute 0.5 with the required threshold in this calculation, such as 5%, if the 50% threshold of the failed condition is too high (for instance, if planning a blanket replacement project for an asset type where failure presents a public safety threat).

$$t = \frac{\log(0.5)}{\log(p_{jj})}$$

**Figure 72. Equation for Markov model-based median life expectancy.**

***Source: Thompson et al. (2012)***

Due to the collapse of condition states, which necessitates the assumption that all assets in the not-failed state are equally likely to fail in the next year, this strategy is described as "quick and easy." This conclusion is improved by using a Markov model for the whole collection of condition states since only the assets in the second-to-last condition state are susceptible to possibly reaching the worst state in the upcoming year. It will be several years before a large number of the not-failed assets fall into the worst condition state if they are now concentrated in the best condition level. As a result, estimates of life expectancy produced using a fully developed Markov model may be more accurate than those generated using the simple and rapid technique.

## WEIBULL SURVIVAL PROBABILITY MODEL

Markov model assumes that the rate of deterioration does not increase with age. It is considered a weakness of the Markov model. The Markov model can be easily transformed into a "Weibull survival probability" model by including age dependency. Figure 73 presents the functional form of the Weibull curve, where $y_{1g}$ is the probability of the not-failed state at age g if no intervening maintenance action is taken between year 0 and year g; β is the shaping parameter, which determines the initial slowing effect on deterioration (e.g., when the galvanized coating is performing well); and $\alpha$ is the scaling parameter.

$$y_{1g} = \exp\left(-1.0 \times (g/\alpha)^{\beta}\right)$$

**Figure 73. Equation. Equation for Weibull curve.**

***Source: Thompson et al. (2012)***

Higher shaping parameters slow the pace of degradation, but it eventually picks up speed as the facility ages. Maximum likelihood estimation, a structured trial-and-error technique to experiment with different beta values until the best fit to the data is obtained, can be used to estimate the shaping parameter. Figure 74 presents the estimation of Weibull model parameter *alpha,* where t is the median life expectancy from the Markov model, as calculated in the preceding section.

$$\alpha = \frac{t}{(\ln 2)^{1/\beta}}$$

**Figure 74. Equation. Alpha for Weibull model.**

***Source: Thompson et al. (2012)***

Perform each step outlined in the section above for the Markov model, but with the following additions to create the Weibull model:

- When dividing the assets into pairs in Step 2, note the age of each asset at the time of the second inspection.
- In Step 3, while filtering pairings, maintain track of the deleted pairs.

Remove from the dataset the pairings where work may have been done and all subsequent pairs for those assets after calculating the Markov model's life expectancy. Since the Weibull model is a time-series study, inspection data for ages at least as high as the Markov median life expectancy are required. The study is most effective on assets when doing life extension work before the median life expectancy is uncommon.

## COX SURVIVAL PROBABILITY MODEL

The Cox proportional hazard model is very similar to a Weibull survival probability model but incorporates a multiplier to the survival probability to account for explanatory variables. Figure 75 presents the equation for the Cox model.

$$y_{1g} = \exp\left(-1.0 \times (g/\alpha)^{\beta}\right) \times \exp\left(b_1 X_1 + b_2 X_2 + \cdots + b_n X_n\right)$$

**Figure 75. Equation. Cox Survival probability model.**

***Source: Thompson et al. (2012)***

When applying the Cox mode, $y_{1g}$ is the probability of the not-failed state at age g if no intervening maintenance action is taken between year 0 and year g; β is the shaping parameter; and α is the scaling parameter, calculated as for the Weibull model. The variables $X_n$ are explanatory variables such as traffic volume or location. They can be continuous variables or 0/1 flags. The coefficients $b_n$ are determined by linear regression or can be estimated simultaneously as the Weibull shaping parameter. The multiplier can shift the survival probability either upward or downward. If all the explanatory variables are zero, then the multiplier has no effect.

# APPENDIX D: TRAFFIC SIGNAL MAINTENANCE INTERVALS

**Table 24. Interval-Based Preventative Maintenance for Traffic Signal Supports**

| **Traffic Signal Supports (Mast Arms, Strain Poles, Pedestal Poles, Pedestrian Stub Poles)** | **Maintenance Intervals** | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Check paint condition and corrosion | | X |
| Check for obstructions in the drain at the pole base (clear drainage holes in pole bases if present) | | X |
| Inspect foundations for damage | | X |
| Inspect the foundation and base plate connection | | X |
| Verify that leveling nuts are in a snug-tight condition with the bottom of the base plate. Snug-tight is defined as the full force of a person on a 12-inch wrench. | | X |
| Verify that a washer is present under each top nut to provide full bearing and seal bolt-hole gaps | | X |
| Visually verify that the top nuts are tight and free of corrosion. | | X |
| Check the condition of the grout or rodent screen at pole bases; replace it if it has been removed. | | X |
| Remove the grout or rodent screening under the base plate if there is evidence of anchor bolt weathering. Remove any debris, and examine the anchor bolts under the base plate for signs of bending, cracking, etc. | | X |
| Adequately secure handhole covers (replace any missing covers) | X | |
| Inspect poles, transformer bases, and arms for damage caused by vehicle impacts, weather, or wear and tear (note any deficiencies) | | X |
| Check the pole for plumbness, shim, or adjust as necessary. | | X |
| Check for rust and tightness of mounting hardware. | | X |
| Check for missing pole and mast arm end caps; replace them as required. | | X |
| Check signal cable for wear at the entrance of poles, brackets, signal heads, and where it is lashed to the span wire. Install or replace rubber grommets as required. | X | |
| Check for wires/cables that may rub or touch mast arm supports | X | |
| Check Guy Wires (inspect guy anchors for proper attachment and damage) | X | |
| Check galvanized nuts, bolts, and washers for any significant signs of corrosion. | | X |
| Inspect for rust and cracks, especially at seams, joints, and base plate | | X |
| Inspect 100 percent of all welds for visual evidence of cracking | | X |

