Asset Management for Mobility and ITS

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16. ABSTRACT The Federal Highway Administration currently requires pavement and bridge National Highway System assets to be managed through a formal plan at the statewide level regardless of ownership. The methods for Transportation Asset Management planning for pavements and bridges are relatively well defined and mature. To incorporate evolving technologies and new industry standards, methods and practices need to continue to progress and evolve. New Intelligent Transportation System and Transportation Systems Management and Operations assets must be managed and maintained, with similar methods to bridges and pavements, to keep the asset management processes consistent. This project outlined a literature review, a state of the practice survey, an assessment of several state-published Transportation Asset Management Plans, and the development and application of a tool for use in varied settings across the Missouri to manage Intelligent Transportation Systems and other new mobility assets and highlights the importance of a common asset management approach, risk management, and quality data management plans. Future recommendations and strategies are provided to the Missouri Department of Transportation to improve and incorporate new mobility assets into existing transportation asset management plans.		

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AN ASSET MANAGEMENT APPROACH FOR MOBILITY AND INTELLIGENT TRANSPORTATION SYSTEM DEVICES

FINAL REPORT ~ TR202117

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl	fluid ounces	29.57	milliliters	mL
oz	gallons	3.785	liters	L
gal	cubic feet	0.028	cubic meters	m^3
ft^3	cubic yards	0.765	cubic	m^3
yd^3	meters NOTE: volumes greater than 1000 L shall be shown in m^3			
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 Celsius or (F-32)/1.8		°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square	lbf/in^2

Contents

1. Executive Summary

PROJECT OVERVIEW

The Federal Highway Administration currently requires pavement and bridge NHS assets be managed through a formal plan at a statewide level; this is regardless of ownership. The methods for Transportation Asset Management (TAM) planning for pavements and bridges are relatively well defined and mature. However, to incorporate evolving technologies and new industry standards, TAM methods and practices needs to continue to progress and evolve. As they advance, many of the transportation systems nationally and worldwide and the assets they manage continue to grow to include Intelligent Transportation System (ITS) components as well. These ITS and Transportation Systems Management and Operations (TSMO) assets must be managed and maintained, just like bridges and pavements and the methods to do so should be similar in order to keep the asset management processes consistent. Management of ITS and mobility assets also gain additional attention as agencies focus on life-cycle cost analysis and targeted levels of service. While practices continue to mature, agencies are encouraged to apply asset management approaches to these other assets, but it is not a requirement. Therefore, methodologies being applied vary.

This project aims to address these issues for the Missouri Department of Transportation (MoDOT). The project had four primary components -- a literature review and state of the practice survey, an assessment of several state-published Transportation Asset Management Plans, development and application of a potential tool for use in varied settings across the state, and a summary report of the findings.

Asset management is a tool that agencies can use to help define goals for assets and prioritize resources in the decision-making process given limited budgets and resources. Well-managed and implemented ITS and TSMO assets can provide a variety of benefits to the transportation and mobility systems, including energy and environmental benefits such as fuel savings and reductions in emissions. Having up-to-date Transportation Asset Management Plans that include clear data collection and management approaches, risk management of assets, and life cycle planning approaches to asset classes outside of bridges and pavement can help these mobility systems reach their full intended efficiency and environmental benefits.

ITS and other mobility assets differ from more traditional assets, such as bridges and pavement in a variety of ways including shorter life cycle, more interdependencies, and lower replacement costs. The data to manage these assets can be collected in a variety of ways, including through LiDAR (Light Detection and Ranging), photogrammetry, video review, and manual tracking, though new ways of tracking data associated with these asset classes may become possible as technology progresses and develops. Performance-based management uses performance information to monitor whether an asset is making progress towards an agency-defined goal. In establishing an asset management approach for assets other than bridges and pavement, agencies will need to determine the benefits from expanding these TAM programs to prioritize adding new assets to existing programs.

Data collection and management processes, risk management, and life cycle planning are all important practices in creating and implementing TAMPs. One of the biggest challenges transportation agencies face is incomplete asset inventories. Having clear, shared and unduplicated data across agencies is important for asset data analysis and decision-making purposes. Risk management has been a component of Transportation Asset Management Plans (TAMPs) since 2018 and is growing in importance. By understanding risks to different asset classifications, more informed decisions can be made about investment strategies. Scenario planning for unique investment strategies applied to asset classes can help agencies plan for potential funding gaps. Life cycle planning is a requirement for agencies developing risk based TAMPs under federal code and provides a strategy for agencies to walk through the sequence of actions that can be used to provide asset functionality at a minimum practicable life cycle cost.

To arrive at primary recommendations, review of literature, a state of current practice survey, and an assessment of state Transportation Asset Management Plans was undertaken.

PRIMARY RECOMMENDATIONS

To maximize the benefits of using ITS and TSMO assets, these assets should be incorporated into MoDOT's existing transportation asset management programs where possible. These plans and programs should outline a clear data collection and management procedure across different divisions to increase efficiency and reduce redundancies, should adopt a risk management approach to transportation asset management, and reduce costs associated with maintaining and replacing assets by adopting a life cycle planning approach.

Given constrained budgets, capacity, and staff, Missouri must consider costs and benefits of incorporating new assets into their TAMP to prioritize asset adoption. Based on survey responses there are several asset classes that are recommended for tracking. Conditional information for ITS and mobility assets is not considered a feasible data item to collect at this time as most of these assets either work completely or not at all, although many devices can be considered "compliant/actively supported", or "end of life" or "end of technical support".

Based on a review of best practice, it is recommended that ITS asset classes to be tracked include but not limited to cameras, message signs, Road Weather Information Systems, sensors, communications, traffic detection, servers, weigh in motion, Highway Advisory Radio (HAR) and state-owned cloud-based software. Data to manage on these ITS assets could include location, installation date and installation cost, device type, model name and number, serial number, firmware version, warranty information, installation location including current and past locations, manufacturer's recommended lifecycle, maintenance records, and replacement costs. While some of these items could be optional, we believe that installation date, estimated life and cost are required to determine budget requirements and estimate future needs.

While many options are available for use as a tool to enter, store and report data included in the management system, at this point we are assuming the use of a simple spreadsheet model that is "standard" in its basic function, but customizable for use by each individual user.

This report summarizes the work completed under this research assignment, beginning with a literature review and summary and detailed results from a comprehensive survey.

OVERVIEW OF FINAL REPORT

This final report is divided into 6 primary sections as detailed in the table of contents. It begins with this Executive Summary, provides details on the Literature Review and Assessment, describes the survey and interview processes, highlights the tool development and prototype, and finally provides concluding details and recommendations

2. Literature Review

The research team prepared a summary of the literature. The primary findings are presented in this chapter.

ASSET MANAGEMENT & ITS

Asset management is a tool that can be used by agencies to help them define goals for their assets and prioritize resources in decision making processes, especially when those agency resources are limited (Amekudzi et al., 2011). More agencies are working to establish efficient, successful, and strategic asset management processes; however, these strategies and methods still vary across agencies, especially regarding data collection methods and data needs. More agencies are expanding their asset management approaches to include roadway safety and mobility assets, meaning analysis of these data collection methods and their associated costs are of significant interest (Amekudzi et al., 2011). ITS deployment can affect transportation system performance in terms of safety, mobility, efficiency, productivity, energy and environment, and customer satisfaction.

Establishing a prioritized approach for selection of assets other than pavements and bridges for addition into an asset management program is a complex process. Therefore, guidance to assist asset owners in this process is critical. One of the components of the process is to identify the data needs for new assets that are being added into the management program (Allen et al., 2019).

Due to this variety of technologies, a variety of performance measures are used to assess the success of any deployed ITS (Bunch et al., 2011). TAM is considered a performance-based approach that analyzes available resources and suggests how these resources should be allocated for the installation, maintenance, repair, rehabilitation, replacement, and operation of transportation infrastructure assets. Traditionally, TAM has focused heavily on pavement and bridge assets; however, many agencies are now expanding TAM to additional assets. As a consequence of the heavy focus on pavements and bridges, there is less information available for state agencies when it comes to adding these additional assets, what data they may need to collect, and what the associated costs will be. Costs are an important factor as agencies will want to ensure that the costs spent on TAM programs yield sufficient benefits when it comes to resource management, allocation, and preserving the life of their owned assets (Allen et al., 2019). A generic framework for asset management systems includes identifying agency goals and policies, asset inventory, performing condition assessments and modeling performance, evaluating alternatives against program goals and budget limitations, selecting and implementing projects, and monitoring performance (Bittner et al., 2008).

Performance-based management means that performance information is routinely collected to monitor whether an asset is making progress towards an agency-defined goal. If an asset is not in line to meet performance goals, the agency can adjust accordingly. Using performance data gives a tangible measurement of how well available funding is being used to achieve agency goals, how resources are being allocated, what performance information is available to support any funding requests, and how agency accountability is improved among other benefits. An important step in the asset management process is to identify asset prioritization; budget limitations require a strategic approach to resource allocation. Agencies will need to determine what benefits can be realized from expanding their TAM programs and the costs associated with the system development, and data collection and management (Allen et al., 2019).

Agencies are likely to evaluate aspects such as risks, changes to existing processes, and gaps between existing and desired management practices. The criteria that can be used to rate each asset class are also important and should reflect vital factors such as how urgent it is to address repairs in this class or how much effort or cost is required to collect asset inventory and performance data. Rating systems can include numerical scales such as from 1 to 5 or 1 to 10 and the same scale should be used for all criteria. Some criteria are difficult to rate objectively on a numeric scale; for these criteria, the agency may use yes/no or other subjective measures. Service life can be a proxy for condition on many assets. There are two general methods to rate assets among different classes: priority score calculation and tiered methods. Relative weights are also required so agencies can consider the relative importance of identified criteria and how these weights are used to calculate the final score for the asset class by multiplying each rating by its corresponding weight (Allen et al., 2019). Even with priority score calculation, some agencies may choose to use a tiered methodology where some assets are ranked over others as shown in Figure 1 below.

RANKED ORDER PRIORITIES		PRIORITIZED TIERS
1	Sign Panels	TIER 1
2	Ancillary Structures	
3	Culverts	TIER 2
4	Guardrails	
5	Storm Sewers	
6	Pavement Markings	TIER 3
7	Rest Areas	

Figure 1. Example of Ranked Order Priorities (Allen et al., 2019).

In 2008, Bittner et al. evaluated the Traffic Operations Asset Management System (TOAMS) practices at state transportation agencies by surveying 33 participants from 16 states. TOAMS are systematic processes for managing and maintaining physical assets associated with ITS devices and traffic operations hardware systems. Managing traffic operations is an area that is increasingly important; in 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) established new resources and investment opportunities for advancing traffic operations with the goals to improve congestion management and deploy ITS to increase access and mobility (Bittner et al., 2008). These advances have also brought about changes to assets; for example, SAFETEA-LU created opportunities for agencies to develop High Occupancy Vehicle (HOV) lane facilities to help manage congestion and stressed the importance of real-time system management including management of traffic conditions and incidents and sharing this information network-wide.

While vital components of advancing traffic systems and traffic operations assets may differ significantly from pavements and bridges, integrating them into a TAM program can be complex. The Federal Highway Administration (FHWA) identified six basic characteristics of traffic operations assets that sets them apart from pavements and bridges: considerably shorter service lives (bridges may last up to 100 years), lower replacement costs (replacing traffic operations assets is relatively lower in cost as compared to road reconstruction or bridge replacement), more dynamic in nature (traffic operations assets require ongoing monitoring and adjustments), higher incidence of failure (failure in traffic operations systems can cause a chain reaction of issues such as a whole network of signals to stop working), both tangible and intangible components (assets like traffic signals include communication links, software, fiber optics, data, and networks), and more system-wide interdependencies (decisions about traffic operations assets often consider interrelationships across different system components to address issues; for example, if one component is identified as a good candidate for replacement, other related components may need to be replaced at the same time).

In addition to these differences, traffic operations assets will have vastly different data and information characteristics. The data involved in ITS is often more heterogeneous and there is a greater importance placed on real-time performance status and failures in the system. ITS involves more detailed data about traffic characteristics such as turning movements, traffic speeds, and traffic variations by time of day or time of year. It is also important that the data gathered be high quality; decision output quality is highly dependent on the data that is input into the management system and decision-making process. There are multiple methods for data collection available, but the four main methods in use for collecting TAM data include manual data collection, video review, photogrammetry, and mobile LiDAR (light image detection and ranging). Agencies may evaluate several considerations when deciding between data collection methods including if the asset is visible from the roadway, level of accuracy, if data collection will expose work crews to traffic, and what resources are available, among others (Allen et al., 2019).

Manual data collection is very labor intensive as compared to photogrammetry and mobile LiDAR; however, manual data collection is the best method for assets that are not visible from the road, and it does not require any specialized technical expertise or equipment. Mobile LiDAR data provides a high degree of accuracy and can be integrated with other data such as automated pavement condition surveys and quality control activities, making it highly versatile. Other data collection options are currently in development that could improve data collection capabilities including the use of 360-degree cameras, flash LiDAR, and airborne LiDAR. When collecting data, it is important to select assets for analysis and determine the constraints. Data collection should also involve quality control and acceptance testing before processing and managing the data. For asset elements like retaining walls or noise barriers, manual and photogrammetry data collection methods are feasible while LiDAR is the preferred method. The same breakdown is found for signals, guardrails, curbs, parking lots, and access ramps. For ITS equipment, photogrammetry and LiDAR are preferred over manual methods.

The top eight technologies for improving mobility include dynamic message signs, advanced signal systems, adaptive signal control, transit signal priority, pre-trip information, surveillance, work zone management, and automatic vehicle location/computer-aided dispatch. The goal of the mobility technologies is to improve travel times on key routes, reduce delay, and improve on-time performance. Bunch et al. (2011) also documented the top eight technologies with productivity improvements including automatic vehicle location/computer-aided dispatch, CVO (Commercial Vehicle Operations) electronic screening, road weather information and management, winter maintenance strategies, CVO credential administration, service patrols, dynamic message signs, and freight and asset tracking. These mobility technologies present a variety of energy and environmental benefits including fuel savings and reductions in emissions. The top eight technologies with the highest number of energy and environmental benefits include advanced signal systems, dynamic message signs, service patrols, roadway surveillance, pre-trip information, speed control, congestion pricing, and electronic toll collection (Bunch et al., 2011).

FHWA provided a state-of-the-practice review in 2004 regarding asset management of signal systems. In general, asset management has fundamental elements that need to be included as the asset inventories of many agencies continue to grow and expand. These fundamental elements include identification of specific performance goals and how the performance of assets will be measured, making informed decisions using high quality information and established analytic tools, monitoring actual performance and costs against agency goals to improve future decisions and operations, and exploring multiple options for achieving these performance goals. Commonly identified barriers include budget limitations and limited funds. Just as in basic engineering economics, a major takeaway is that capital is limited; therefore, how this capital is allocated and invested is a major goal of a lot of analysis. Many previous asset management efforts focused on maintenance and replacement decisions for pavements and bridges. With ITS technology and other operational assets, the focus has been shifting to how to use asset management practices for operations assets (FHWA, 2004).

One example of operation assets are signals and signal systems. Signals illustrate some of the challenges of expanding asset management to other assets beyond pavements and bridges. As previously mentioned, one unique feature of a lot of ITS technology is interdependencies. A decision to replace one signal can impact an entire signal system and other related assets. In the state-of-the-practice review in 2004, FHWA explored what signal systems asset management practices were taking place, including what elements were involved in these practices and how the system could be used to support signal system management and decision making.

The signal systems asset management system includes physical components (signal heads, loop detectors, cameras, controller boxes), system components (design features and operational characteristics of the traffic management functions provided by the whole signal system integrated components), and personnel (staff resources for operating and maintaining signals) (FHWA, 2004). In total, 26 agencies responded to the interview and of those respondents, 52% were city agencies while the remainder were split between States and Counties. Data collection efforts focused on mid-sized agencies with 200 to 1,000 signals to ensure sufficient complexity for a comprehensive analysis. Twelve respondents reported jurisdiction over between 300 and 500 signals and another seven respondents reported jurisdiction over between 501 and 1,000 signals.

Most respondents reported having fewer than 5,000 miles of center-line road and the average staffing reported was 0.32 staff/100 signalized intersections in operations management, 0.34 staff/100 signalized intersections in maintenance management, 0.50 staff/100 signalized intersections in operations staff, and 1.45 staff/100 signalized intersections in maintenance staff. Most agencies had traffic engineers and electricians, but only half reported having electrical engineers, mechanical engineers, or communications engineers on staff (FHWA, 2004). Agency budgets are analyzed based on three major categories including signal system construction budget, signal system maintenance budget, and signal system operations budget; this breakdown of costs allows for better understanding of which areas of operation require the most resources.

Respondents were also asked about the software tools being used to manage the signal systems and responses included inventory tracking for field equipment, inventory tracking for spare parts, hardware/software version control, maintenance/maintenance work order management, performance monitoring, signal timing optimization/simulation, and budgeting. The greatest software usage was reported in optimization and simulation software as well as maintenance/work order management and inventory of equipment. The physical data collected and stored for assets is a major component of asset management. Respondents in this study reported the types of data they maintain about major components such as signal heads, detectors, controllers, structures, and communications equipment. Table 1 below shows the breakdown of responses for the type of data maintained by component.

Table 1. Data Maintained for Signal Systems (FHWA, 2004).

Information	Signal Heads	Detectors	Controllers	Structures	Communications Equipment
Characteristics of Components (equipment, models, functions, etc.)	46%	46%	62%	35%	50%
Serial Numbers of Components	12%	12%	31%	80%	12%
Maintenance Requests	12%	15%	27%	80%	12%
Maintenance Costs/History	42%	38%	46%	35%	38%
Repair/Failure History	38%	31%	50%	35%	38%
Age/Conditions	19%	27%	46%	23%	31%

As can be seen, a lot of survey respondents report maintaining data on component characteristics such as the equipment models or functions as well as maintenance information and repair or failure history. Fewer respondents report maintaining data on serial numbers of components and maintenance requirements with the exception of structures components. Data maintenance for age and condition is mixed. It is also important to analyze how the data is being used; respondents were asked if they use this data for making purchase decisions, adjusting maintenance schedules, estimation of maintenance repair and replacement costs, for life-cycle cost analyses, or for estimating personnel needs.

The most common uses included equipment purchase decisions and cost estimation while the least common uses included life-cycle cost analyses and estimation of personnel needs. Since life-cycle cost analysis requires more complex cost-tracking data, not all agencies have the data necessary to perform these analyses (FHWA, 2004). The types of system performance data being collected, and the methods of data collection were also of major interest in the 2004 study. Respondents reported collecting data such as intersection crashes and fatalities, volumes and speeds on routes, complaints about routes, delay, and queue lengths at intersections.

A variety of methods were used to collect data including police reporting, crash records, traffic counts, video data, signal system control software and other types of automated and manual tracking systems. As can be seen, this wide variety of methods is likely to result in variety in data format, especially for monitoring and tracking inquires and complaints. Crash data and volume, speed, and throughput data may also vary depending on what methods are available to a particular agency and how this data is collected and managed. For example, the police crash reporting methods vary across states and how quickly crash reports are available in a statewide accident database (if one exists) can also vary, which can impact access and dataset completeness. Most respondents reported using performance data to make decisions about locations that could benefit from signal coordination, locations that need traffic control changes, and areas needing improvements. Some respondents also reported using the performance data to aid in planning of equipment replacement (FHWA, 2004). Overall, this report does indicate that agencies have been tracking and managing signal system components, but that the levels of sophistication and methods vary based on the scale and complexity of their systems. While variation in methodology across agencies is expected, within one singular agency there is a need for cohesive methodology to ensure agency-wide data is comprehensive and consistent.

In 2013, the ITS Joint Program Office (JPO) launched the ITS Asset Viewer web site, which was developed by Oak Ridge National Laboratory. A survey of states and municipalities was used to develop the website, which provides a map-based view of ITS asset inventory across the United States. The accuracy is dependent on states' survey responses (Athey, 2020). The site includes some device attributes like manufacturer and type; however, the site has not been updated much since the initial setup and therefore the data does not accurately represent the current inventory (Athey, 2020). FHWA is currently studying ways to provide guidance on how to incorporate ITS asset reporting into TAMP development. Some states already report ITS in their TAMP and document their asset inventory, value, and condition. These states include Alaska, California, Colorado, Connecticut, Georgia, Minnesota, New Jersey, Pennsylvania, Rhode Island, and Utah (Athey, 2020). The goal of including ITS assets in asset management plans is to help agencies optimize their investment in their ITS devices, such as through performance prediction or cost prediction. This optimization requires the agency to decide how to maintain, upgrade, replace, or discontinue investments in their ITS assets. Performance prediction involves anticipating future performance of existing and potential new ITS assets and how this aligns with agency goals. Cost prediction analyzes the costs to procure, deploy, operate, and maintain ITS assets (including money that has already been spent). Agencies may also consider agency mission and the impact of other projects on ITS assets (Athey, 2020).

Performance and reliability are both critical factors in asset management. Performance trends assess changes in performance of an ITS asset over time. As an example, for weigh-in-motion sensors, as the roadway ages this sensor may become less accurate potentially providing less accurate and less valuable data. Performance trends usually analyze inventory items such as make and model, serial number, specifications, quantity, components, contract and warranty, and status. They also analyze location, history, and system environment. Reliability trends examine how reliability changes as an asset ages; as assets age they may require more maintenance, replacement, they may have more downtime, and provide less useful data (Athey, 2020).

RISK MANAGEMENT

Managing risks to assets is a key aspect of asset management practices (*Case Study 4,* Varma et al., 2020). While risk management has been a component of transportation asset management plans (TAMPs) since 2018, this component has been growing in breadth and importance ever since. The 2019 TAMPs expanded upon the risk management pathways and described how agencies can use risk management analyses in life-cycle planning and investment decisions. Risk management should also be communicated to key stakeholders and users. While there are many unique risks to assess, the most common risks appearing in TAMPs include funding uncertainty, construction inflation, loss of skilled staff (due to retirement, downsizing, low salary, etc.), weather risks (including seismic activity), data gaps concerning asset condition and performance, lack of support for necessary long-term investments, deteriorated assets with investment needs exceeding forecasted revenues, and competing demands for capacity or economic development projects (*Case Study 4,* Varma et al., 2020).

As an example, in Case Study 4, Varma et al. (2020) analyzed the Washington State Department of Transportation (WSDOT) TAMP and its related risk analysis components. Risk management appeared in most sections of the WSDOT plan. WSDOT's chapter on asset inventory and condition discussed risk management extensively and categorized assets that created the greatest risks to the asset management objectives. Over 50 percent of the agency's asphalt pavements were more than 50 years old at the time of the TAMP development; this is considered a typical design life for asphalt pavements and thus these pavements had risk due to lack of preservation, maintenance, and rehabilitation. While pavements are not expected to fail if maintained properly, delays in treatment or funding issues could create risks to pavement condition and performance, especially for aged pavements such as the asphalt pavements described here (*Case Study 4,* Varma et al., 2020). Other risks that were analyzed in the TAMP included the concrete lane miles; WSDOT reported that 50 percent of the concrete lane miles were more than 40 years old totaling approximately 1,000 lane miles where 100 lane miles were reported as more than 60 years old. Since concrete replacement is extremely expensive at the end of its service life, WSDOT identified this as a risk to be managed immediately. Similar risk analyses were summarized for bridges and remaining pavement assets.

Through this analysis, WSDOT was able to identify gaps that created risks to their asset performance and manage risks to life-cycle performance. By identifying characteristics of the bridge and pavement inventory that created risks, WSDOT worked to reduce these identified risks. Since these characteristics were in line with the life-cycle planning chapter, these reductions improved the life cycles of the assets as well. WSDOT was also working at this time to develop methods, tools, and measures for forecasting life-cycle performance for their bridge assets; the bridge management software in the works had an expected release of March 2021 and would allow WSDOT to assign costs to identified risks and assign monetary values to assets for prioritization of repairs, rehabilitation, and replacement work. A lot of the risk strategies for pavements focused on lowering the risk of incurring higher costs due to inadequate maintenance or repair responses; for ITS assets, risks are likely to heavily focus on safety and mobility.

By understanding the risks to different asset classifications, more informed decisions can be made about investment strategies. Proper investment of funds and planning will aid an agency in reaching its performance goals and help mitigate risks associated with high costs of repairs and replacement and catastrophic failures (*Case Study 4,* Varma et al., 2020). As part of their work to mitigate risks to assets, WSDOT considered four unique investment strategies applied to two asset classes, bridges and pavements. The scenarios included a no build/no expenses scenario, a current investment levels scenario, a minimum investment levels scenario, and a scenario in which they receive $500 million less as compared to the current investment levels. Their analysis found current funding to be adequate for sustaining asset condition for four years, but not for ten years. The analysis showed a large preservation funding gap, indicating to WSDOT the need to plan for these issues sooner rather than later. This information was integrated into WSDOT's TAMP wherein they stated they would continue to communicate this preservation funding gap information to the Legislature and the Governor (*Case Study 4,* Varma et al., 2020).

In California, the California Department of Transportation (Caltrans) developed an asset management plan in 2019 that included a wide range of risks impacting asset conditions as well as strategies for addressing these risks and suggestions for coordinating efforts with other partners including Federal, State, and local entities. Caltrans identified risks related to state size, diverse landscapes and climate, the coastline, and the seismic activity. Earthquakes have caused significant damage to portions of highways in the state and could very well do so in the future, especially as weather patterns and events have become increasingly volatile. In the TAMP, Caltrans stated that they had established an Office of Enterprise Risk Management in 2013 responsible for performing biennial enterprise risk assessments.

This work included an Enterprise Risk Profile that Caltrans develops every two years using the International Standards Organization (ISO) 31000 Risk Management Standard. Risks are identified by district or program and the likelihood of each risk as well as its impact is evaluated (*Case Study 4,* Varma et al., 2020). This is a common risk management approach; Figure 2 below shows a generic risk matrix that can be adapted and used for evaluating risk based on impact and likelihood. This matrix can then be used to identify the most severe risks and to help prioritize which risks to focus on first. Agencies can also incorporate the risk levels into their long-term planning by assigning risk categories to timelines for addressing these risks.

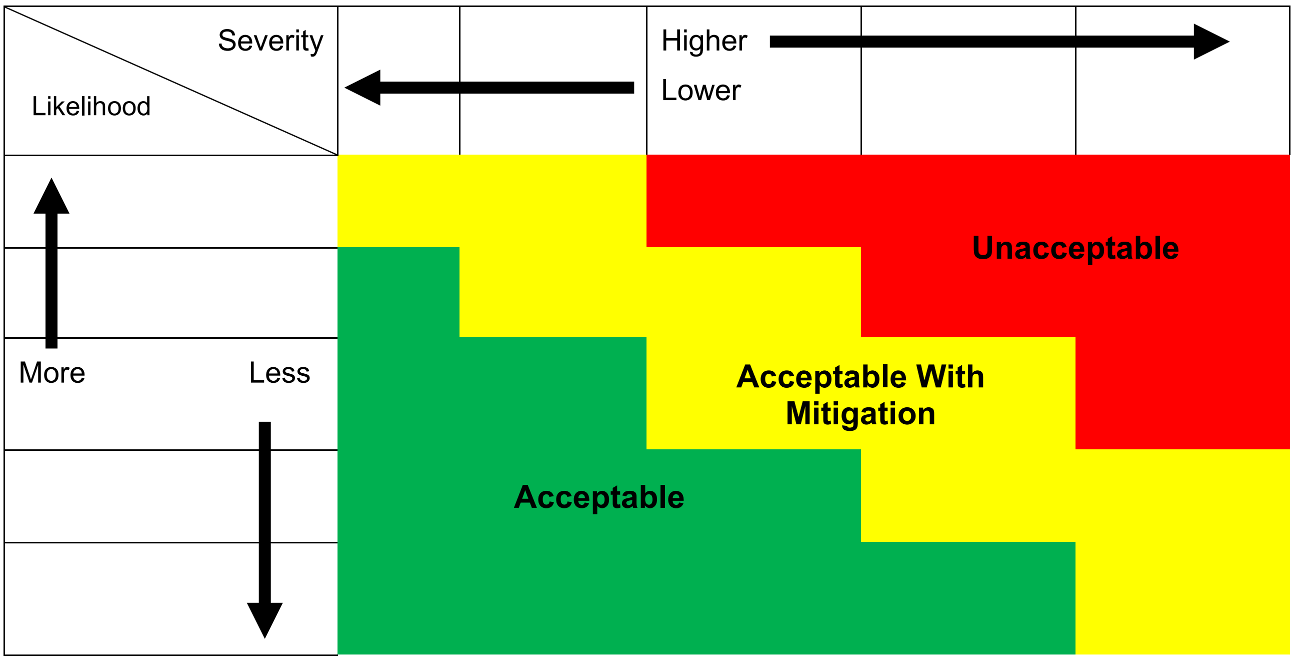


Figure 2. Risk Matrix Example (Skybrary Aero).

Another proactive measure taken by Caltrans included participation in a multi-agency effort called Safeguarding California. This effort worked to identify and assess risks associated with climate change and work towards solutions for mitigation of these risks. Some of the strategies identified as part of Safeguarding California and included in the Caltrans 2019 TAMP include gaining a better understanding of climate trends that can impact transportation, complete vulnerability assessments, prepare adaptation plans for selected vulnerabilities, improve transportation decision making and system resiliency, and enhance information sharing capabilities (*Case Study 4,* Varma et al., 2020).

DATA MANAGEMENT APPROACHES

The importance of data collection has been discussed; however, the management of large amounts of transportation data is also a key consideration to build an effective transportation asset management approach. Building Information Management (BIM) for infrastructure is one model framework for storing and sharing data across organizations to help integrate asset management strategies. BIM is a system of processes used for collecting, storing, and exchanging data that can be used for planning, design, construction, operation, or maintenance of highway infrastructure. Data can include physical characteristics as well as functional characteristics (Allen et al., 2019). BIM also aids in the transition from incomplete asset inventories to complete or agency-wide inventories so that agencies can easily share data such as cost, attributes, and program information. The better the integration of this data statewide, the more comprehensive and effective the TAM system is and the more effective the TAM system operates, the lower the anticipated costs. The collaboration across an organization is especially important as many agencies have multiple districts or offices and having one cohesive data management system ensures all districts are operating with the same procedures and information. It also allows different districts to share data that can be used in planning, surveying, design, construction, maintenance, and management of assets and risks. Integrating the data also helps with budget limitations that agencies are working within; the agency can ensure that the data upon which they are basing funding decision making is the best information available.

One of the biggest challenges transportation agencies face is incomplete asset inventories. Incomplete inventories end up being more expensive in the long term as agencies may try to redevelop the inventory multiple times and they may end up making inadequate decisions with this incomplete information. Incomplete or inaccurate information is a major limitation of decision-making processes. Establishing clear data collection methods and standards (sometimes called Data Dictionaries) can reduce expenses and improve accuracy of asset inventory compared to traditional methods of driving to inspect sites in person or basing inventory on paper plans (Allen et al., 2019). Another issue that comes up in data management is duplicate data; if asset inventories are completed at different times or with different methods, an asset may appear in a dataset more than once.

If a different business unit collects data and notes different attributes for one asset or using different reference systems or collection methods, duplicate data could now exist in the inventory, making any integration efforts difficult. Newer technologies including mobile data collection, digital field collection technology and cloud-based mapping have improved data management significantly. These systems allow data to be uploaded or downloaded from multiple locations and easily share, search, or analyze the data from a desktop computer or mobile tablet or other device in real time. Workers could quickly check on any data discrepancies or improve or update an inventory item in the field if errors are suspected or the entry has been flagged as incomplete or in need of an update. Figure 3 below shows one possibility for setting up a central data hub in a way that supports full circle or cradle-to-cradle asset management.

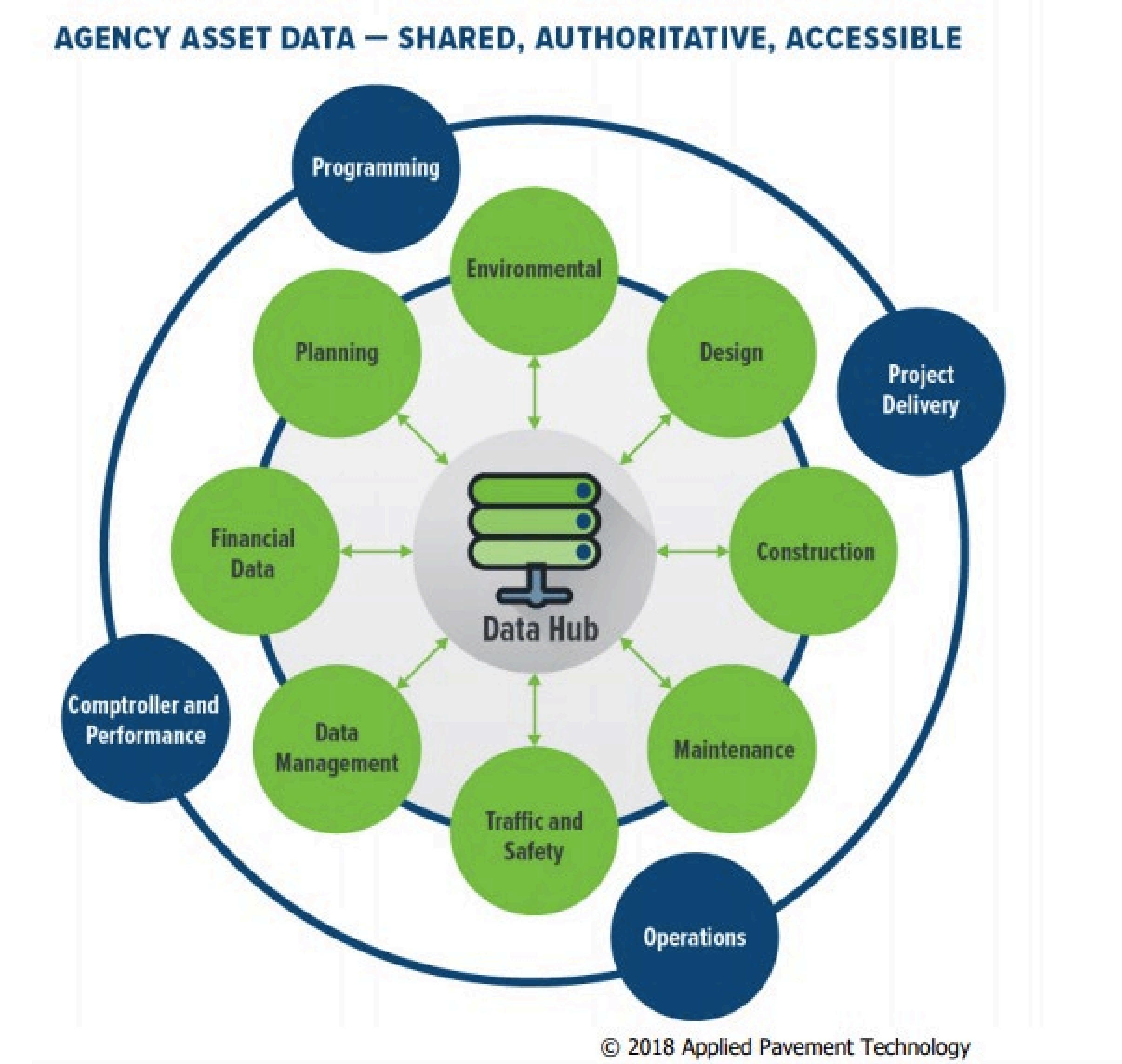


Figure 3. BIM for Infrastructure Central Data Hub Example (Allen et al., 2019).