| Traffic Signal Supports (Mast Arms, Strain Poles, Pedestal Poles, Pedestrian Stub Poles) | Maintenance Intervals | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Document any evidence of weld metal or base metal cracking | X | |
| Document any adverse bolted connection findings | X | |
| Verify luminaire(s) are operational during dusk to dawn periods | | X |
| Mast Arm Supports | | |
| Inspect horizontal and vertical angles of arms and poles (check pole and arms for warping or other damage: note deficiencies) | | X |
| Visually inspect connections. The connection should be tight, with no visible gap between the connection or flange plates, bolts, nuts, or washers. | | X |
| Verify that a washer is used between the connection or flange plate and each nut | | X |
| Visually inspect arm-to-column connections. The connection should be tight, with no visible gap between the connection or flange plates, bolts, nuts, or washers. | | X |
| Check for cracks in the vertical column-to-base plate connection; any cracks generally initiate opposite the arm-to-shaft connection (about 180° from the centerline of the arm for single-arm structures) | | X |
| Check for cracks in the welded connection between the arm or column connection plates; any cracks generally initiate at the uppermost (12 o’clock) or lowermost (6 o’clock) positions of the connections due to the dead load and oscillation (galloping) caused by wind loads. | | X |
| Strain Pole Supports | | |
| Check for cracks in the shaft or column-to-base plate connection; any cracks generally initiate opposite the span wire connections. | | X |
| Check the condition of strain vises, if applicable. | | X |
| Check the bonding of the span wire and tether wire to the strain pole. | | X |
| Visually inspect each tether wire for excess sag; adjust as necessary. | | X |
| Inspect all connecting span wire hardware (anchors, guards, cable lashing, supporting brackets); tight or replace as necessary. | | X |

***Source: PennDOT (2020)***

**Table 25. Interval-Based Preventive Maintenance for Controller Assembly**

| Controller Assembly | Maintenance Intervals | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Check anchor bolts and banding for rust or tightness. | | X |
| Check controller cabinet condition. If necessary, relocate so vehicle impacts do not damage the controller. | | X |
| Lubricate door hinges and locks | | X |
| Clean/vacuum inside the cabinet | | X |
| Verify conduit entering the cabinet is sealed. If necessary, re-seal conduit (use approved duct seal) | | X |
| Seal around the cabinet base with silicone caulking | | X |
| Check the gasket around the cabinet door. | | X |
| Check the drain plug (if equipped); Check for obstructions in drainage if evidence of water accumulating in the cabinet. | | X |
| Check for infestation, and address as needed. | | X |
| Replace air filter | X | |
| Check the operation of the cabinet light and switch - replace them if necessary. | | X |
| Check fan operation (thermostat set to operate at 85 - 90 degrees Fahrenheit) | | X |
| Visually check wiring and connectors | X | |
| Check and tighten all terminal connections. | | X |
| Verify that all spare conductors are landed on spare terminal blocks or taped off | | X |
| Verify all cables are tagged or otherwise identified | | X |
| If missing, place the latest permit plan and cabinet wiring diagram(s) in the cabinet. | | X |
| Check the Power Supply module | X | |
| Check Load Switches and verify the operation of each switch position | X | |
| Check the condition of the incoming line voltage. | | X |
| Test Circuit Breakers (cabinet and main) | | X |
| Check police functions | | X |
| Verify the operation of vehicle detectors (including the timing of delayed or extended output) | X | |
| Verify vehicle and pedestrian calls | | X |
| Verify the operation of detector panel relays | | X |
| Check the flasher unit for proper operation | X | |
| Check Radio Frequency Interface | X | |
| Check Traffic Optimization Processor | X | |
| Verify the correct date, time, and DST (Daylight Saving Time) function for the controller | | X |
| Verify communication with the master controller, if applicable | | X |
| Place user and programming manuals in the cabinet if missing. | | X |
| Note and record make, model, firmware version, and serial number for controllers, conflict monitors, and other significant components. | | X |
| Conflict Monitor Unit (or Malfunction Monitor Unit) | | |
| Scan conflict monitor for logged events, and note any entries. | | X |

| **Controller Assembly** | **Maintenance Intervals** | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| During intersection operation, observe the conflict monitor indicators and display screen to verify sensing of all indications and proper monitor settings. | X | |
| Verify operation of conflict monitor – remove load switch to create red fail and observe the response of the monitor | X | |
| Test conflict monitor by a computerized conflict monitor tester; replace the monitor if it fails the test. | | X |
| Test the cabinet wiring and harnesses using a jumper wire and pulling the load switch; if cabinets are frequented by rodents that chew on electrical wires/cables. | | X |
| Controller Unit (Electromechanical) | | |
| Check time, phasing, and sequencing settings. | X | |
| Check dial assembly for wear, burned contacts, and critical positions | X | |
| Check cam assembly for wear, cracks, burned contacts, and tension on contacts. | X | |
| Clean and lubricate the cam assembly. | | X |
| Controller Unit (NEMA, Type 170, Type 2070, ATC) | | |
| Check the time, phasing, and sequencing settings (verify input time versus approved timing, including coordination and time-of-day parameters; yellow & red clearance intervals) | X | |
| Run an internal diagnostic routine on the controller | | X |
| Upload controller timing and parameters via a laptop; place copy in the controller | | X |
| Check the response to the detector input | X | |
| Check indicator lamp and replace if burned out | X | |
| Check real-time on the clock. | X | |
| If a master controller is, check that it is operating appropriately and signals are coordinated | X | |
| Disconnect the controller from the master (if applicable) and check that the signal goes into a backup or free operation | | X |
| Please verify that the permittee is on the manufacturers' mailing or email list so that they are notified of software or firmware upgrades | | X |
| Check the time provided for the pedestrian crossing. Any noticeably short timing for the safe pedestrian crossing of the street should be reported and addressed. | | X |

***Source: PennDOT (2020)***

**Table 26. Interval-Based Preventive Maintenance for System and Communications**

| Systems and Communication | Maintenance Intervals | |
|---|---|---|
| | **6 Months** | **12 Months** |
| Perform preventative maintenance following the manufacturer's recommendations | | X |
| Check the operation of the communication system<br>▪ Verify that communications between all system components are functioning<br>▪ Verify the function of system components, including modems, ethernet/ethernet bridges, managed network switches, transmitter/receivers, antennas, servers, and system software | X | |
| Check master controller | | X |
| Check the time-based coordinator unit; verify that the time clock is accurate and adjusted for daylight savings. | | X |
| Check communication cables and connections | X | |
| Check mounting hardware | | X |
| Verify integration with Department's Unified Command & Control (UCC) where applicable | X | |
| Verify consistency between system database and controller databases, and ensure all databases match the approved permit | X | |
| Check overhead communications cables; verify that trees or vegetation are not encroaching on aerial lines. Address as necessary. | | X |
| Check the fiber optic cable.<br>▪ If aerial, check from where it is connected at the trunk line, and check that all coils are secure and at the proper bend radius<br>▪ If attached to a wood pole, check that the drop and u-guard are secure<br>▪ In the controller cabinet, open the patch panel and check all tip connections | | X |
| Check the wireless signal strength<br>▪ Test wireless signals at each intersection to verify they are operating within limits<br>▪ Adjustments shall be made to correct any deficiencies found in the communications system; including trimming of trees/vegetation that may be interfering with signal reception | X | |

***Source: PennDOT (2020)***

**Table 27. Interval-Based Preventive Maintenance for Electrical Distribution**

| Electrical Distribution | Maintenance Intervals | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Measure service voltage | X | |
| Check the physical condition of the meter and power service disconnect box. The disconnect box should be locked appropriately and free of rust. | X | |
| Check Service Receptacle (check GFCI receptacle on power distribution panel: replace if necessary) | | X |
| Check wire and cable | X | |
| Check wire connectors | | X |
| Inspect all splices in each traffic signal pole base and handhole to verify they are all solidly connected and not degraded. If deterioration is identified, re-splice using splices consistent with National Electric Code (NEC) for wet environments. | | X |
| Visually check the condition of the traffic signal cable for dry rot, nicks, cuts, or other damage to the outer jacket insulation; perform resistance and continuity tests, if required) | | X |
| Check all overhead cables and connections. | | X |
| Check that the signal cable is not rubbing against the cable outlet (free-swinging, end-mounted signals only) | | X |
| Test for grounding, corrosion, and loose connections. Verify that fuses or power breakers are functioning. | | X |
| Check relays and lightening arrestors for burned or pitted contacts | X | |
| Check the integrity of the lightning arrestor | X | |
| Check all surge protectors for critical applications of controls or signals that exit or enter the cabinet and the power supply. Includes: detectors, pedestrian pushbutton loops, service loops, and communication systems. | X | |
| Grounding and Bonding | | |
| Check ground rod, clamp, and ground wire connections | X | |
| Check that each pole, metal conduit, metal junction box, and other required metal components are properly electrically bonded. | X | |
| Check controller cabinet neutral and grounding bus. | | X |
| Check the ground rod, clamp connection, and bonding of conduits (secure all straps and rod connections) | | X |
| Check ground bushings and lugs (check grounding bushings on rigid metallic conduit; replace as necessary) | X | |
| Handhole - check ground rod, clamp, and ground wire connections | X | |
| Junction Boxes and Conduit | | |
| Check that junction boxes are sealed from water with securely seated covers. | | X |
| Clear the lip of the junction box cover to ensure proper seating of the cover; tighten cover bolts if present. | | X |

| **Electrical Distribution** | **Maintenance Intervals** | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Inspect inside the junction box for abnormal amounts of water or water damage. If water is present, take measures to drain by installing weep holes. | | X |
| Check junction boxes for proper grade and any surrounding ground erosion that could draw water; note any deficiencies. | | X |
| Clear debris and overgrowth around the junction box | | X |
| Check visible conduit (check above-ground conduit for damage; replace damaged and missing conduit straps) | | X |
| Check for any exposed ground conduit.<br>▪ If the conduit is undamaged, bury it<br>▪ If the conduit is crushed or cracked, it needs to be replaced and buried | | X |
| Check the wiring insulation for damage that could cause electrical shorts. | | X |
| Emergency Generator Connection | | |
| Inspect the disconnect enclosure, transfer switch, surge protection, and connector cable assembly. | | X |
| Check that the connector cable is<br>▪ Sufficient length to allow the attachment of an external power source following the latest NEC<br>▪ Compatible with the municipal generator and has neoprene all-weather flexible protective boots on each end | | X |
| Check the operation of the traffic signal for a minimum of five minutes using a municipal generator and provided cord. | | X |
| Test the electrical automatic relay switch over | | X |
| Uninterruptible Power Supply (Battery backup) | | |
| Test the UPS following the manufacturer's specifications to verify that it is working properly | | X |
| Test battery(s) for loss of charge – replace every three years | X | |
| Check Uninterruptible Power Supply | X | |
| Verify automatic transfer switch operation | | X |
| Verify incoming line voltage | | X |
| Verify DC output to batteries | | X |
| Verify AC output on the inverter | | X |
| Check electrical connections | | X |
| Test system via simulated power outage at cabinet | | X |
| Record events and run time either saved on the UPS unit manually or uploaded to the laptop. | | X |