Here, the outer ring shows typical functions such as programming, project delivery, operations, and comptroller and performance (internal controls and performance management). Moving inward, the inner ring shows agency divisions including environmental, design, construction, maintenance, traffic and safety, data management, financial data, and planning. Each agency division produces asset data and uses asset data for analysis and decision-making purposes. Each data element coming from the hub should be one central and authoritative source for all data concerning that element. This will help reduce duplicate data located elsewhere and ensure that when agency personnel access data from this central hub they are accessing the most current, accurate, and complete data available. From this central hub, the agency can also identify data elements that need updating or improvement to make them more complete and/or more accurate. It also ensures data is being shared from one central location each time data is shared within or outside of the organization. While integrating data into a central hub, agencies need to identify where data is currently located and what type of data each element includes. It is likely that some agencies will find data with multiple formats; it is also important to identify what divisions or groups are responsible for collecting and producing data and what divisions or groups are accessing or using the data and how it is being used. Having one singular reference system will improve the geospatial foundation for all data and help reduce data duplication and ensure asset location data is highly accurate, especially relative to other assets in the data.

The Florida Department of Transportation (FDOT) has been implementing a statewide effort for organizing and managing agency data. As part of this effort, FDOT has been working to change the agency culture surrounding data and help transform data into usable information. The initiative is known as ROADS and stands for:

- **R**eliable, accurate, authoritative, accessible data
- **O**rganized data that produces actionable information
- **A**ccurate governance-produced data
- **D**ata and technology integration
- **S**hared agency data to perform cross-functional analysis

The ROADS initiative is working toward making the data as useful as possible and easy to access, share, and understand (Allen et al., 2019). Since data collection and storage is time consuming and costly, it is wise to ensure the data collected is as useful as possible. Usability includes elements from every part of the ROADS acronym; there is sometimes a stigma that data is a collection of numbers that is meaningless to anyone who is not an expert. In reality, transportation asset data should be usable by a wide variety of users with varying expertise and experience. This ensures it has a large breadth of use and is being used more accurately. If the data is highly complex and poorly integrated, it does not preclude someone in the agency from accessing and using it in decision making, even if their interpretation or use of the data is incorrect. Coordination within an agency ensures the value of the data is maximized and helps simplify data collection, data management, and data sharing efforts.

Integrating asset data is easily accomplished once a central data hub is established. Individual agency divisions such as maintenance or construction can load their data into the central data hub, where it becomes an authoritative source with controlled access. Users can access needed data through this hub from department servers or cloud locations and public access can be controlled as necessary. Proper data management allows for improved collaboration across agency divisions as well as with other agencies if desired. Data management also allows agencies to determine how data should be organized and what formats are accepted into the central hub. This provides uniformity in the presentation of any data across divisions or to the public through controlled access. Once a data hub is established for an agency, data can be extracted from agency division offices and translated into the hub through a series of software scripts and routines. These would ensure the data is loaded in readable formats that are intuitive and usable.

Additional considerations for effective data management include establishing strong foundations including clear and uniform definitions for methods, standards, and protocols to be used in data collection. Uniformity among data elements included and protocols used are of particular importance as there is often variability in these areas (Pierce et al., 2013). Part of effectively managing data is ensuring only high quality and useful data is stored in the first place; agencies should aim to collect specific, realistic, and attainable quality standards for data items and identify the specific measures that will be used to determine acceptable data quality (Pierce et al., 2013). To ensure high quality data, quality control measures can be taken including calibrating equipment, training personnel (on calibration, operation, and troubleshooting), controlling test sites, and verifying data accuracy and completion before uploading into the central storage hub.

As mentioned, having a singular unified location referencing system will be a vital component to reducing data duplication and ensuring accurate data. Data management systems rely on data from multiple sources; the data must be managed such that it can be readily accessible by a variety of users at multiple levels and in all divisions of a transportation agency. Many users will be interested in being able to identify data for a specific location or object along a roadway and using that data to reference objects to each other. This requires a location referencing system (LRS), which includes identification of a known point (such as a mile marker), a direction, and a distance (Pierce et al., 2013). The LRS will allow users to integrate multiple sources of information and data for specific locations and link roadway attributes and conditions to locations. From here, visual displays of data can be created for analysis, decision making, and official report generation.

NCHRP Project 20-27(3) (*Workshop on Functional Specifications for Multimodal, Multi-dimensional Transportation Location Referencing Systems*) identified ten central functional requirements for LRS. These requirements include the ability to locate, place, and position objects and events in three dimensions and time, accommodating a time reference to relate the database to the real world, allow data transformation, support mapping, support display and analysis of objects, support navigation of objects along the network, support regeneration of objects and network states over time and maintain event history, support association of error measures with space and time data, store metadata to guide data use, and support time relationships among objects and events and support time delay of events (Pierce et al., 2013). Common location referencing methods include route-mile point, route-reference post, link-node, and route-street reference. For pavements, agencies may collect a variety of data for planning, programming, budgeting, pavement management system applications, condition-reporting, and project scoping among other uses. Pavement data typically includes International Roughness Index (IRI), rut depth, faulting, cracking, patching, raveling, and at the project-level may include distress maps, structural capacity evaluations, or base characterization (Pierce et al., 2013).

Agencies may also collect video, GPS data, geometric data, other asset data, events, site conditions, and speeds concurrently. This data can then be used for decision making processes and to support planning and programming of preservation, rehabilitation, and replacement or reconstruction. It is important that data be able to help agencies determine current conditions, predict future conditions under several budgetary scenarios, and develop several possible courses of action that are reasonable and achievable. For pavement data, data may be collected as often as annually while some data can be collected once every two to four years. Most transportation agencies have developed data collection procedures for commonly included assets such as pavements and bridges. It is desirable for these procedures to be standardized within a singular agency across all divisions and that data collection procedures be developed for multiple types of assets the agency may wish to collect data for.

In terms of assessing data quality, measurement of data quality has shifted in the last several decades. Traditional data quality assessments or error approaches assume one single true value with the objective to be as close to this value as possible, approaches have since shifted to what is known as an uncertainty approach (Pierce et al., 2013). In the uncertainty approach, an acceptable range of reasonable values is defined instead, and the approach acknowledges that there are limits to the amount of detail that can be measured. The newer approach also better fits asset management data, which often contains large amounts of data; in the older approach, the large number of measurements taken tended to impact that type of errors found in the data and can result in large total errors for individual measurements. Two terms that come up often when referencing data quality are precision and accuracy. While these terms are sometimes used interchangeably, this is not correct. Precision refers to how close measurements of the same item are to each other while accuracy refers to how close measurements are to a true or accepted value. Figure 4 below shows examples of precision vs. accuracy.

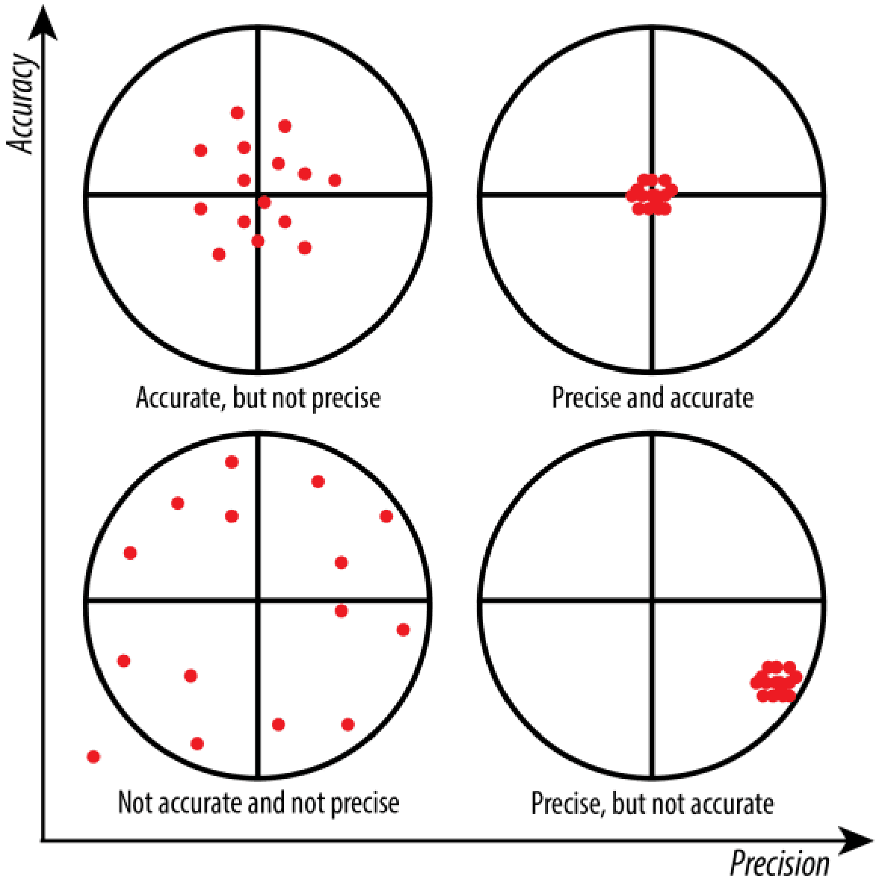


Figure 4. Precision vs. Accuracy (https://wp.stolaf.edu/it).

In the new approach to data quality assessment, terms such as bias, precision, and accuracy are replaced by new terminology including trueness and uncertainty. Trueness evaluates how closely the mean of a large number of measurements agrees with a true value and uncertainty evaluates what a reasonable dispersion of measured data should be for different items. In either approach, the goal is to assess how close a measurement is to some accepted value or reference range. Data quality may also look at other measures of acceptability including repeatability and reproducibility, as well as validation. Repeatability assesses the variation among results obtained by the same operator as a test is repeated; this is essentially precision of measurements under a single operator. Reproducibility looks at the variation in results obtained by different operators using the same methods, while validation is the mathematical comparison of independent data sets to assess if it can be assumed the data came from the same population (Pierce et al., 2013).

LIFE CYCLE PLANNING

Agencies developing risk based TAMPs will also work extensively with life cycle planning. Life cycle planning (LCP) is a requirement for agencies developing risk based TAMPs under Federal regulation 23 CFR 515.5. In the regulations, life cycle planning is defined as a “process to estimate the cost of managing an asset class, or asset sub-group over its whole life with consideration for minimizing cost while preserving or improving the condition of said asset” (Zimmerman et al., 2019). Most regulations lack guidance for how to perform an adequate LCP analysis or what strategies agencies can use for adopting LCP for the assets they own. In response, FHWA published guidance on LCP in 2017 and several workshops were held to help agencies develop LCP strategies and apply them.

LCP analysis is vital to TAM processes and provides a strategy for agencies to walk through the sequence of actions that can be used to provide asset functionality at a minimum practicable life cycle cost considering all components of that asset's life. A major strength of LCP is that it applies the engineering economic concept of the time value of money to account for the factor of time in financial planning and projections (Zimmerman et al., 2019). Performing LCP analysis at the network level allows consideration of multiple assets within the same asset class simultaneously and may be performed for a whole inventory or some specified set of assets within the agency. 23 CFR 515.7(b) states that "a State DOT shall establish a process for conducting LCP for an asset class or asset sub-group at the network level (network to be defined by the state DOT)." This puts a focus on the technical aspects of LCP analysis processes and requires state agencies to develop LCP processes in compliance with the regulations and discuss it in the TAMP (Zimmerman et al., 2019).

LCP helps agencies with long-term performance management and relates to other risk-based strategies included in a typical TAMP including 2- and 4-year performance targets, performance gap analysis, and risk management as discussed below. A vigorous LCP process helps agencies develop strong asset management programs by helping them make decision in the present that can address long-term needs, future budget constraints, and user needs. LCP also helps reduce annual system preservation costs without sacrificing network conditions by evaluating different effective treatment strategies available. It also helps agencies use funding and resources optimally considering the long-term implications of financial decisions and provides a transparent process for meeting infrastructure and asset preservation needs while still planning for the future of those assets (Zimmerman et al., 2019).

Part of accomplishing long-term objectives involves establishing goals for both 2- and 4-year projections. These targets are interim indicators of changing condition levels and agencies can use this data to determine if they are moving towards long-term state of good repair (SOGR) objectives. LCP analysis results directly impact establishment of these 2- and 4-year goals, which are required for Federal reporting under 23 CFR 490.105. These goals need to be achievable within current and projected funding scenarios and a comprehensive LCP analysis will provide results to inform the formation of these goals (Zimmerman et al., 2019). In performance gap analysis, agencies will identify gaps between forecasted asset conditions and target SOGR conditions. Gap analysis used in the agency's TAMP will consider the needs in other performance areas including travel time, reliability, and safety and how these performance areas could be improved by improving asset conditions. LCP helps inform this gap analysis and is informed by the results of a gap analysis such as selection of a life cycle strategy. Risk management considers impacts of unexpected events on system performance as well as the likelihood of these events occurring.

STATE TAMP REVIEWS

As part of this effort, the TAMPs for five states were examined: Nevada, Minnesota, Utah, California, and Colorado.

Nevada Department of Transportation

Nevada DOT's fully compliant TAMP was published in April of 2019. The TAMP includes life-cycle planning considerations as well as risk management. They also include an appendix detailing the assumptions used in the LCP analysis for their ITS assets. Figure 5 below shows the inventory count by asset type for Nevada's ITS assets.

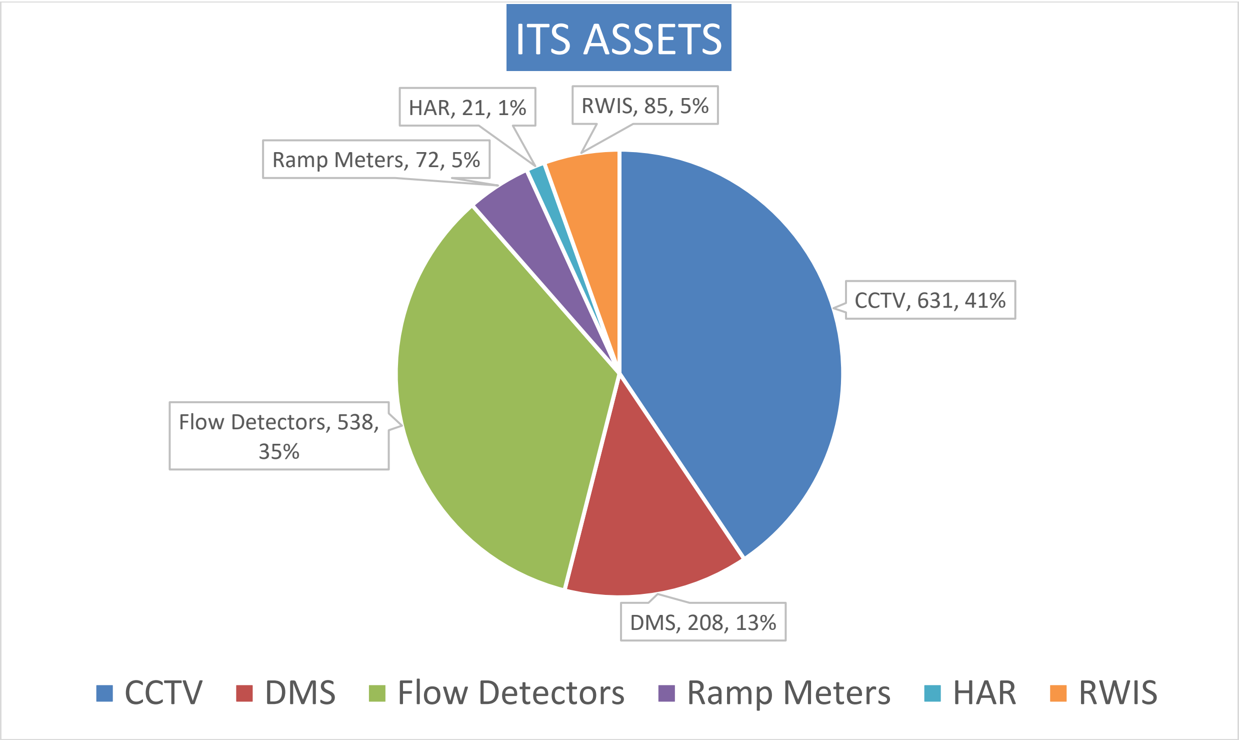


Figure 5. ITS Assets Inventory (NDOT, 2019).