***Source: PennDOT (2020)***

**Table 28. Interval-Based Preventive Maintenance for Signal Heads**

| Signal Heads | Maintenance Intervals | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Check vehicle and pedestrian indications | X | |
| Check optically programmed signal heads. | X | |
| Check lane use control signal heads. | X | |
| Check the alignment of vehicular signal heads (aim toward the center of approach at a point approximately 150 feet in advance of the stop bar) | X | |
| Check alignment and visibility restrictions of optically programmed heads and heads w/ louvers to verify they operate correctly with desired viewing intent. | X | |
| Check the alignment of pedestrian signal heads relative to the crossing they serve | X | |
| Check the visibility of traffic signal indications to verify that advance signs, foliage, and overhead utilities, do not impair visibility—schedule one of these semi-annual checks when leaves are present. Overhanging trees which block signal indications shall be trimmed to meet the visibility requirements in MUTCD Section 4D.12. | X | |
| Check horizontal lane-positioning of vehicular signal heads/signs to verify they are mounted according to Traffic Signal Permit. | | X |
| Check the clearance between the roadway and the bottom of signals and signs located over the roadway; adjust the height as necessary. | | X |
| Check terminal block connections. | | X |
| Housing Assembly (including Backplates, Visors, Louvers, Lenses & Reflectors) | | |
| Inspect signal housings for cracks and damage and secure assembly of all attachments (backplates, visors, louvers). Tighten up as necessary. | | X |
| Clean and inspect backplates for cracks and damage and secure attachment. Tighten up as necessary Backplates (dull black), including a 2-inch (minimum) fluorescent yellow retroreflective border, are required on all new traffic signals, including replacing existing signal heads. | | X |
| Clean and inspect visors for cracks and damage and secure attachment. Visors must be dull black on the side toward the indication. Tighten up as necessary. | | X |
| Clean and inspect louvers for cracks and damage and secure attachment. | | X |

| **Signal Heads** | **Maintenance Intervals** | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Check that when louvers are used, they are installed with a tunnel or full-circle visors. | | X |
| Clean and inspect lenses and reflectors, as necessary; replace damaged ones. | | X |
| Mounting | | |
| Check for cracked and damaged mounting brackets. | | X |
| Check gaskets and mounting hardware and retighten as necessary. | | X |
| Check for wear on the span wire and signal mounting hardware. | | X |
| Check bushings on cable outlet and universal hangers; replace as necessary. | | X |
| Check that signal heads on mast arms are mounted using fixed mounts unless approved on the Traffic Signal Permit. | | X |
| Indications (LED Modules / Incandescent Lamps) | | |
| Re-lamp all existing incandescent signal indications | | X |
| Check LED indications for brightness level to ensure replacement before complete failure. Note serial numbers and date of manufacture for LED modules. | | X |
| Re-lamp all sealed beams for programmed signal heads | | X |
| Remove white strobe light indications within the red lens and replace them with approved red indications; these types of indications are prohibited (Section 4D.06 of the MUTCD) | X | |

***Source: PennDOT (2020)***

**Table 29. Interval-Based Preventive Maintenance for Detectors**

| **Detection** | **Maintenance Intervals** | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Perform preventative maintenance following the manufacturer's recommendations | X | |
| Verify that detectors are performing and operating as designed for the intersection per the Traffic Signal Permit | X | |
| Verify that the CCTV system is performing and operating as designed. | X | |
| Vehicle Detectors- Pavement Invasive (Inductive Loops, Magnetic, Magnetometer) | | |
| Visually inspect the sensor in the roadway | X | |
| Check sensor/lead-in splices. | X | |
| Measure each loop sensor for resistance (R), inductance change DL%, and loop quality (Q) | | X |
| Check that all sensor leads are correctly tagged. | | X |
| Check sensor amplifiers for false actuations by vehicles in adjacent lanes | X | |
| Check the sensor amplifier for the failed light indicator | X | |
| Tune the detector if necessary (re-tune the sensor detector amplifier at the cabinet if necessary) | X | |
| Check that the connectors are tight and secure | X | |
| Check that necessary delays are functioning properly | X | |
| Vehicle Detectors - Pavement Non-Invasive (Video, Radar, Infrared) | | |
| Check the alignment of detectors and verify that detection zones are in the proper location relative to lane(s) being detected with the proper traffic direction configured, as appropriate. | X | |
| Check that detector device positioning is proper for the type of system used. | X | |
| Check detector device mounting hardware for proper and secure connections. | | X |
| Check that detector device cable connections are properly secured. | | X |
| Inspect detector device for damage | | X |
| Verify operation of detector processor at cabinet | | X |
| Verify that the detection system is using the latest software version and upgrade (update card firmware, if applicable) | X | |

| **Detection** | **Maintenance Intervals** | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| Verify detector cables are labeled for identification | | X |
| For video detection, assess the impact of changes in the sun's seasonal position on detection accuracy. | X | |
| For video detection, check the camera lens for moisture or dirt buildup; clean the camera lens. (More frequent maintenance may be required during the winter months due to road salt spray) | X | |
| For radar detection, verify that the system correctly identifies the gaps and that vehicles are being detected in only one direction. | X | |
| Pedestrian Detectors | | |
| Verify the operation of each push button and visually verify pedestrian signal operation<br>▪ Check for button tightness<br>▪ Check the house for damage or signs of vandalism, and replace it as necessary | | X |
| Check push button signs for location, legibility, and damage; clean as necessary<br>▪ If two buttons for crossing in different directions are located on the same support, the appropriate signing should be in place to ensure that it is clear and easily understood which button applies to which crossing<br>▪ Signs should be securely mounted and aligned with the appropriate crosswalk | | X |
| Verify that accessible pedestrian system (APS) features are operating following the permit. Maintenance of APS includes ensuring none of the following has occurred or is occurring:<br>▪ No response to ambient sound<br>▪ Weak or no vibration<br>▪ malfunction of audible message or tone and direction<br>▪ Delay between the onset of walk interval and the start of speech message<br>▪ failure due to wire short going to the vibrator cover/pushbutton<br>▪ Mechanical failure of pushbutton magnetic switch<br>▪ failure of the control board | | X |
| Vehicle Preemption Systems (Emergency and Specialized) | | |
| Check/test emergency vehicle preemption (EVP) systems for proper timing and operation:<br>▪ Check that operation complies with traffic signal permit and current standards | | X |

| Detection | Maintenance Intervals | |
|---|---|---|
| **General** | **6 Months** | **12 Months** |
| ▪ After the preempting vehicle has cleared the intersection and a preset time, verify that the signal returns to regular operation. Pay special attention to the transitioning into and out of a preemption sequence; the interval timings for both vehicles and pedestrians should be verified. Any available logs should be checked for abnormal activity/inactivity.<br>▪ For Optical EVP systems, test for pick up, range, and that unwanted light refraction does not actuate other phases; adjust detectors as needed to optimize performance<br>▪ For Acoustic EVP systems, test the emergency vehicle sirens for compliance with Class A siren specifications<br>▪ For GPS EVP systems, there is little preventative maintenance required as problems with communication links are identified during regular use | | |
| Optical & Acoustic EVP systems use fail-safe, or confirmation lights, to indicate to the driver that the approach is being preempted. When EVP is in operation, the confirmation light flashes for the preempted approach and is dark for the conflicting approaches. Maintenance responsibilities include:<br>▪ Verifying the lights are correctly aligned with each corresponding approach and testing for confirmation light off/dark operation using the appropriate transmission signal for the area (acoustical, optical)<br>▪ Re-lamp confirmation lights, as needed | | X |
| Button-activated EVP typically operates within a building, such as a fire company/emergency building. Verify button operation and repair, replace, or clean as necessary. | | X |
| Check the railroad preemption system. Verify that the system is working correctly; refer to the traffic signal permit, Publication 149 (Appendix D), and Publication 408, Section 953. | | X |
| Complete comprehensive joint inspections of the preemption system for railroad interconnect following Federal Railroad Administration guidelines. | | X |
| Check queue & ramp preemption system. Verify that the detection system is functioning correctly, following the traffic signal permit | | X |
| Check the transit priority system. Verify that the system is working correctly. Transit signal priority software manages the system, collects data, and generates reports. It is recommended that an experienced technician perform maintenance. | | X |

***Source: PennDOT (2020)***

**Table 30. Interval-Based Preventive Maintenance for Advanced Traffic Signal Technology**

| Advanced Traffic Signal Technology | Maintenance Intervals | |
|---|---|---|
| | 6 Months | 12 Months |
| Verify that the adaptive signal system (system) is providing real-time corridor optimization, including handling incidents and traffic shifts | X | |
| Verify that system can function in an actuated-coordinated mode or adaptive mode selectable by the time of day and day of the week or as specified on the approved plans | | X |
| Verify that system allows preemption phases to override the system and operate per the approved preemption sequencing, if applicable | | X |
| Verify that system accommodates queue preemption, if applicable | | X |
| Verify that the system fallback state is configured for loss of adaptive processor and server communication, including controller operation and alarms as applicable | X | |
| Verify adaptive operation is using and receiving proper detection data to generate signal timings | X | |
| Review system logs and resolve any unexpected errors which have been recorded | X | |
| Verify remote communications connectivity to all field devices | X | |
| Verify that system is connected to the Commonwealth Network to allow PennDOT access | X | |
| Verify that system is collecting and storing local, real-time traffic data for a minimum of 4 weeks or as specified on the approved plans | X | |
| Verify that system can be operated and monitored from a TMC, if applicable | X | |
| Verify that system's detection system provides the necessary functional requirements to allow the system to function as designed | X | |

***Source: PennDOT (2020)***

# APPENDIX E: INTERVIEW QUESTIONS

## TRAFFIC SIGNAL CONDITION ASSESSMENT INTERVIEW

### Interview Preparation

We will ask interview participants to review the draft signal assessment procedures and condition levels before the interview. We will also share a copy of the interview questions and a paragraph summarizing our project beforehand. The interviews can be in-person or via Zoom depending on location and schedule. No audio or video recordings will be made. Instead, notes will be recorded and shared with interviewees for their review and confirmation. Interviewees will provide informed consent via email before scheduling the interview. You may take breaks or discontinue at any time.

### Questions

*Assessment Operation*

1. The assessment tool will have four key parts: a check-off sheet documenting which features are present (e.g. preemption), structural component assessments, control component assessments, and cabinet component assessments. What order do you suggest completing the documentation/assessment?

2. The current plan is to collect signal assessments digitally, where technicians would use a tablet to enter the findings and attach pictures. There will be an option to print the questions and answer in paper format. What are your thoughts on those options?