Most of the state's ITS assets are in the form of closed-circuit television cameras (CCTV) and flow detectors, but they also inventory ramp meters, road weather information systems (RWIS), highway activity radios (HAR), and dynamic message signs (DMS). Figure 6 shows the current ITS asset conditions.

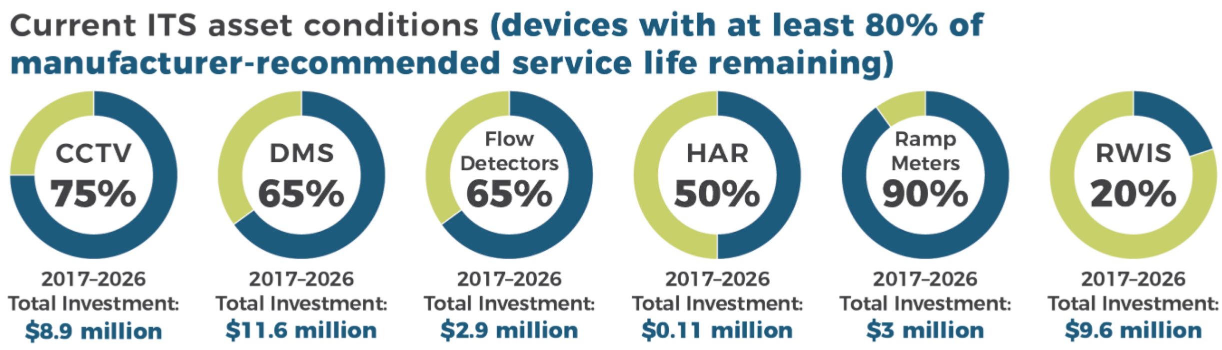


Figure 6. ITS Asset Conditions (NDOT, 2019).

Nevada DOT's investment strategy for ITS assets focuses on maintaining current levels of service for the next ten years, requiring an average annual investment of roughly $3.6 million (not including new ITS assets that will be added to the system in this time). Significant factors identified as impacting ITS asset conditions include fabrication quality, installation quality, traffic hits, strong winds, firmware issues, and obsolescence as newer technologies are developed and utilized (NDOT, 2019). Unlike pavements and bridges, measuring ITS asset performance is difficult as there are no formally established performance metrics for condition reporting. NDOT utilized a subjective performance metric based on the manufacturers' recommended service life for each device. Table 2 below shows the ITS condition rating scale used for NDOT.

Table 2. ITS Condition Rating Scale (NDOT, 2019).

Condition Category	Condition Description
Good	Age of the device is less than 80 percent of the manufacturers' recommended service life
Low Risk	Age of the device is between 80 and 100 percent of the manufacturers' recommended service life
Medium Risk	Age of the device is between 100 and 125 percent of the manufacturers' recommended service life
High Risk	Age of the device is greater than 125 percent of the manufacturers' recommended service life

These risk categories are based on the likelihood of the device failing, determined from subjective assessments of historical experiences at NDOT. The estimated condition based on percent of total asset counts for ITS assets find RWIS, HAR, and flow detectors as having the largest percentages in the "High" risk category (70%, 30%, and 25% respectively). A majority of CCTV, DMS, flow detectors, HAR, and ramp meters are rated as "Good"; only 5% of RWIS are rated as "Good". The condition of the ITS assets were estimated based on input from subject matter experts. While NDOT has not formally adopted ITS performance measures reported in their TAMP, they are looking to implement a performance-based approach for ITS asset management (NDOT, 2019). The current replacement value of the ITS assets is estimated at $42.2 million.

NDOT has also integrated ITS asset management into their life-cycle management analysis. The same condition categories shown in Table 2 are used in the LCP analysis. NDOT then developed a maintenance activity impact matrix shown in Table 3 below.

Table 3. Maintenance Activity Impact Matrix (NDOT, 2019).

Current Conditions	Resulting Condition After			
	Inspection	**Minor Repair**	**Major Repair**	**Replacement**
Good	Good			
Low Risk	Low Risk	Good		
Medium Risk	Medium Risk	Medium Risk	Low Risk	
High Risk	High Risk	High Risk	Medium Risk	Good

NDOT also developed a condition transition probability matrix for each ITS device. These matrices were used by NDOT to model an asset's deterioration based on expert opinion and show the time required for the device to deteriorate from category to another (from "Good" to "Low Risk"). Inspection involves routine maintenance of the device or asset typically performed by NDOT annually or biannually. Minor repairs involve repairs performed on site including adjusting loose cables, replacing batteries, and upgrading firmware. Major repairs require the device to be sent back to a maintenance location for repairs and include replacing one or more key parts. Lastly, replacement refers to completely removing and replacing the device (NDOT, 2019).

A life-cycle planning analysis was performed to determine how effective NDOT's current ITS asset maintenance practices are over a "worst-first" approach (devices are not repaired and maintenance is not performed; instead, devices are replaced after they fail). NDOT used a 20-year analysis period and a 2 percent discount rate and completed a comparison of the two life-cycle management practices. Figure 7 below shows the results of this analysis.

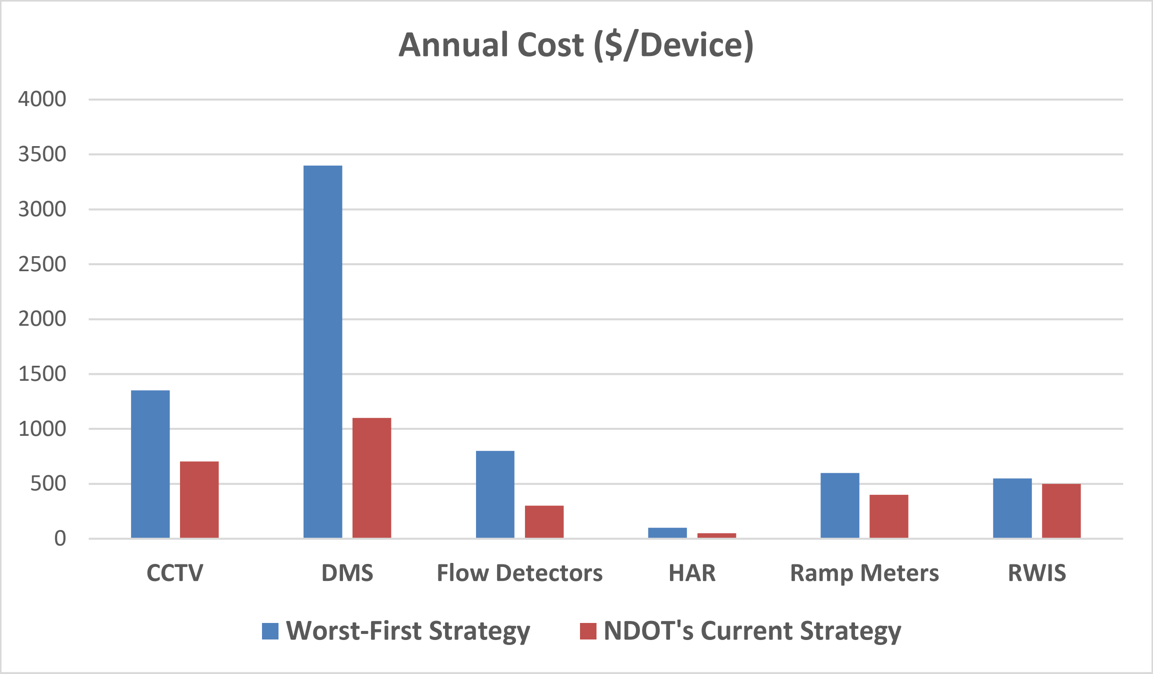


Figure 7. ITS Asset LCP Analysis (NDOT, 2019).

As can be seen, using preventative maintenance and preservation treatments on assets in good condition is highly cost effective as compared to the worst-first strategy. In their risk management section of the TAMP, NDOT identified several risk factors to their transportation assets including extreme weather events (floods and storms), adverse economic climate (shortage of materials, price fluctuations, and shortage of experienced workforce), uncertainty in future funding levels, and operational hazards (vehicle collisions, earthquakes, mudslides, wildfires, and rockfalls). These can result in significant issues such as personal injury, loss of life, damage to private property and infrastructure, harm to public health, the environment, and agency reputation, traffic congestion, loss of access and economic activity, litigation, and resource wastage (NDOT, 2019). NDOT analyzed the types of risks and where the responsibility for managing these risks falls (executives, program managers, or project managers).

NDOT's risk management approach involves establishing context, identifying risks, analyzing risks, evaluating risks, and treating risks. The contextual information allows asset management goals and objectives to be identified and the likelihood and consequence ratings to be developed. Risks are then ranked and prioritized and assigned likelihood and consequence ratings before a risk management strategy can be identified including identifying costs involved, time frame for implementation, and the plan for accomplishing these items (NDOT, 2019). The risk types identified by NDOT include financial, information, asset, program, decision, and climate. The mitigation strategies are classified into one of five categories: terminate (eliminate threat posed by risk), transfer (shift risk to third party), treat (reduce probability or impact of risk), tolerate (deal with risk and monitor for changes), and take advantage (use risk as opportunity to seek external funding). Table 4 shows the risk likelihood ratings and risk impact ratings for NDOT.

Table 4. Risk Likelihood and Impact Ratings (NDOT, 2019).

Ranking	Likelihood	Frequency	Score
Almost Certain	Near Certainty (90-100%)	Likely to occur within the year	5
Likely	Highly Likely (70-90%)	Likely to occur within two years	4
Moderate	Likely (30-70%)	Likely to occur within 3 to 5 years	3
Unlikely	Unlikely (10-30%)	Likely to occur within 6-10 years	2
Rare	Remote (<10%)	Not likely to occur for 10 or more years	1

Impact	Score
Catastrophic Impact on System Performance	5
Major Impact on System Performance	4
Moderate Impact on System Performance	3
Minor Impact on System Performance	2
Insignificant Impact on System Performance	1

The investment strategy for ITS assets includes determining initial device conditions, defining general procedures and protocols for inspections, repairs and replacement and the costs of each, identifying appropriate activities, and determining maintenance and repair activities. The total annual investment needs for ITS assets for 2017 through 2026 are estimated at $3,589,000.00 statewide (NDOT, 2019). NDOT has entered an Interlocal Agreement with the Regional Transportation Commission of Southern Nevada (RTC) to provide funding to them for operating and maintaining their ITS devices.

Minnesota Department of Transportation

Minnesota DOT's TAMP was published in June of 2019. MnDOT was one of three pilot states to create a TAMP in 2014. After this pilot TAMP was completed, FHWA released a final rule on TAMPs titled "Asset Management Plans and Periodic Evaluations of Facilities Repeatedly Requiring Repair and Reconstruction Due to Emergency Events" 23 CFR Parts 515 and 667 on October 24, 2016. MnDOT developed a draft TAMP that added six additional asset classes including noise walls, signals, lighting, pedestrian infrastructure, buildings, and ITS (MnDOT, 2019). The ITS assets include fiber communication network, fiber network shelters, traffic management system cabinet, dynamic message signs, traffic monitoring cameras, traffic detector stations/site-loops and radar, various communication equipment, MnPass readers, reversible road gates, ramp meters, rural intersection conflict warning systems, road weather information systems sites, automatic traffic recorders, weigh-in-motion system sites, and road closure systems.

A goal identified in MnDOT's TAMP is to improve data management, which is a theme explored in this literature review as well. Expanding asset management principles to a broader collection of assets other than pavements and bridges requires methods for effectively managing these additional assets and their data. MnDOT explored three different investment approaches for scenario planning: Approach A (focus investments on repairing and maintaining existing state highway pavements, bridges, and roadside infrastructure), Approach B (balance investments in repairing and maintaining existing infrastructure with strategic investments to improve travel time reliability), and Approach C (focus investments on improving travel time reliability, non-motorized investments, and regional and locally driven priorities). The performance measure for ITS assets includes looking at the share of sub-asset approaching or beyond its useful life. ITS assets are monitored continuously; they provide data about the operation of the roadway system. Complete inspections for each asset occur in intervals ranging from annually to every five years. The state target for ITS assets varies (MnDOT, 2019). MnDOT recorded 14,310 units of ITS assets with an estimated replacement value of $151 million; the current asset value is not calculated. Most of the ITS assets are located and managed within Metro District including the fiber communication network, fiber network shelters, traffic management system cabinets, dynamic message signs, traffic monitoring cameras, traffic detector stations/sites, MnPass readers, communication equipment, reversible road gates, and ramp meters. Rural intersection conflict warning systems, road weather information systems sites, automatic traffic recorders, weigh-in motion system sites, and road closure systems are located and managed by the various MnDOT districts and offices.

The ITS data collection depends on the asset type and no official reporting of ITS data is currently recorded. Table 5 and Table 6 below show the ITS assets rating scales and metro specific ITS assets rating scales for MnDOT.

Table 5. ITS Assets Rating Scales (MnDOT, 2019).

Rural Intersection Conflict Warning Systems	Good <5 years	Fair 5-9 years	Poor 10-14 years	Critical >14 years	
Road Weather Information System – Electrical Components	Good <4 years	Fair 4-7 years	Poor 8-10 years	Fail >10 years	
Road Weather Information System – Structure	Good <21 years	Fair 21-35 years	Poor 36-40 years	Fail >40 years	
Automatic Traffic Recorders and Weigh-In-Motion Controllers	Very Good <4 years	Good 4-6 years	Fair 7-9 years	Poor 10-12 years	Very Poor >12 years

Automatic Traffic Recorders and Weight-In-Motion Sensors*	Good >3.0 RQI	Fair 3.0-2.1 RQI	Poor ≤2.0 RQI	
Road Closure Systems	Good <3 years	Fair 3-32 years	Poor 33-39 years	Very Poor >39 years

Note: sensors in Automatic Traffic Recorders and Weight-In-Motion sites are in the roadways pavement surface and their deterioration is tied to the pavement's ride quality index

Table 6. Metro Specific ITS Assets Rating Scales (MnDOT, 2019).

Fiber Communication Network	Good <15 years	Fair 15-19 years	Poor 20-24 years	Critical >24 years
Fiber Network Shelter	Good <10 years	Fair 10-14 years	Poor 15-19 years	Critical >19 years
Traffic Management System Cabinet	Good <8 years	Fair 8-15 years	Poor 16-20 years	Very Poor >14 years
Dynamic Message Sign	Good <9 years	Fair 9-12 years	Poor 13-14 years	Very Poor >14 years
Analog Traffic Monitoring Cameras*	Good <5 years	Fair 5-8 years	Poor 10-14 years	Very Poor >14 years
IP Traffic Monitoring Cameras	Good <5 years	Fair 5-8 years	Poor 9-11 years	Very Poor >12 years
Traffic Detector Stations/Site Loops and Radar	Functional ≤14 years	Non-Functional >14 years		
MnPASS Readers	Good <10 years	Fair 10-12 years	Poor 13-14 years	Very Poor >14 years
Communication Equipment**	Functional ≤10 years	Marginal >10 years	Non-Functional Hardware Failure	

Reversible Road Gates	**Good** **<9 years**	**Fair** **9-12 years**	**Poor** **13-16 years**	**Very Poor** **>16 years**
Ramp Meters	**Good** **<25 years**	**Average** **25-49 years**	**Poor** **>49 years**	

*Analog Traffic Monitoring Cameras are being phased out of service and being replaced with IP Traffic Monitoring Cameras

**Generally communication equipment technology has been updating every 10 years. Equipment may still be functional after 10 years but may be technologically obsolete and scheduled to be replaced.

Currently, MnDOT reports most ITS assets as within tolerable limits, with some metro specific ITS assets approaching or beyond useful life. A required investment of $82.3 million would be needed to achieve the targets for the percentage of metro specific ITS assets approaching or beyond useful life. For rural intersection conflict warnings an investment of $6.1 million is required to meet targets, for road weather information systems sites an investment of $8.0 million is required to meet targets, for automatic traffic recorders and weigh-in-motion system sites an investment of $11.1 million is required to meet targets, and for road closure systems an investment of $0.8 million is required. This is an estimated total investment requirement of $108.2 million for all ITS assets to meet state targets (MnDOT, 2019). MnDOT also performed a risk management analysis. Table 7 shows the risk rating matrix for MnDOT.