3. In your estimation, how many hours of fieldwork will the assessment each signal assessment take?

*Assessment Procedures*

4. Reviewing the recommended procedures for signal structural elements, what changes do you suggest?

5. Reviewing the recommended procedures for signal control elements, what changes do you suggest?

6. Reviewing the recommended procedures for signal cabinets elements, what changes do you suggest?

7. Are there other/different practices that you suggest we consider including?

8. What are your recommendations about assessing aerial infrastructure (e.g. mast arm welds)?

9. What are your recommendations about checking controller program settings with the other signal control elements?

10. What are your recommendations on having routine inspection items as part or separate from this assessment?

*Condition Thresholds*

11. Focusing on the signal structural element assessments, which thresholds do you suggest we revisit and why?

12. Focusing on the signal control component assessments, which thresholds do you suggest we revisit and why?

13. Focusing on the signal cabinet assessments, which thresholds do you suggest we revisit and why?

14. We plan to include pictures of several components. Do you suggest additional conditions have pictures? Which ones?

15. Do you have pictures or can you recommend locations where our team can document qualitative signal conditions such as corrosion?

16. What is the most important factors that will lead to consistent assessments of traffic signals and multiple locations by multiple people? For example, clear description of criteria, pictures, and assessor training.

*Current Practices*

17. How do you distribute the responsibilities of maintaining your traffic signals?

18. Among the local agencies you are familiar with, how to they distribute the responsibilities of maintaining their traffic signals?

19. What changes should be made to policies and agreements to implement signal assessments in your jurisdiction?

20. Who do you recommend complete the signal assessments in your district. For example, IDOT technicians or signal contractors and/or engineering staff.

21. In your opinion, what is the most pressing need for traffic signals in your jurisdiction?

22. Does your jurisdiction have a system of updating Malfunction Management Units (MMUs) or Conflict Monitors?

23. Does your jurisdiction repair or recycle signal components. For example, if a signal controller fails, do you normally send it for repair and future use? If so, which components?

24. Is there other information that you would like us to know?

*Personal Info*

25. How many years have you worked with traffic signals?

26. Which companies/agencies were included?

27. Who else do you recommend we gather input from?

## TRAFFIC SIGNAL CONTROLLER LIFESPAN INTERVIEW

### Disclosure

This study aims to identify how vendor support and other factors can influence the lifespan of traffic signal controllers. Your input will support a student thesis, your responses will remain anonymous, and the findings will only describe average answers and which companies participated in the interviews. These questions and the research methods have been reviewed and approved by the SIUE Institutional Research Board.

### Controller Types

Your company offers many different types of traffic signal controllers. In your opinion, do certain types of controllers last longer than others? (If asked, can give example types like TS-1, TS-2, ATC).

If yes, which types last longer and shorter?

### Controller Support Practices

What is the typical period that your company produces a specific model of traffic signal controller?

If the answer depends on the model/type, describe some examples.

After a controller is discontinued from manufacturing, how long does your company typically provide software and technical support to agencies?

How frequently do you receive support requests from agencies for discontinued traffic signal controller models?

1. Once a year

2. A few times a year

3. Monthly

4. Every two weeks
5. Weekly
6. Daily
7. Other_______

What are the standard ways that you know traffic signal controllers are replaced because they are obsolete?

8. Not enough phases
9. Lack of communication ability
10. FYA issue
11. Coordination capability
12. Intersection redesign

## Observed Lifespan

Based on your experience, how long do traffic signal controllers last before a repair is required?

If they answered yes to question one, ask for answers for each type.

What are the different ways that a traffic signal controller could fail and need replacement?

13. Lightning damage
14. Power surge damage
15. Cycle failure?
16. Other___________

For each of the failure methods you identified, can you estimate the annual likelihood or suggest how we could find this information?

In your experience, how common is it for an agency to repair and reuse signal controllers?

What failure types allow repair?

# APPENDIX F: EXAMPLE CONDITION LEVELS


**Figure 76. Photo. Example of base plate coating in critical condition.**

***Source: NYSDOT (2013)***


**Figure 77. Photo. Example of transformer base in critical condition.**

**Figure 78. Photo. Example of foundation and base plate connection in fair condition.**

***Source: NYSDOT (2013)***


**Figure 79. Photo. Example of foundation and base plate connection in poor condition.**

***Source: NYSDOT (2013)***

**Figure 80. Photo. Example of foundation and base plate connection in critical condition.**

***Source: NYSDOT (2013)***

**Figure 81. Photo. Example junction box in poor condition.**


**Figure 82. Photo. Example of bolted aerial connection in fair condition.**

**Figure 83. Photo. Example of bolted aerial connection in poor condition.**

**Figure 84. Photo. Example of a bolted aerial connection in critical condition.**

**Figure 85. Photo. Example welded aerial connection in fair condition.**

**Figure 86. Photo. Example welded aerial connection in poor condition.**

**Figure 87. Photo. Example welded aerial connection in good condition.**

**Figure 88. Photo. Example welded connection in critical condition.**


**Figure 89. Photo. Pole and post plumbness in fair condition.**


**Figure 90. Photo. Example of pole plumbness in critical condition.**

**Figure 91. Photo. Example pole dent in critical condition.**

**Figure 92. Photo. Example of mast arm in fair condition.**

**Figure 93. Photo. Example of mast arm in poor condition.**

***Source: NYSDOT (2013)***

**Figure 94. Photo. Example of a power service in poor condition.**


**Figure 95. Photo. Example of a power service in critical condition.**

**Figure 96. Photo. Example of a base plate and pole in critical condition.**

**Figure 97. Photo. Example of a base in critical condition.**

**Figure 98. Photo. Example of a base in poor condition.**


**Figure 99. Photo. Example of span wire tension in fair condition.**


**Figure 100. Photo. Example of span wire tension in fair condition.**

# APPENDIX G: RECOMMENDED CHANGES TO MUNICIPAL SIGNAL AGREEMENTS

The following updates are recommended for the IDOT Signal Maintenance Provisions, Section E, which describes annual maintenance activities. Text with strikethrough should be removed and bold text should be added.