Table 7. Risk Rating Matrix (MnDOT, 2019).

CONSEQUENCE RATINGS	LIKELIHOOD RATINGS AND RISK LEVELS				
	RARE	UNLIKELY	POSSIBLE	LIKELY	ALMOST CERTAIN
CATASTROPHIC	Medium	Medium	High	Extreme	Extreme
MAJOR	Low	Medium	Medium	High	High
MODERATE	Low	Medium	Medium	Medium	High
MINOR	Low	Low	Low	Medium	Medium
INSIGNIFICANT	Low	Low	Low	Low	Medium

Risk identification and mitigation includes consideration of global risks; MnDOT's risk management plan emphasizes undermanaged risk areas where there are clear opportunities for improvement. Table 8 shows the risks identified for ITS assets.

Table 8. ITS Risks Identified by Asset Groups (MnDOT, 2019).

RISKS	CONSEQUENCE	LIKELIHOOD	OVERALL RISK RATING

*System design, construction issues or system flaws (vulnerability)**	*Moderate*	*Likely*	*Medium*
*Inadequate operations/maintenance funding and staff***	*Moderate*	*Likely*	*Medium*
Not identifying an appropriate responsible party for maintenance/operations	Moderate	Possible	Medium
Ineffective (poor) vendor accessibility, communication or relationship	Moderate	Possible	Medium
Technology Shift/obsolescence	Moderate	Possible	Medium
Extreme Weather	Moderate	Likely	Medium

*Undermanaged risks identified and prioritized in TAMP

The high priority tasks for managing ITS asset risks include developing a statewide ITS system sample plan and standard details and specifications. Lower priority tasks include developing an inspection and maintenance cycle protocol to identify what ITS assets should be inspected or maintained including a staffing need/gap assessment (MnDOT, 2019). MnDOT also completed a life cycle planning analysis, which included analysis of ITS infrastructure. Each sub-asset in the ITS infrastructure class has a different life span, making it difficult to complete one common analysis time frame when completing LCP analysis. For example, dynamic message sign LCP have an analysis period of 15 years based on the life of this asset. The key goal of LCP analysis is to manage assets at the optimal level of preservation and keep life cycle costs at a minimum (MnDOT, 2019). There are 14 different ITS infrastructure assets to analyze; MnDOT completed LCP analysis for dynamic message signs as an example of the process for ITS infrastructure. Dynamic message signs are inspected annually by checking the fan, pixel board, power supply, and checking for animal infestations, leaks, and debris. Rehabilitation for dynamic message signs may include fan replacement, pixel board replacement, and power supply replacement. The LCP analysis included two scenarios: a minimum maintenance scenario does not include any preventive or reactive maintenance while the second scenario added a scheduled fan replacement every four years, pixel board replacement every ten years, and power supply replacement every thirteen years. The second scenario is anticipated to increase the expected life from 6 to 15 years (MnDOT, 2019). Table 9 shows the results of these planning scenarios.

Table 9. Dynamic Message Signs Life Cycle Planning Scenarios (MnDOT, 2019).

TREATMENTS	TYPICAL COSTS	STRATEGY A MINIMUM MAINTENANCE	STRATEGY B CURRENT PRACTICES
Filter Change	$250	None	Annual
Fan Replacement	$250	None	Every 4 years

Pixel Board Replacement	$250	None	Every 10 years
Power Supply Replacement	$250	None	Every 13 years
EXPECTED LIFE	**N/A**	**6 YEARS**	**15 YEARS**
MNDOT EUAC PER SIGN	**N/A**	**$8,493**	**$286**

ITS has several sub-categories of assets with different target setting methodologies. In general, the target percentage of assets approaching or beyond useful life for ITS assets ranges from less than or equal to 2% to less than or equal to 10%. Reversible road gates target is set at 0%. A unique feature of ITS assets is the impact to users; several sub-categories of ITS assets are prioritized due to public safety issues they pose if non-operational. Reversible road gates and intersection warning systems are continuously monitored and maintained or replaced immediately to protect public safety (MnDOT, 2019).

Utah Department of Transportation

The Utah TAMP was published in 2019. Aside from the typical pavement and bridge assets, UDOT includes other assets such as Active Traffic Management Systems (ATMS) devices, signal systems, walls, pipe culverts, barriers, signs, pavement markings, rumble strips, fences, and cattle guards (UDOT, 2019). UDOT uses a tiered approach to allocate transportation funding towards the most value assets based on risk to system operation. In Tier 1, performance-based management includes pavements, bridges, ATMS devices, and signal devices. In Tier 2, condition-based management includes pipe culverts, signs, walls, rumble strips, ADA ramps, barriers, and pavement markings. In Tier 3, reactive management includes cattle guards, interstate lighting, fences, rest areas, curb and gutter, trails, bike lanes, surplus land, and at-grade railroad crossing. Tier 1 assets are managed with accurate data collection where performance targets are identified and measured; predictive modeling and risk analysis is performed, and dedicated funding is provided through UDOT's annual STIP process. Tier 2 assets are managed with accurate data collection compared to condition targets and risk assessment is primarily based on asset failure. Tier 3 assets risks are based on asset failure through general condition analysis, and they are repaired or replaced when damaged (UDOT, 2019).

The two strategies for ATMS assets include replacing the highest value devices prior to the end of their expected life and to maximize funding by replacing devices within projects developed for other assets. Traffic signals receive preventative maintenance regularly to meet the target of 95% of system in average or better condition and emergency maintenance is performed when emergencies occur. Regular maintenance accomplished using established maintenance protocol helps minimize equipment downtime and unexpected failures. UDOT also analyzed the performance gap for both ATMS and signal infrastructure. ATMS devices need to be in operation and reliable so that UDOT can achieve their safety and mobility goals; this makes ATMS assets a high priority. Table 10 shows the replacement schedule for ATMS assets for UDOT.

Table 10. ATMS Asset Replacement Schedule (UDOT, 2019).

DEVICE TYPE	ADDRESSED IN CONST.	BACKLOG (<2017)	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
VMS	4	21	34	8	6	18	31
TMS Freeway Operations	17	0	19	90	43	79	27
CCTV	14	0	1	154	1	113	198
Express Lanes Freeway Operations	18	105	24	0	18	37	0
RWIS	0	0	53	26	58	117	90
Communication Switches	33	18	1	541	0	246	0
Misc.	6	1000	0	0	321	0	0

The Utah Legislature allocated $3.9 million each year for device replacement and upgrades, which will help eliminate the backlog over the next few years. For the signal system, signalized intersections and related infrastructure are prioritized as they aid in traffic management and mobility. As of 2019, UDOT reported the signal system to be below target condition. The management plan to bring the signal system up to the target condition includes updating signal assessment processes to improve consistency, map signal conditions in an interactive mapping platform (UPLAN), communicate signal replacement and upgrade needs to the regions so they can incorporate these costs into project scoping and construction estimates, and replace the highest priority locations first when funding is available (UDOT, 2019).

UDOT also includes ATMS devices in their LCP analysis. The most effective management strategy for the ATMS assets considers the entire life cycle of each device type. A workshop was held to determine the perceived relative value of each ATMS device, and the Decision Lens tool was used to help prioritize the devices and determine which would be replaced and on what schedule. Figure 8 shows the device priority for ATMS assets.

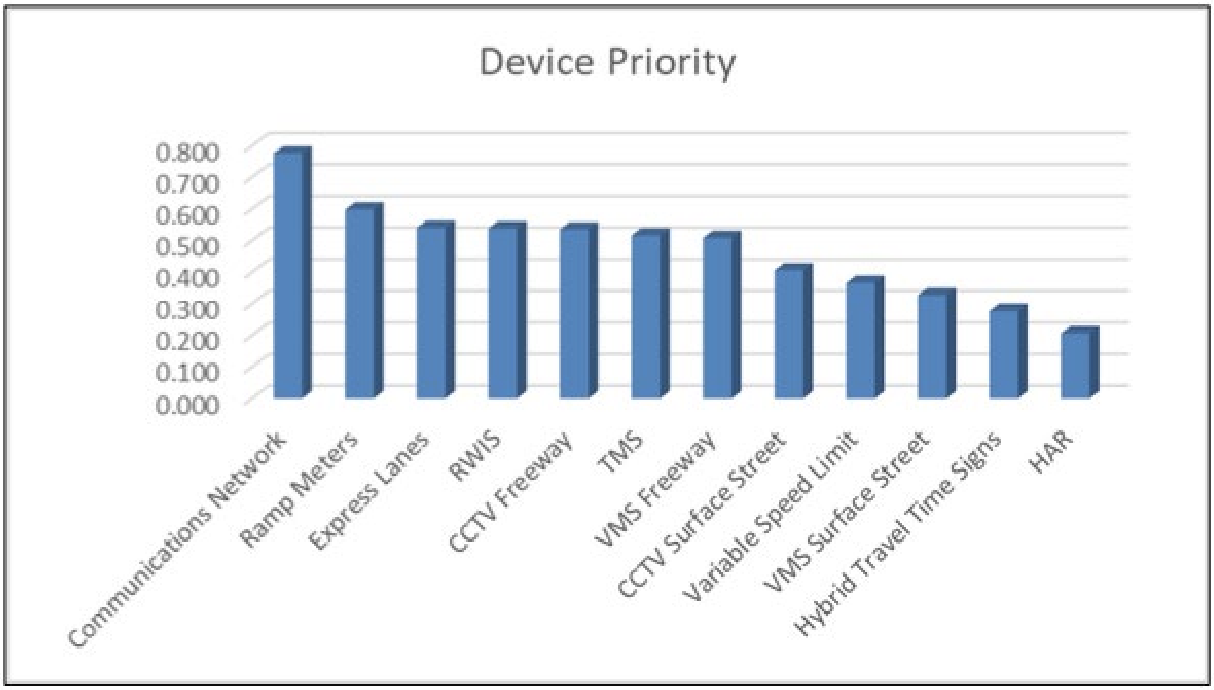


Figure 2. ATMS Device Priority (UDOT, 2019).

The plan for each device includes the following four steps:

1. Estimate the year each device will fail through projection of expected service life from the installation date.
2. Each device will be assigned a replacement year based on this estimate and the relative importance of that device.
3. Determine which devices will fall within a construction project so they can be included in the project scope and funding.
4. Replace the highest priority assets first in each funding year.

UDOT's asset inventory/work order system is a web-based application, which includes a work order management system, inventory control management system, staff management system, work group management system, and other sections. This system working in conjunction with the LCP process allows UDOT to replace each device at the end of its life before it fails to support strategic goals (UDOT, 2019). LCP analysis is under development for the signal system as well.

California Transportation Commission

The California TAMP for fiscal years 2017/18 to 2026/27 was published in January 2018. In addition to pavements and bridges, the California Transportation Commission (CTC) also includes transportation management system (TMS) assets in their TAMP. Their asset inventory in the TAMP included 18,837 assets; 58.8% were denoted as being in "Good" condition and 41.2% in "Poor" condition. At this time, TMS assets are not differentiated between the typical three classifications (Good, Fair, and Poor). TMS are a broad class of technology assets that include hardware, technologies, and processes for performing an array of functions such as data acquisition, command and control, computing, and communications. System failures in these assets can cause measurable economic loss and increase congestion, fuel consumption, pollutant, and crashes (CTC, 2018). The CTC monitors TMS conditions by classifying each asset as being in good or poor condition. Good condition indicates that the asset is operational and not obsolete. Poor condition indicates that the asset is obsolete or non-operational. CTC does not use Fair condition for TMS assets since they consider the asset condition to be binary. These 18,837 TMS assets include closed circuit televisions, changeable message signs, traffic monitoring detection stations, highway advisory radios, freeway ramp meters, roadway weather information systems, traffic signals, traffic census stations, and extinguishable message signs. Table 11 shows the asset performance 10-year targets including TMS assets.

Table 11. Asset Performance 10-Year Targets (CTC, 2018).

10-Year Desired State of Repair			
Asset (unit of measure)	**Good**	**Fair**	**Poor**
Pavement Class I (lane miles)	**60.0%**	**39.0%**	**1.0%**
Pavement Class II (lane miles)	**55.0%**	**43.0%**	**2.0%**
Pavement Class III (lane miles)	**45.0%**	**53.0%**	**2.0%**
Bridge (deck area)	**83.5%**	**15.0%**	**1.5%**
Drainage (linear feet)	**80.0%**	**10.0%**	**10.0%**
TMS (assets)	**90.0%**	n/a	**10.0%**

The CTC also includes operational objectives such as performance management targets for safety, congestion, and level of service. Caltrans currently uses a TMS inventory database to track their statewide TMS assets. The database is populated by district personnel and includes information on each system such as system type, location, and installation date. LCP models are used for TMS assets to include deterioration rates, treatments, and unit costs for TMS assets on the state highway system. Figure 9 shows the estimate for TMS asset needs over the next ten years.

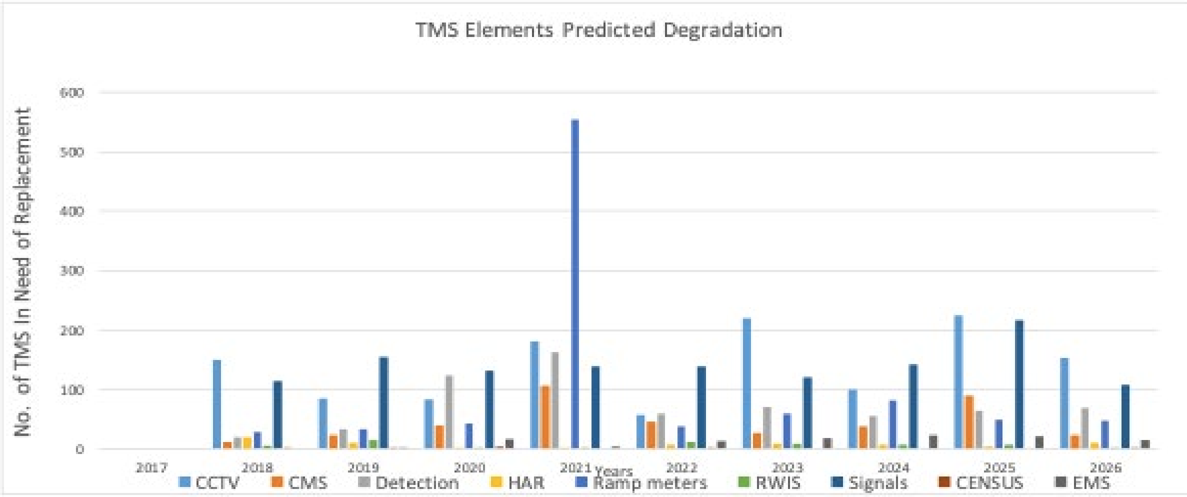


Figure 3. TMS Assets in Need of Replacement over next 10 Years (CTC, 2018).

The LCP analysis for TMS assets in the network included three scenarios. Scenario one is to maintain condition. Here, the current condition of good and poor TMS is maintained. Using deterioration rates and a statewide average unit cost helped predict the amount of work predicted to accomplish annually for the life span of the asset. It resulted in a total estimated investment of $1.2 billion. In scenario two, the focus was on replacing all poor TMS assets. The total estimated investment for scenario two was $4.0 billion. Scenario three focused on a balanced approach, considering a mix of rehabilitation or replacement work. The total estimated investment for scenario three was $1.8 billion. Figure 10 shows the graphical representation of the three scenarios.

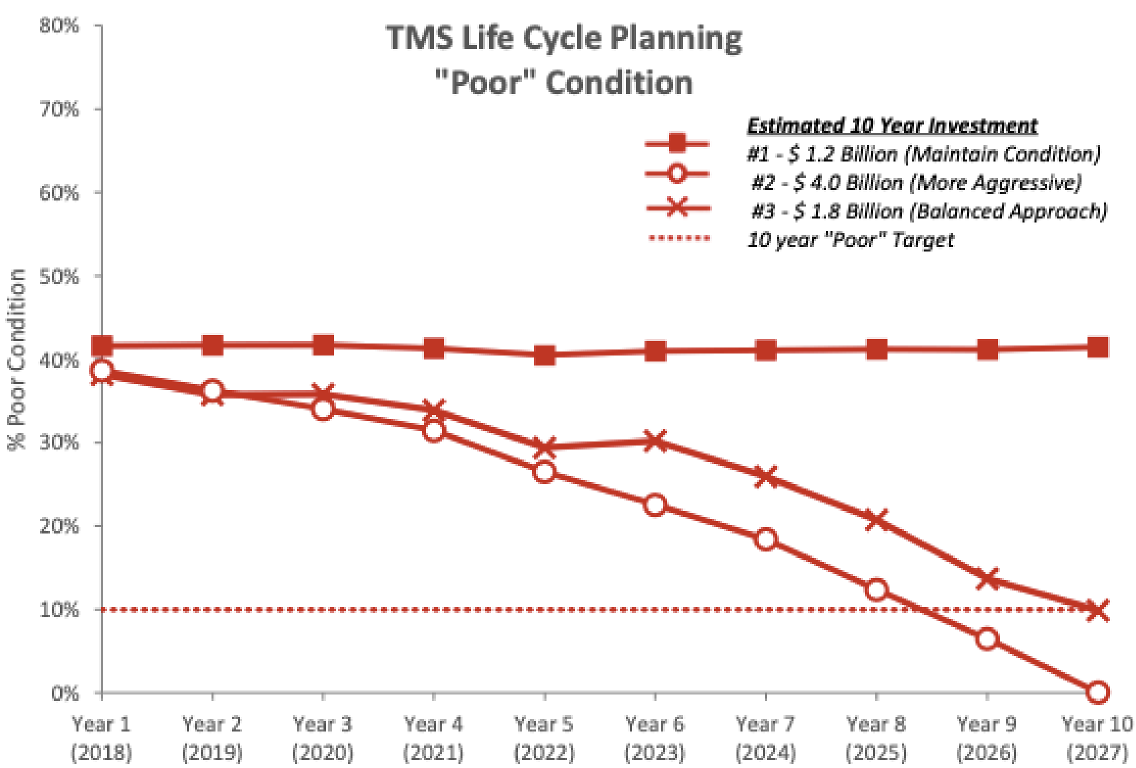


Figure 10. TMS Life Cycle Planning (CTC, 2018).

California anticipates additional maintenance and operations staff will be needed to preserve the TMS inventory as it continues to expand. It is expected that over the next 10 years the increase in average cost to maintain and operate TMS will be over $18.5 million (CTC, 2018).

Colorado Department of Transportation

The Colorado DOT Risk-Based Asset Management Plan was published in June of 2019. The second version of this risk-based plan focused on identification of threats to CDOT's assets and how to manage and monitor those risks over time. In addition, Colorado has developed an *Intelligent Transportation Systems Technical Plan.* Their ITS inventory goes through CDOT's Asset Investment Management System (AIMS) which predicts the long-term performance of each asset given various budget scenarios. Colorado has nearly 3,000 ITS devices installed on the roadway and 1,200 ITS network devices installed in CDOT Node Buildings (CDOT, 2019). While the ITS program is statewide, CDOT regions are responsible for communicating needs for maintaining or acquiring new ITS assets on an annual basis. The ITS inventory goes through CDOT's Asset Investment Management System (AIMS) to help predict the long-term performance of each ITS asset under different budget scenarios. In addition to the assets, ITS also manages 1,600 miles of fiber optic cable statewide. CDOT uses useful life to assess asset condition; useful life is specific to each device and a value of 100 percent indicates that a piece of equipment has reached its useful life. If a value is greater than 100 percent, this indicates that the equipment has exceeded its useful life (CDOT, 2019).

The ITS program has goals to develop statewide policies, procedures, and guidelines on design, maintenance, life-cycle asset management, integration, and operation of traffic signals and ramp meters. The ITS program also must manage different funding scenarios and facilitate decision making. The performance target for device capital replacement has been defined as 90 percent of device useful life, calculated by dividing the device age by the device life cycle (CDOT, 2019). The main sources of funding for the ITS Asset Management Program are the State Highway Fund and federal reimbursement. Table 12 shows the ITS asset management program allocation.

Table 12. ITS Asset Management Program Funding in Millions (CDOT, 2019).

Budget Type Per Fiscal Year	Actual FY 2016-17	Actual FY 2017-18	Budget FY 2018-19	Proposed FY 2019-20
Budget Amount in Millions	$17.6	$25.6	$25.6	$23.5

CDOT also analyzed lifecycle management to help prioritize maintenance and capital replacement activities. ITS tracks device life cycles through inventory of unique device acquisition or installation date, manufacturer's expected life cycle, maintenance costs, and instances of device failure. Since ITS asset lifecycle analysis can be quite challenging, CDOT also uses FHWA's lists of device life cycles, based on state surveys. CDOT also coordinates with local partners for off-system assets (CDOT, 2019).

PLANNING GUIDANCE

Identify ITS assets owned by the agency & develop a common ITS asset framework

ITS technologies include a variety of assets that are meant to improve safety, mobility, and provide environmental benefits including reduced emissions and fuel savings (Zimmerman et al., 2019). Creating a valid and accurate inventory of assets will be extremely important in developing a management approach. Along with the inventory, the agency should plan to document data such as when the devices were installed and the manufacturer's expected useful life for that asset. This will help the agency determine how to measure the asset condition and measure this against the performance targets in their strategic goals. Transportation agency culture is evolving to recognize additional aspects of transportation asset management and planning. Recent state TAMPs show a tendency for agencies to treat ITS assets the way they treat pavement and bridges. ITS assets provide unique attributes as compared to pavements and bridges including software/firmware updates, dependence on communications and power for operation, technological obsolescence, and security concerns (Athey, 2019). When creating a reliable inventory of ITS assets, the agency should create a centralized location for all ITS asset information; a lot of states store ITS asset information across multiple locations such as location and status in their ATMS and condition and maintenance information in other tracking software. Keeping information in one centralized location will make the data easier to aggregate for analysis. Some states have worked on strategies for centralizing ITS asset data; each state tends to find a customized solution and some states have developed dedicated software for tracking their ITS asset inventories (Athey, 2019).

In Wyoming, the agency developed a database to manage their ITS assets and support systems operations. This database can be called upon by other systems in use by office and field staff. Wyoming includes operations-specific information such as status of devices and utility and contact information. Since ITS assets do not have uniform definitions of condition, agencies will develop ways to evaluate ITS asset condition. In South Dakota, a new ITS asset management system enables users to include attachments of photos of their devices to capture photographic evidence of asset condition and structures supporting these devices such as mast arms or housings or wiring (Athey, 2019).

Perform Risk-Based Assessment & LCP

Risk management analysis is a key step in transportation asset management. Additionally, risks and their associated risk management strategies are constantly evolving. Some risks such as environmental and weather hazards and financial insecurity persist, yet everyday new risks such as risks to technology and security must also be included. Transportation assets could be impacted by hazards such as floods or less salient hazards such as hackers targeting the computer networks. For example, Caltrans identified risks related to state size, diverse landscapes and climate, the coastline, and the seismic activity. Earthquakes have, in the past, caused significant damage to portions of highways in the state and could very well do so in the future, especially as weather patterns and events have become increasingly volatile. Each agency should identify the possible risks facing the security of the future of their ITS assets. After risks are identified, they are classified based on likelihood and potential consequences are assessed. Risks that end up in high likelihood of occurrence and or have detrimental consequences need to be addressed first in the mitigation process.

Different methods of risk mitigation can be explored; while some risks will not be tolerable and will require immediate attention, other risks may fall lower on the priority list and may be tolerated until time and resources are available to address it or until it moves into a higher priority risk category or more severe consequence category.

Establish a Data Quality Management Program

An effective asset management system is dependent on reliable, accurate, and comprehensive data. High quality asset data allows agency asset management systems to create reliable recommendations in a timely manner and make informed decisions for allocation of limited funds as well as plan for future repairs, replacements, and reconstructions. High quality data produces high quality decisions, which also increases the confidence of stakeholders that funds are being applied wisely and reasonably. Benefits of implementing a data quality management program include increasing accuracy of reported conditions, increasing accuracy of reported deficiencies and repair needs, and increasing accuracy of budget need determinations.

Without an established data quality management plan, agencies might over or underestimate maintenance needs. Under estimation of maintenance needs can lead to higher risks of asset deterioration or failure and over estimation can lead to wasting limited funding and resources. Higher quality data helps improve data consistency and helps agencies better comply with internal and external data requirements and produces cost savings by helping agencies make better informed decisions and select appropriate treatment recommendations (Shekharan et al., 2006). Managing data quality involves several key steps. Figure 11 shows an example of a data quality management cycle.

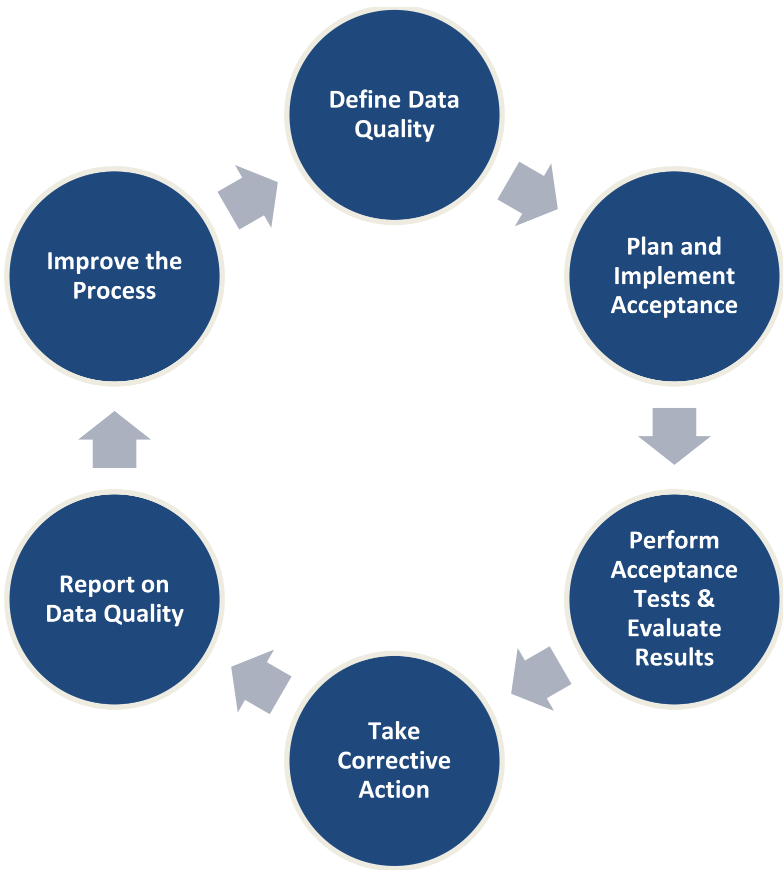


Figure 11. Data Quality Management Cycle (Pierce et al., 2013).

Agencies should define acceptable levels of data resolution and accuracy as well as develop procedures that will be used to produce data and check that it is acceptable quality. Data should be tested against defined acceptability metrics and a process should be in place for recollection or reprocessing of data that does not meet the standards. Statistical analysis can be used to verify asset condition data; the sample size should consist of enough asset sections/objects/pieces to allow these samples to be a representative sample for the population. Required sample size can be determined using Equation 1 below.

$$n = (\frac{z_{\sigma/2}\sigma}{E})^2 \quad (1)$$

Here n is sample size, $z_{\sigma/2}$ is the Standard Normal Distribution (1.960 for a 95% confidence interval or 1.645 for a 90% confidence interval), σ is the population standard deviation and E is the tolerable bias. Checking data against acceptable standards often includes assessing differences in key values such as mean condition values, which can be done with a paired t-test to determine if the data collected is under or overestimating actual asset condition. However, other statistical methods can be used; the British Columbia MoTI uses the kappa statistic, the Alabama DOT uses a Person's r correlation, and the Nebraska DOR uses multivariate factor analysis (Pierce et al., 2013). Agencies should also define data acceptance criteria; for example, a DOT may decide that for IRI data, 95% needs to be within acceptable limits and if not, the deliverable based on this data is rejected.

Regular reporting on data quality standards, procedures, equipment, staff involved, processing methods, and results of acceptance tests will provide transparency of data management efforts and improve confidence in data driven results and decisions. Finally, the experiences and results can be used to improve the data quality management cycle over time. If issues are found in the data quality, there are several possible corrective actions the agency can explore including recalibration of equipment, retraining of personnel, and re-collection of data. Agencies should also consider the practical limits to the cost-quality tradeoff of their quality management procedures; optimal quality level for an agency is not necessarily the highest quality possible. A quality management program also must be cost effective and the level of data quality that is the most cost effective will vary by agency based on available resources, data collection methods used, and agency size.

3. Survey Results

INTRODUCTION

While it is currently only required by federal code to manage pavement and bridge assets at a statewide level, evolving technologies and new industry standards increase the number and type of assets other than pavements and bridges under a transportation system's authority. In order to address and maintain a transportation system's safety and mobility needs for all of its assets, these Intelligent Transportation Systems (ITS) and Transportation Systems Management and Operations (TSMO) assets need to be managed and maintained following similar philosophies.

To help Missouri address these issues, a research project was initiated to consider asset management for mobility. This section provides a summary of the survey results. The purpose of the survey is to understand what states agencies are doing in terms of incorporating ITS and mobility assets into their TAM processes, including what types of asset classes they track and what types of data they track for each asset class. The survey also includes questions about how they are storing and managing this data and what resources they utilized to incorporate the ITS and mobility assets into their TAM processes. A major difference between asset management of pavements and bridges and ITS and mobility assets is how to classify their condition. While standardized methods exist for classifying pavement or bridge condition, these same methods are not available for ITS and mobility assets. Additionally, while pavement and bridge condition are a continuum, where the asset can be in perfect shape or degrade in different areas along this continuum before reaching a state where it needs to be replaced, ITS assets are very different. Most ITS assets are either fully functional or they are not; the asset may go from completely functional to not working at all due to many factors. The condition of an ITS asset does not necessarily indicate its chances of failing at a particular time.

In this survey data, many agencies report having trouble classifying or rating ITS and mobility asset condition. These results help identify the items being tracked and what of those items could be recommended for tracking for other agencies. Those recommendations are discussed in the summary section, after the discussion of the survey data. In the summary, the results of the survey are used to inform how other agencies might start implementing ITS and mobility asset tracking into their TAM processes, what ITS asset classes they can consider tracking, and what type of data to include for those asset classes.

SURVEY STRUCTURE

The survey was built using Qualtrics, which allows for dissemination via an anonymous link and provides survey feedback about the usability of the survey before it is published. The survey questions included in this study are included in Appendix A. The survey link was sent to identified AASHTO RAC contacts in all 50 states in mid-December of 2021, with responses requested by December 31st, 2021. As of mid-January of 2022, 15 total responses have been received. The purpose of this report is to summarize the survey results received and to aid in decision-making regarding querying additional responses. Not every respondent answered every question; some state agencies indicated that due to upcoming plans to incorporate ITS assets into the TAM process, their responses to the survey would be limited.

SURVEY RESPONSES

The state agencies that have responded to the survey include:

- Alaska Department of Transportation and Public Facilities

- Delaware Department of Transportation
- Illinois Department of Transportation
- Kansas Department of Transportation
- Kentucky Transportation Cabinet
- Michigan Department of Transportation
- Minnesota Department of Transportation
- North Dakota Department of Transportation
- Nebraska Department of Transportation
- Nevada Department of Transportation
- New Jersey Department of Transportation
- Ohio Department of Transportation
- South Dakota Department of Transportation
- Utah Department of Transportation
- Washington State Department of Transportation

Respondent roles within these agencies included ITS program manager, ITS coordinator, ITS engineer, research coordinator, senior director of mobility, traffic operations administrator, traffic management center manager, traffic management center director, asset management program manager, ITS project manager, ITS unit manager, and program manager of traffic operations. Respondents were asked to report how long they have been in this role and were given four options: 6 months to 3 years, 3 to 6 years, 6 to 10 years, and more than 10 years. Figure 12 below shows the breakdown of the responses to this question. As can be seen in the figure, most respondents have been in their roles for 6 years or less, with the majority (40.0%; 6 respondents) reporting having been in their role for 6 months to 3 years.