## SECTION 2

~~Inspect all mast arm assemblies, mast arm poles, brackets (or other types of hardware) supporting traffic heads or pedestrian signal heads on an annual basis. The inspection shall focus on the structural elements of the mast arm assembly and must include a close-up arm's length investigation of the mast arm, pole, mast to pole connection, base plate, and anchor bolts.~~

~~The arm of the assembly shall be visually inspected at all signal head connections for any defects, such as cracks or buckles. Inspect the mast arm to pole connection for significant loss of section, cracks in welds or base metal, and deterioration of the connection plates. The bolts of the arm to pole connection shall be inspected for tightness and condition. Check the pole for external corrosion, impact damage, rust through perforation, deflection, distortion, or cracking. Closely inspect pole for corrosion near the base plate, especially if mounted on a grout bed.~~
~~Check welds of the pole to base plate connection for cracks. Inspect base plate for section loss or deformation. Inspect mast arm anchor bolts for any corrosion or bending, and for loose or missing nuts.~~

**Complete the IDOT traffic signal condition assessment (hyperlink to assessment) for each location, including the submission of component pictures. If the survey is completed in a paper format, the findings and pictures shall be submitted digitally.**

## SECTION 3

Test all conflict monitors and MMUs once every two years in accordance with manufacturer recommendations. **Attach a label indicating the in-service date or most-recent passed test.** Failed conflict monitors or MMUs shall be replaced with new units.

The GOVERNMENTAL BODY, upon request, shall submit copies of the CMU/MMU test reports to the DEPARTMENT. These reports shall be maintained pursuant to Part 2, Paragraph E., "Records Preservation" of the AGREEMENT.

## SIGNAL ASSESSMENT DESCRIPTION

The following page includes an example flyer describing the assessment procedure and its purpose. The intended audience includes Illinois counties and municipalities that operate traffic signals. The information on this flyer is also presented in a video clip.

## Signal Assessment Tool

The Assessment Tool steps guide you through how to inspect signal components and what criteria should be considered for each different condition level. Using research-informed best practices, the process is guided by signal technician input to focus on signal component condition, and not operational effectiveness.

**Instructions:**

- Online completion of questions
  - This allows for direct submittal of pictures
  - Can be completed in paper format, but should be entered digitally afterward
- Prepare for your site visit
  - Proper equipment includes but is not limited to steel-toed boots, safety vests, protective eyewear, and a hard hat
- Read each question carefully and utilize the example photos to aid your rating
- Recommended to upload pictures of any poor or critical conditions (as seen on this page)
  - This would allow for the tracking of signal conditions over time and the ability to make comparisons before/after incidents
- For components present at multiple locations, may assess altogether or individually for each intersection quadrant
- Complete one assessment for each signalized intersection per year





# APPENDIX H: RECOMMENDED AERIAL INSPECTION PROCEDURES

## DRONE TRAFFIC SIGNAL INSPECTION GUIDELINES

The following is guidance for inspecting aerial components of traffic signals using small unmanned aircraft systems (sUASs), commonly referred to as drones.

### General

- Federal regulations (14 CFR Part 107) require any individual operating a drone for commercial purposes be licensed as a FAA-Certified Drone Pilot.
- It is expected that the pilot in command (PIC) for the inspection operation will have a drone pilot license and will therefore be familiar with all operational rules and restrictions established under 14 CFR Part 107. Of particular interest for traffic signal inspection operations are the following restrictions:
    - § 107.39 – Operation Over Human Beings
    - § 107.145 – Operations Over Moving Vehicles
- It is strongly recommended that a trained visual observer (VO) be present to aid the PIC during the inspection operation.
- It is important that the PIC be familiar with the operating characteristics and limitations of their drone. PICs should reference owner's manuals or other materials supplied by the manufacturer of their drone.
- Equipment required for a safe drone inspection operation includes, but is not limited to:
    - Drone compliant with 14 CFR Part 107
        - Payload capable of capturing high quality still images and/or video (Zoom capabilities recommended)
        - Spare batteries
        - Propeller guards (if not already equipped)
    - Proper traffic control devices
    - Personal protective equipment (PPE) including safety vest and hard hat

## Pre-Flight Planning (Off-Site)

Prior to entering the field, the following steps should be taken to ensure a safe and legal operation:

- Ensure all firmware and software for the drone and drone accessories are up to date and that all components are in good operating condition.
- Check the proposed inspection location for any controlled or restricted airspace, no-fly zones, or manufacturer geofencing.
    - If the location is in controlled airspace that is enabled through Low Altitude Authorization and Notification Capability (LAANC), then apply for automatic airspace authorization through LAANC.
    - If the controlled or restricted airspace is in a non-LAANC enabled area, then apply for the appropriate authorizations or waivers through the FAA.
    - If the location is in a geofenced area in which flight is restricted by the drone manufacturer, then apply for the necessary unlocking licenses, if available.
- Check the proposed location for any temporary flight restrictions or Notices to Airmen (NOTAM).
- Check weather conditions at the proposed location.

## Pre-Flight Procedure (On-Site)

- Assess the location of the signal to be inspected relative to the nearest edge of the roadway and/or sidewalk and establish a desired flight area that does not cause a flight over people or moving traffic.
- If it is determined in 3a that the signal component to be inspected will require flight over a sidewalk or travel lane, then the necessary traffic control shall be set in place to close the sidewalk and/or travel lane.
- Assess the operating environment, considering risks to both persons and property. Potential hazards to be aware of related to signal inspections include, but are not limited to:
    - Overhead power lines, trees, light poles, and other aerial obstacles.
    - Nearby bird nests and/or other wildlife that may create a hazard.
    - Changing weather conditions.
- Ensure all people involved in the operation are aware of their roles and responsibilities, potential hazards, and emergency and contingency procedures.