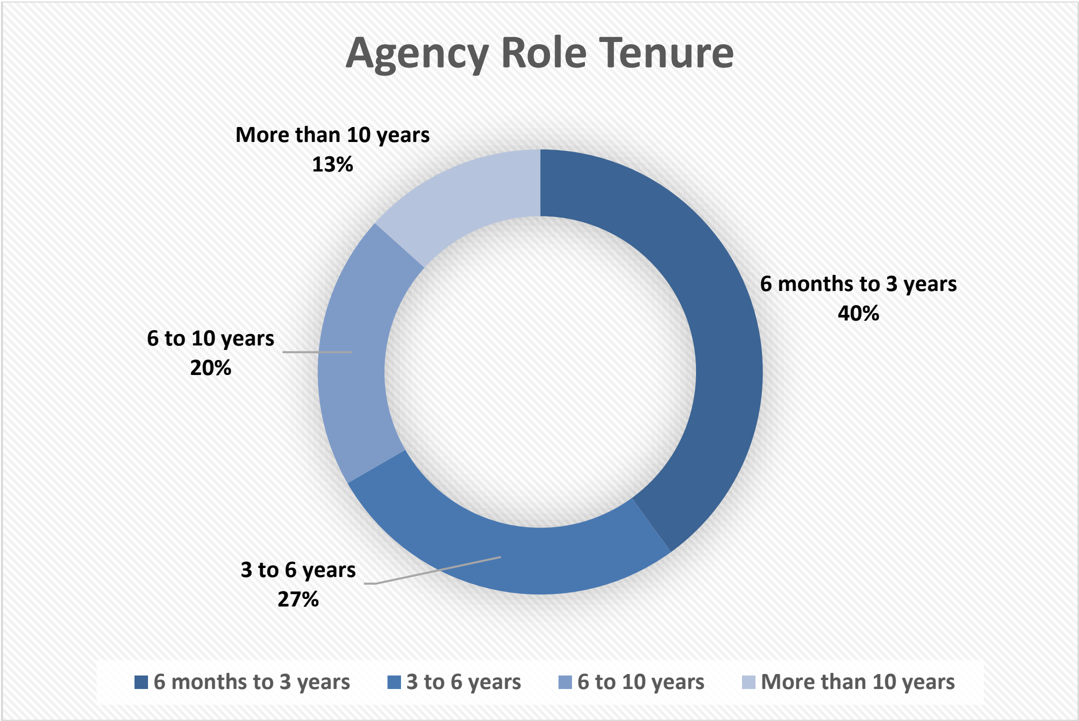
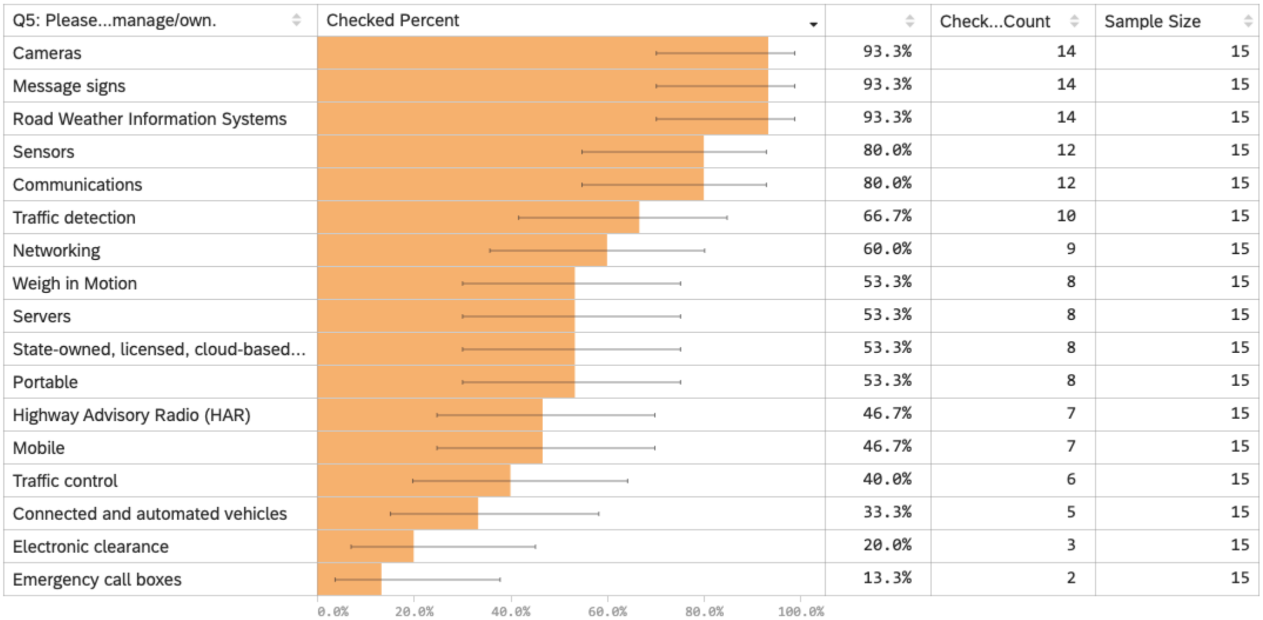


Figure 12: How long served in reported role.

Next, respondents were asked to select from a list any ITS and mobilty assets that they own and/or manage. Figure 13 shows the results of these responses.



Q5: Please...manage/own.	Checked Percent		Check...Count	Sample Size
Cameras		93.3%	14	15
Message signs		93.3%	14	15
Road Weather Information Systems		93.3%	14	15
Sensors		80.0%	12	15
Communications		80.0%	12	15
Traffic detection		66.7%	10	15
Networking		60.0%	9	15
Weigh in Motion		53.3%	8	15
Servers		53.3%	8	15
State-owned, licensed, cloud-based...		53.3%	8	15
Portable		53.3%	8	15
Highway Advisory Radio (HAR)		46.7%	7	15
Mobile		46.7%	7	15
Traffic control		40.0%	6	15
Connected and automated vehicles		33.3%	5	15
Electronic clearance		20.0%	3	15
Emergency call boxes		13.3%	2	15

Figure 13: ITS assets managed/owned.

The options for selection are listed below.

1. Cameras
2. Connected and automated vehicles
3. Emergency call boxes
4. Electronic clearance
5. Highway Advisory Radio (HAR)
6. Message signs
7. Sensors
8. Road weather information systems
9. Traffic control
10. Traffic detection
11. Weigh in motion
12. Communications
13. Networking
14. Servers
15. State-owned, licensed, cloud-based software
16. Mobile
17. Portable
18. None of the above

As can be seen in the figure, the ITS assets that are the most common among these responding state agencies include cameras, message signs, Road Weather Information Systems, sensors, communications, and traffic detection. Approximately half of respondents reported Weigh in Motion, servers, state-owned, licensed, cloud-based software, and portable assets. Least common assets were electronic clearance (reported by 3 respondents: Delaware, Illinois & South Dakota) and emergency call boxes (reported by 2 respondents: Minnesota & Nevada).

Respondents were asked to describe what specific information they are currently tracking for life cycle management of each ITS asset they selected from the previous list. South Dakota reports tracking make, model, serial number, MAC address, IP address, and other information dependent on device type. They also track purchase date, cost, installation history, repair history, highway number, mileage reference markers, latitude, longitude, South Dakota Department of Transportation (DOT) region, area, maintenance reporting unit, and expected life. They will track other items dependent on the asset. Several other states reported tracking installation dates and costs as well, including Alaska, North Dakota, New Jersey, Ohio, Michigan, Illinois, and Kansas. Kentucky reports tracking replacement costs. In addition to installation dates, North Dakota is tracking warranty dates and assigned each device an expected life to determine approximate replacement date. New Jersey tracks manufacturing dates and replacement costs in addition to installation dates. Ohio tracks warranty information, inspection condition, and installation dates. Utah Department of Transportation's survey respondent reported that they have only been in the position a short time and are still onboarding to the ITS data tracking process, but has plans for tracking installation dates and costs among other key data items. Minnesota's tracking varies by asset, but methods are predominantly age-based.

Nevada is tracking ITS asset health for CCTV, RWIS, DMS, and HAR. Nevada DOT formally implemented this as part of their Transportation Asset Management Plan (TAMP). They perform preventative maintenance and life cycle replacement based on their ITS asset health index, which is based off of the manufacturer's recommended life cycle. In addition to installation dates, Michigan DOT tracks maintenance that was performed on their ITS assets. Illinois DOT tracks device type, model name and number, installation date, location, Illinois DOT district, and other information when applicable, including direction of travel, IP address, internal Illinois DOT ID number, power source, and mounting height. Delaware DOT tracks inventory of ITS assets, but tracks limited data on features. In addition to installation dates, Kansas also tracks replacement costs and planned replacement timelines. Nebraska DOT reports still developing their specific asset management plan and life cycle metrics for its ITS assets and that this is an agenda item for the coming year.

For agencies tracking specific information on their ITS assets, they were asked how they are collecting this information. Many states reporting using methods other than visual or automated inspections or spreadsheets for information collection for these ITS assets.

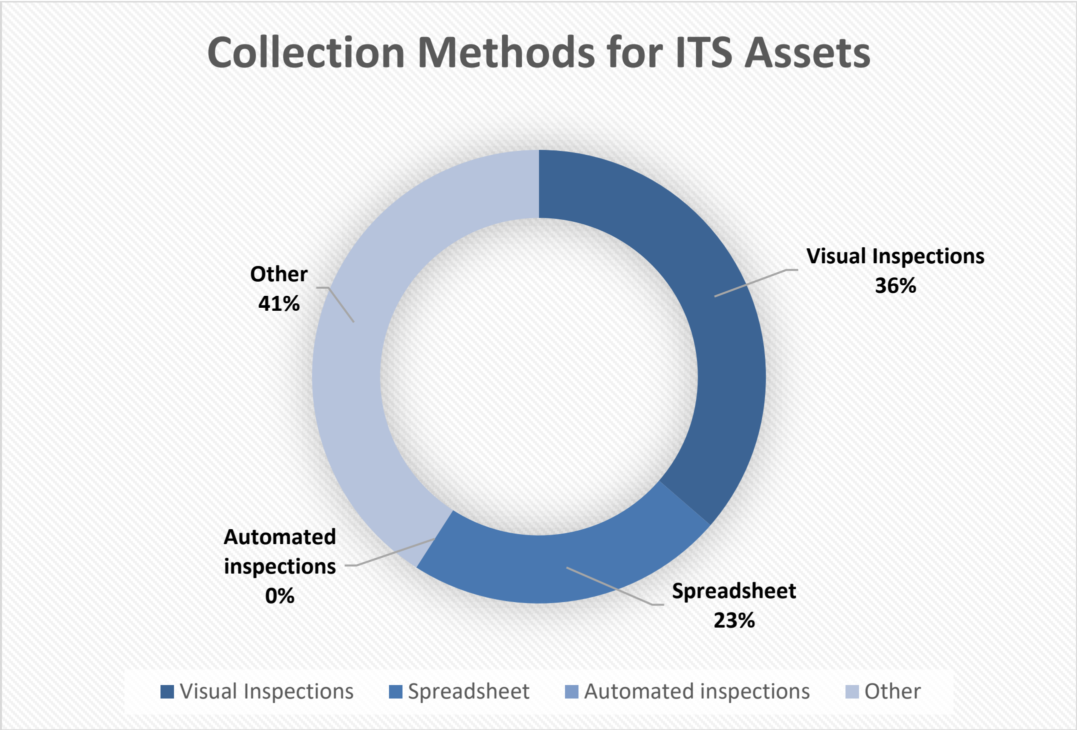


Figure 14: Information collection methods.

No states reported using automated collection methods. States were asked if they store specific ITS asset costs such as installation or replacement costs. A total of 6 respondents (46.2%) said yes, 5 respondents (38.5%) said no, and 2 respondents (15.4%) said sometimes. For those 8 respondents reporting yes or sometimes, they were asked how they are storing these costs. Kansas stores specific asset costs in their accounting system. Delaware DOT uses an asset management software called Maximo. Illinois DOT utilizes tracking sheets with contract numbers. Nevada uses their ITS asset management program to store these costs. In Minnesota, primarily internal (staff) maintenance costs and materials are captured via work orders in the transportation asset management system. Installation cost data is available by mining contract data, but this is not typically captured. Utah reported that they sometimes store specific ITS asset costs, but the storage method was not known. New Jersey stores this data per contract requirements and South Dakota stores bid item cost histories in their ITS asset management system.

Next, respondents were asked if their agency tracks asset condition. A total of 8 (61.5%) said yes while the remaining 5 (38.5%) who answered this question said no. A reminder that not all questions were answered by all respondents dependent on their level of ITS asset management activity in their state. Any respondents answering yes were asked to report what rating method is used.

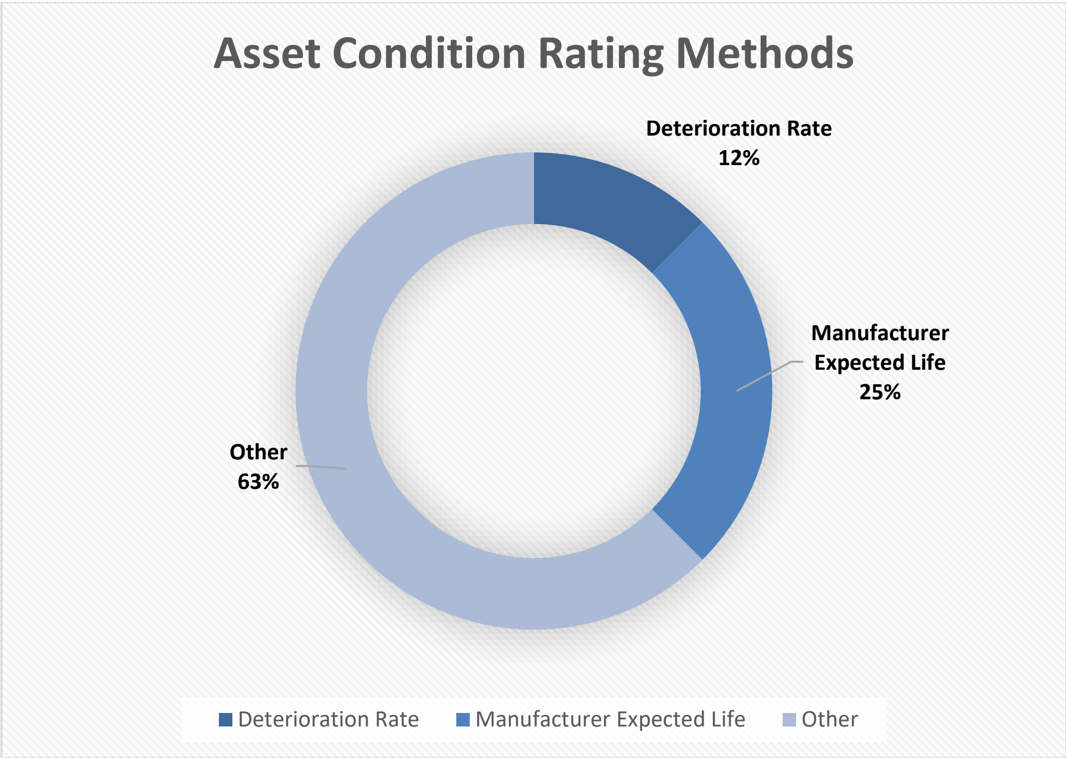


Figure 15: Rating methods.

For those answering other, they were asked to describe the methods used. Some of these other methods included useful condition (Delaware), average lifespan based on installation date (Michigan), various methods dependent on asset class including condition used relative to structural components or age used relative to electrical components (Minnesota), methods based on inspection condition and technology advancements (Ohio), and expected life, though estimation of this for ITS assets is challenging (South Dakota). States were also asked if they use condition ratings or expected service life to predict future need. A total of 13 answered this question with 7 (53.8%) responding yes and the remaining 6 (46.2%) responding no. For those replying yes, when asked to describe, Kansas DOT reported that expected service life is included in the asset management plan. Illinois reports that most districts program replacement of assets based on expected service life or asset condition. Minnesota responded that forward-looking analysis forecast waves could be used. Ohio DOT said this is done only for sign and signal support structures. North Dakota assigns expected years of service for devices to determine replacement needs. South Dakota DOT is just starting to get sufficient history to project life on some ITS assets. The most difficult to predict is sudden failure due to electronic failure or damage from traffic or weather events.

State agencies were asked what software programs are used and if they were purchased or developed in-house. Kansas uses SWRI Active ITS ATMS software, but no asset management software. Delaware DOT uses Maximo, which is a commercially available software package.

Illinois utilizes Excel and in-house asset tracking programs. Michigan uses software that was developed by outside consultants. Nevada uses an asset management program that was developed by Mobile MMS, which is customized to their needs. Minnesota reports using AgileAssets, which was purchased to replace an in-house legacy system in 2015. This program is deeply integrated with other systems and asset classes and Minnesota reports that it is working very well for them. Ohio DOT uses ServiceNow, ESRI, and Collector. New Jersey DOT uses the manufacturer's software per device (signs, cameras, etc.) for version numbers and upgrade alerts. North Dakota uses ArcMap. Kentucky uses an in-house program (goky.ky.gov). Alaska uses national architecture for ITS data and South Dakota uses a COTS product called BarCloud from ASAP Systems.

The survey then asked respondents to report if they currently include ITS assets in their Transportation Asset Management processes (TAM processes). A total of 13 answered this question with 7 (53.8%) responding yes and the remaining 6 (46.2%) responding no. The 7 agencies that reported they do include ITS assets in their TAM processes include Alaska Department of Transportation and Public Facilities, Ohio Department of Transportation, Utah Department of Transportation, Minnesota Department of Transportation, Nevada Department of Transportation, Michigan Department of Transportation, and Delaware Department of Transportation.

Another key question includes what resources state agencies used to integrate ITS assets into the TAM process. Delaware DOT utilized electronic scanning devices. Michigan DOT reports that ITS has its own program where this is managed. Nevada DOT used consultant support to develop their TAMP; the agency member who responded to the survey was not directly involved in this process but believes this was based on Federal guidance. Minnesota utilized TAMP project management staff, ITS staff, and asset management staff as well as some use of consultants for the life cycle planning pieces. The Ohio DOT's Office of Data Governance manages the policy, collection methods, integration, and standards. All the Ohio DOT ITS field data was collected via a consultant adhering to these requirements. Alaska used strategic planning efforts and collaboration.