- Ensure all communication links between the aircraft and controls are operational.
- Ensure that there is enough battery life to operate the drone for the duration of the operation.
- If the drone is GPS-capable, ensure that return-to-home (RTH) functions are enabled.

### Inspection Procedure (In-Flight)

- Launch the aircraft from a safe location clear of any ground or aerial hazards.
- Slowly and carefully maneuver the aircraft to the proper location and viewing angle. It is recommended that the PIC utilize a VO to maintain situational awareness of the operating environment during maneuvers.
    - Keep in mind that the signal is operating under live traffic. While the PIC should fly as close as necessary and/or practical to the signal component being inspected to get clear footage of the component, effort should be made to maintain as much distance as possible from the signal indications in order to limit distraction for drivers utilizing the signal. Zoom capabilities are beneficial to allow aircraft to remain further from the signal while still capturing clear footage.
- Collect sufficient footage to provide coverage of the entire component being inspected. This may require repositioning the aircraft several times in order to capture footage of the component from all angles.
- Carefully maneuver the aircraft back to a safe landing location that is clear of any hazards and land the aircraft.
- It is critical that the aircraft never be positioned in a manner that blocks drivers from seeing a signal indication. This applies to all phases of the operation from takeoff to landing.

### Post-Flight Procedure

- Review footage to ensure sufficient footage has been collected to adequately assess the condition of the signal component being inspected.
- Remove all traffic control.

## INSPECTION WITH CAMERA AND TELESCOPING POLE

For collecting mast arm weld pictures during the study, a data collection tool was made using a GoPro and telescopic rod. The camera was mounted on a telescopic rod with a specialized connector, see Figure 101. It was useful that the camera could connect to the inspector’s mobile device so the view area and focus could be confirmed before recording each picture. This functionality should be sought when selecting a camera for this use.

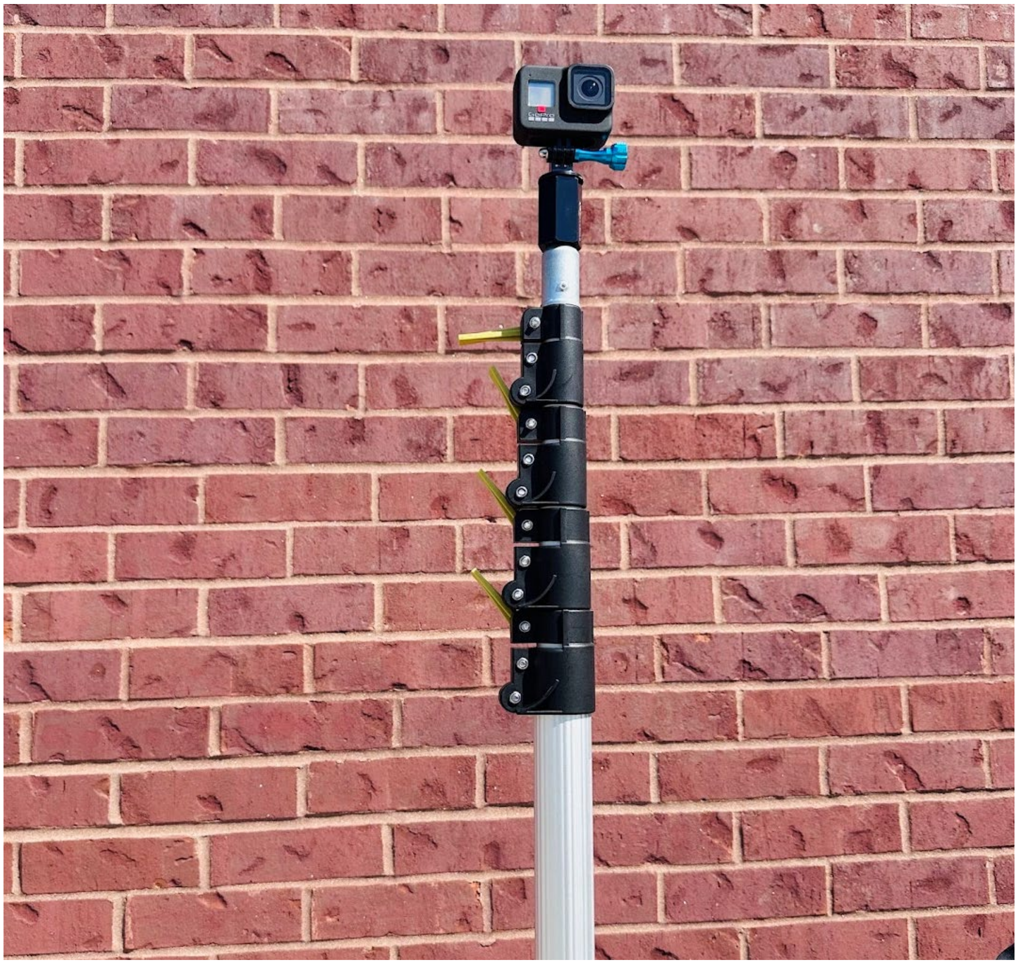

**Figure 101. Photo. Aerial weld assessment tool assembly.**

The camera was placed approximately two to four feet from the welded connection to capture a picture with enough the detail to assess the weld. Pictures were taken from all the sides of the connection, with special attention to the top and bottom. The photos were focused well and clear to see any kind of corrosion, cracks, or other degradation in the welded connection between the pole and the mast arm.  Two inspectors are recommended for this procedure, so one can watch traffic while the other is using the rod and camera assembly.

Illinois Department of Transportation

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