Respondents were asked if they found resources and planning guidance on incorporating ITS and mobility assets into the TAMP to be sufficient; a total of 6 answered with 4 (66.7%) saying yes and the remaining 2 (33.3%) saying no. They were also queried on what feedback they have about the resources available and how it could be improved. Minnesota DOT mentioned that if referring to technical resources, identifying methods other than age-based methodology would be helpful. Alaska DOT responded that the resources could be more easily accessible and distributed more widely. No other respondents provided feedback in this area. Respondents who indicated they do not currently include ITS assets in their TAM process were asked if their agency has plans to integrate these items into the TAM process. This question yielded 6 total responses; only 1 respondent (Illinois DOT) indicated yes while the remaining 5 indicated no. For the follow-up question of when they plan to integrate these items into the TAM process, Illinois DOT answered they did not currently know the timeline.

Lastly, states were asked what the major challenges they foresee for agencies looking to integrate ITS assets into a TAMP and what advice they have for states considering tracking ITS and mobility assets. Kansas DOT sees staff resources as a major challenge and recommends agencies schedule a consultant project to summarize information and provide a plan. Delaware DOT indicated that they believed the biggest challenges would be creating a baseline for existing inventory, time, funding, and bringing in knowledge to get started. They note that there is value in tracking assets, but that it takes a lot of resources and time. Illinois DOT indicated that the large number of differing asset types and the large number of actors (nine districts multiplied by the number of people/units responsible for individual asset types) is the biggest challenge. They recommend using a simple system that people are willing to engage with as that is better than a more complex systems that isn't usable.

Michigan DOT sees information accuracy resources as a challenge and recommends ITS assets and mobility tracking is developed as a separate program as opposed to integrating into the TAMP. Nevada is currently still in the inventory phase, inputting all the assets into the AMP and tracking their current health and manufacturer information. Due to staffing, they will need contractor support to finish this inventory. Training district staff to get them on-board with new methodologies has also been a challenge. They are looking to expand in the future using the manufacturer's recommended lifecycle for the health index by developing device specific key performance indicators. Minnesota DOT cites lack of data, personnel, and bandwidth as challenges and recommends agencies think long-term and invest accordingly in systems and processes. Ohio DOT responded that dedicated staff and resources to maintain the integrity of the data is a challenge and that the data is used across many ODOT offices such as planning, design, forecasting, and construction, making it very valuable. New Jersey did not cite challenges but did respond that keeping up with the structural evaluation of ITS devices (poles, gantries, etc.), continuously updating servers (security, version upgrades, etc.), and working to integrate end of life documentation would be helpful.

North Dakota DOT cited collecting all the information and keeping it up to date as a major challenge and advised keeping records up to date as the devices change often and it is hard to keep all the information accurate in the databases. Alaska sees having to start from scratch as a major challenge and recommended utilizing methods other states are using. South Dakota, while answering that they do not have current plans to integrate ITS into the TAM process reports that they might, but it depends on decisions by other staff members who work to maintain the TAMP. Major challenges would include acquiring and maintaining accurate inventory and collection data, predicting future condition and need, and quantifying the benefit of ITS assets compared to pavements and bridges. They feel that tracking is important and worthwhile and recognize that there are some important differences between ITS assets and pavements and bridges. While pavements and bridges typically deteriorate slowly and steadily, ITS assets (often electronic) can fail suddenly, so predicting condition is not as easy. Additionally, ITS assets can move from one location to another, so the ITS asset management system must be able to track history both by device and location. For example, a camera may be installed in one place, removed for repair, and then reinstalled at another place.

SUMMARY & DISCUSSION

Based on the survey responses, there are several asset classes that are recommended for tracking. In addition, this section will identify what types of data can be collected for those asset classes. A major takeaway from the survey is that conditional information for ITS and mobility assets is not a feasible data item to collect at this time; as mentioned, most ITS and mobility assets either work completely or do not work at all. As some agencies mentioned, the asset often works until it fails entirely. This makes data collection methods used for pavement and bridge assets (such as condition) not suitable for ITS and mobility assets.

Table 14: ITS asset classes tracking recommendations.

ITS Asset Class
Cameras
Message signs
Road Weather Information Systems
Sensors

ITS Asset Class
Communications
Traffic Detection
Servers
Weigh in Motion
Highway Advisory Radio (HAR)
State-owned, licensed, cloud-based software

Table 15: ITS Data collection recommendations.

Data to Manage
Installation date & installation costs
Device type, model name & number, serial number
Warranty information
Installation location (current and any past locations) including highway number/direction, mileage reference marker, latitude, longitude, etc.
Manufacturer's recommended lifecycle
Maintenance records (maintenance that has been performed and when)
Replacement costs
Location

This set of recommended asset and data types were presented to the project committee. The committee ultimately selected a modified set described in the following chapter. When do you plan to integrate these items into the TAMP process and what resources do you plan to utilize?

1. What are the major challenges do you foresee for agencies looking to integrate ITS assets into a TAMP?
2. What advice do you have for states considering tracking ITS and mobility assets?

4. Tool Development

MoDOT ITS Spreadsheet Background and Design Features

Asset management is a tool that agencies can use to help define goals for assets and prioritize resources in the decision-making process, given limited budgets and resources. Transportation asset management approaches vary across different State DOT agencies and is further complicated by the deployment and management of new technologies. Traditionally, transportation asset management has focused on pavements and bridges: to incorporate Intelligent Transportation Systems into asset management, new software, practices, or processes may be needed. As part of this project, ARA was tasked with developing an Asset Management Tool for Mobility and ITS assets. The goal of this task is to provide a useful, simple tool for tracking and managing ITS information that is accessible to all users, easy to update, and user-friendly. A preliminary inventory, management, and analysis tool was developed to demonstrate the functionalities of a full-service ITS asset management tool.

In order to fulfill the project goals of developing a tool with limited training required that functions statewide across districts, and provides inventory and analysis functions, a Microsoft Excel spreadsheet tool was created. Using this tool, MoDOT is able to keep all their own data and records in house, eliminating any data security concerns that can arise from using transportation asset management tools. This inventory tool also allows for easy preliminary analysis given certain constraints, allowing the user to simply develop budget and other reports, or identify needed potential revenue to fulfill broader agency goals.

The tool contains the following features:

- Start-up menu
- Temporary database creation categories
- Temporary database to run reports
- Add records to existing permanent database
- Permanent database
- Create reports

Many options were considered for the structure of the database itself. Originally it was thought that having a database that contained only the asset types and attributes desired by each division/District be developed. However, the structure is now designed to contain all items and attributes available, and the individual user is allowed to choose only his desired items for review and reporting. This allows, if desired, any or all locations to merge their data for statewide review or analysis without the issue of multiple database structures.

The database spreadsheet utilizes multiple worksheets for ease-of-use and differentiates functions of the spreadsheet. Upon starting the tool, users will see a drop-down menu where they are able to select their district. This selects only the relevant counties for dropdown lists when adding a record to the database. From this point, users will be prompted to continue to their desired function: to either set up data to be tracked, add records to the database, or work within the existing database.

The existing database is an essential component of the tool. Having standardize data collection headings on any databases will allow for easier state-wide data collection and analyzation processes and can automate some of these features. Current database design allows for the collection of a variety of data on records including, point coordinate, log mile, remaining service life, installation date, manufacturer, serial number, asset class, and county among others. If MoDOT wishes to move forward with this project, these headings can be modified to incorporate what data MoDOT currently keeps, to allow for easier integration.

If users would like to add a record, they can do so on an adjacent worksheet. This workbook utilizes different worksheets for different programmed functions so users are easily able to navigate to what they want to do. These different functions have been programmed using buttons, excel macros, and VBA codes. If users would like to add a record, they can enter any information they have on the record in the add data worksheet. Data validation is active on the worksheet; for a variety of categories, there are drop-down menus users can choose to make the record entry process easier (such as N, E, S, or W for Direction). When users add a record to the database, it copies the data entered from the add entry worksheet to the top of the database worksheet and automatically calculates the remaining service life and age of the asset. The macro then is set to clear the data entered in the data entry worksheet to allow users to enter another record. Every time data is entered, the temporary database worksheet is updated.

The intended goal for this tool is not just data inventory, but also analysis and the ability to produce reports and other outputs. To accomplish this in a way that is most meaningful for users of different counties who would choose to highlight different aspects of assets, a way to filter assets and data displayed in the reports was needed. Instead of appending or changing the permanent existing database, it was decided that a temporary database is needed to be used to create budget and other reports that allows user to highlight only the data and asset classes that they want to. As such, users have the ability to set-up their temporary database in an adjacent worksheet. Users can select which attributes of an asset they would like to include in their temporary database, and therefore their reports (such as only including relevant information, such as RSL, cost to replace, and location information, or including all information, such as serial number, make/model, or even the installation date). Users can also select specific assets they want to look at, instead of looking at all assets in the database. Upon creating a temporary database using the macro-enabled button on this worksheet, the existing temporary database is destroyed and a new one is created given the parameters users have selected on this page.

Finally, to expedite the report creation process, four preliminary budget analysis and reports can be created using macro-enabled buttons. These four situations capture a variety of different analysis including general cumulative cost analysis, reports that examine service life, asset classes or even route designations. There are no limits to how many of these reports can be created. All reports draw on the selected data from the temporary database. The first report summarizes the cumulative cost to replace all assets and displays at what point an estimated budget is insufficient to replace assets. A second report can be created that sorts data by remaining service life, outlines the assets that need to be replaced within the next year, and creates a cumulative cost for each asset. A third report sorts data based on asset classes, displays the remaining service life of assets that need to be replaced within the next year first, and runs two cumulative costs, one for all assets, and one for each particular asset class. The fourth and final programmed report sorts assets by route designation and runs a cumulative cost for all assets and for each route designation. If a full tool is moved forward, additional programmed reports can be assigned to this worksheet based on MoDOT's perceived needs. Introduction and scope of work

Since Departments of Transportation and organizations of all types need to maintain the facilities and assets they manage, as they are integral to providing clients and the public key services and access to employment, leisure, and other opportunities. These assets must be managed given a limited amount of money, capacity, resources, and staff-hours. Proactive maintenance of these resources require the department to consider the various maintenance, rehabilitation and replacement options of said assets against the costs of the options, proper timing of options, benefit of options, current asset conditions, expected future asset condition, and the availability of resources to perform the work. This form of asset management is further complicated by size and number of assets needed to be managed within a state and new asset classes requiring new approaches and data collection methodologies, such as TSMO and ITS assets. To provide a simple, easy to use, dynamic, and financially flexible tool, we are ultimately recommending that MoDOT use the Infrastructure Asset Management (iAM) tool, an open-source asset management data analysis tool once the user community is comfortable with the prototype Excel based option.

Defining the assets and establishing how they will be tracked, what information will be collected, and how the information will be used for asset management is done differently at each state. Signal & ITS asset management involves managing assets that are installed on the highway ('field location') as well as assets that are in warehouses (or shop locations) for repairs; those being transferred in the state; some in testing; and others purchased new from a supplier or salvage. For instance, Wisconsin DOT uses an internally developed software approach to help track and monitor the management of these assets (signs, signals, lights, pavement marking, video equipment, fiber network) Our research and expertise in the field of asset management suggests that there are currently two general sets of practices in the industry:

- Agencies who maintain inventory, work planning and operations of assets at the site level (e.g., North Carolina DOT, Louisiana Department of Transportation & Development, Georgia DOT).
- Agencies who include further detail and are doing this at the individual component level (e.g., Minnesota DOT, New York State DOT). Each asset component is tracked using an ID, and its life-cycle events are managed, from the time the asset is purchased from a supplier to the time it is installed in the field and reaches the end-of-life. An asset may in fact be uninstalled from the field location multiple times during its life cycle and may get repairs done in the shop or warehouse before it is transferred back.

ARA was tasked with developing an Asset Management Tool for mobility and ITS assets. The goal of this task is to provide a useful, simple tool for tracking and managing ITS information that is accessible to all users, easy to update, and user-friendly. We are proposing a spreadsheet tool to be used in close concert with the TAC and MoDOT Research to understand the needs of the varying units prior to and as the tool is being developed. This can ultimately lead to use of an open-source analysis tool, iAM, as opposed to a more traditional model, as this open-source model allows for financial flexibility, easy access, sharing across departments, and helps manage data privacy concerns.

5. Conclusions and Recommendations

The research team strongly recommends MoDOT continue on its expansion of using asset management and data-driven approaches to manage its infrastructure components. The use of TAM principles will enhance the ability to ensure that the residents of Missouri receive the economic benefit of transportation investments for years to come.

We have observed that there is a wide diversity of opinion within MoDOT on how best to manage ITS and mobilty assets. There are myriad approaches within the various districts and none of the systems are integrated with each other. This has substanitally limited the abilty to adopt a common approach for assets and influenced the decision to develop a spreadsheet based tool with minimal features.

Several specific recommendations are presented:

- MoDOT should consider **hosting a peer exchange** to further advance and discuss the management practices in other states for ITS and mobility infrastructure. This peer exchange would build upon past Federal and state specific work to encourage a wide range of approaches and software tools.
- MoDOT could consider supporting the ongoing conversion of the spreadsheet tool to a **web-enabled open source software like iAM**. This approach would provide a user interface and reporting element that is missing from the spreadsheet prototype.
- Additional research should be conducted on the **expected lifecycles of equipment like fiber optic lines that have a long linear profile**. These assets have a unique life expectancy and condition ratings. The failure can be sudden and catastropic on some of this type of equipment.
- Complete a **self asssessment on asset management practices** throughout the agency. Understand how the organization is currently approaching their transportation asset management processes, what data is collected, and how this integrates across the different districts beyond pavement and bridge or ITS and mobility assets.
- Incorporate transportation asset management **into agency priority and policy goals**. For effective management of transportation assets, data collection efforts, allocation of finite capacity and financial resources, and prioritization of certain assets or certain asset classes needs to linked to an agency's priorities, goals, and policy goals. Ensuring that TAM and prioritization of scarce financial resources moves strongly in tandem with MoDOT's agency priority goals is integral to reach the intended cost-and-time savings of transportation asset management.
    - Consider ways that ITS Asset Management and increased ITS asset deployment furthers agency priority and policy goals. ITS assets allow different organizations to communicate effectively within the transportation system to reach efficiencies in the mobility of goods, people, and services, and improve traffic management systems. In light of ITS gaining importance in transportation networks, considering how the effective use of these assets can help agencies achieve policy goals, such as reduced congestion or increased safety, efficiency, or reliability is important
- **Incorporate equity considerations into ITS TAM**. Transportation systems in the United States have a historical legacy of exclusion, physically separating communities and further inequities and inequalities in American cities. As ITS assets become more mainstream and are incorporated into traditional asset management strategies, a window of opportunity to mainstream equity considerations into ITS Asset Management

to further incorporate inclusivity into the mobility system becomes integral for State agencies managing said assets.

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Additional Sources

Below are the four Transportation Asset Management Plans that explicitly prioritize and report on the management and performance of ITS/mobility assets. Other states report on assets beyond pavements and bridges, but these four specifically differentiate Intelligent Transportation System, Transportation Management System, and Advances Transportation Management System assets in their most recent TAMPs. They include similar advanced devices that help promote mobility and reduce congestion for their respective DOTs and are some of the best examples for us to consider:

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In addition, the Colorado DOT has prepared an *Intelligent Transportation Systems Technical Plan.* Their ITS inventory goes through CDOT's Asset Investment Management System (AIMS) which predicts the long-term performance of each asset given various budget scenarios.

APPENDIX A: SURVEY QUESTIONS

1. What is your name?
2. What is your state agency name?
3. What is your role in this agency?
4. How long have you been in this role?
    a. 6 months to 3 years
    b. 3 to 6 years
    c. 6 to 10 years
    d. More than 10 years
5. Please select any ITS and mobility assets you manage/own
    a. Cameras
    b. Connected and automated vehicles
    c. Emergency call boxes
    d. Electronic clearance
    e. Highway Advisory Radio (HAR)
    f. Message signs
    g. Sensors
    h. Road weather information systems
    i. Traffic control
    j. Traffic detection
    k. Weigh in motion
    l. Communications
    m. Networking
    n. Servers
    o. State-owned, licensed, cloud-based software
        i. Mobile
        ii. Portable
    p. None of the above
6. For each item you selected, what specific information are you currently tracking for life cycle management of these ITS assets? Examples include manufacturing dates, installation dates, replacement costs, deterioration models, planned replacement, etc.
7. How are you collecting this information?
    a. Visual inspections
    b. Automated inspections
    c. Spreadsheet
    d. Other

8. Does your agency store specific ITS asset costs? (Installation? Replacement?)
9. If yes or sometimes, how are you storing these costs?
10. Does your agency track asset condition?
11. What rating method is used?
    a. Remaining service life
    b. Deterioration rate
    c. Manufacturer expected life
    d. Other
12. Does your agency use condition ratings or expected service life to predict future need?
13. Does your agency use any software programs to collect and/or store ITS data?
14. What software programs are used and were they purchased or developed in house?
15. Do you currently include ITS and mobility assets in your TAMP?
16. What resources did you use to integrate ITS assets into the TAMP?
17. Did you find resources/planning guidance on incorporating ITS and mobility assets into the TAMP to be sufficient?
18. What feedback do you have about the resources available and how it could be more helpful?
19. Does your agency have plans to integrate these items into the TAM process?