# Ancillary Asset Data Management in State Departments of Transportation: Enhancing Current Trends in Data Collection, Management, and Utilization

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**Abstract**

This study investigates the current ancillary asset management practices of state Departments of Transportation (DoTs) in the United States through a combination of a comprehensive survey of 39 state DoTs, cluster analysis, and case examples of the Michigan and Minnesota DOTs. The research examines how state DoTs collect, manage, and utilize data for 38 different ancillary asset classes which reveals quite significant variations in data collection methods, frequency, repository management, and updating processes across different asset types and state DoTs. Cluster analysis identified distinct patterns for the management practices; generally, the assets that were identified as safety-critical received more frequent attention in a more systematic manner. Also, centralized data management with increased automation in data collection and updates are highlighted as general trends for technical and frequently monitored assets. Additionally, it uncovers challenges related to integrating data and standardization, as well as achieving consistent upper management engagement. Implementation strategies associated with successful case example in both MDOT and MnDOT are identified, including risk-based strategies, robust quality control measures, and the integration of advanced technologies. The findings of the study bring insight into best practices in ancillary asset management, offering ways to improve them though providing valuable insights to those state DoTs that have ambitions to enhance their ancillary asset management strategies in an era of aging infrastructure and limited resources.

## 1. Introduction

Ancillary assets such as guardrails, traffic signs, lighting systems, drainage structures are critical items of transportation infrastructure but often have a lower priority against primary elements while their effective management plays an important role in maintaining the overall system performance and optimizing resource allocation (Nassereddine et al. 2024). It is becoming increasingly important for state Departments of Transportation (DOTs) that require high infrastructure performance levels with limited budgets to rely on sophisticated ancillary asset management strategies (Ammar et al. 2024b). The foundation of proper ancillary asset management involves the identification of what to collect on each asset type which requires proper identification of key attributes, performance indicators, and condition metrics necessary to tap a foundation for making informed decisions (Allen et al. 2019). These ancillary asset classes vary with respect to their data requirement reflecting the difference in their functions and characteristics. For example, the data that needs to be used to manage signs (e.g., retro-reflectivity and legibility) is totally different from the data required for drainage structures (e.g., capacity, and sediment accumulation). It is critical to understand these specific, detailed data needs to develop complete and meaningful asset inventories. It is also important to understand the behaviour of the ancillary asset associated data. In other words, understand the trends in changes over time in attributes of different assets, why those changes are occurring, and the influence such changes may have on asset performance and maintenance needs. For instance, the degradation patterns may be completely different between guardrail reflectors and pavement markings. Thus, differences in asset type can easily require differences in approaches when collecting or analysing data. In that respect, the next step should be to decide "how" data should be collected, managed, and used which is a critical aspect in continuously digitalizing transportation infrastructure management. Techniques and technologies for data collection may have a notable impact on the accuracy, completeness, and timeliness of asset information. This understanding of ancillary asset management's current degree of digitalization forms the focal basis on which advanced analytics, predictive maintenance, and integrated asset management systems could exist (Ammar et al. 2023). While there had been past research into various other aspects of ancillary asset management, this study, founded on a detailed surveying and comprehensive interviews with Michigan Department of Transportation (MDOT) and Minnesota Department of Transportation (MnDOT) by questioning varied dimensions in the practice of ancillary asset management, is going to delve deeper into answering "how" questions regarding 38 permanent ancillary asset classes based on responses gathered from 39 state DoTs. In particular, it seeks to answer such questions as:

- How is ancillary asset inventory and condition data being collected?
- How often is ancillary asset inventory and condition data collected?
- How do state DoTs manage the repositories for ancillary assets?
- How and how often is the ancillary asset data being updated?
- How is the responsibility for updating ancillary asset data distributed across state DoTs?
- How do different stakeholders access ancillary asset data?

This research incorporates various cluster analyses and statistical evaluations of survey data tabulated from state DoTs to identify patterns, trends, and correlations in ancillary asset management practices. The study will look for best practices, areas needing improvement, and possible standardization opportunities based on analysis of these relationships. The value of this research lies in its potential to inform and enhance ancillary asset management strategies throughout the nation. The pressures that aging infrastructure and limited resources place on transportation agencies, along with increased demands for using data to make decisions, have made understanding the operational aspects of ancillary asset management critical to this study. Its findings can help policymakers, transportation officials, and researchers in more effectively guiding toward better, efficient, and effective standardized ways of managing these important infrastructure components. Its holistic approach may further lead to more focused improvements within the data collection, storage, updating, and access practices, and eventually more resilient and sustainable transportation systems. The study consequently marks one of the major steps taken towards the realization of ancillary asset management practices.

## 2. Literature Review

Transportation Asset Management (TAM) has become one of the key methods to maintain and improve infrastructure systems effectively and efficiently. The American Association of State Highway and Transportation Officials (AASHTO) defines TAM as a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle" (AASHTO 2014). Although TAM traditionally has focused on major assets such as pavements and bridges, there is a growing recognition that ancillary assets are important to overall system performance. Ancillary assets can be defined as the supporting elements of highway infrastructure that contribute to operational efficiency, safety, and longevity of the primary assets (Ammar et al. 2024b). The ancillary asset systems can include a wide array of elements including, but not limited to, guardrails, traffic signs, lighting systems, and drainage structures. Despite their critical functions in preserving life and maintaining a safe operational condition, most of them are often overlooked during proper comprehensive asset management strategies (Nassereddine et al. 2024). Therefore, ancillary asset management has been identified as an important aspect in numerous research works. (Ammar et al. 2024c) showed that appropriate ancillary asset management will assure the standards of safety and improve the performance of the whole system. They identified that neglecting Ancillary Assets leads to an increase in maintenance costs and a reduction in the service life of primary assets. This economic perspective has gained more and more importance today, as state DOTs face budgetary constraints and are desperately looking at better analytics for prioritizing resource allocation.

Additionally, there are other studies focusing on road safety related ancillary assets. For example, (Moins et al. 2020) analysed accident rates combined with the condition of roadside protective features such as guardrails and crash cushions. The findings pointed out that these assets make immense contributions towards minimizing the severity of run-off-road crashes and great attention should be directed to their maintenance and timely replacement when deterioration has taken place. Management of ancillary assets with an environmental impact view has also been given attention. (Amekudzi et al. 2011) reviewed the numerous environmental impacts, associated with various types of ancillary assets, flowing into a detailed overview of drainage systems and their working in managing stormwater.

Furthermore, among ancillary asset management activities, data gathering and data management are two of the most important ones. (Allen et al. 2019) considered variant assessment of data collection methods for ancillary assets, including manual inspections, mobile mapping systems, and remote sensing technologies. They emphasized that one of the bases for effective decision-making is an accurate and up to date inventory. Moreover, the frequency of data collection and updates for ancillary assets has received considerable discussions; although some researchers believe in indispensable continuous monitoring, others indicate sufficiency of periodic assessments in most ancillary asset classes. Another critical challenge is the repository management of ancillary asset data. (Natsui et al. 2022) discussed about an integrated asset management system able to cope with diverse data types and sources. They also indicated the advantage that ancillary asset-related spatial data management may receive from Geographic Information Systems (GIS). Moreover, integrating ancillary asset management into larger smart city initiatives is a new frontier. (Ammar et al. 2024d) explored the possibility of deploying IoT technologies for the monitoring and management of ancillary assets; a real-time data collection and analysis framework that would allow responsive maintenance strategies, as well as predictive maintenance. There also exist other studies that have discussed the policy and governance that influence ancillary asset management practices. For instance, (Akofio-Sowah et al. 2014) examined how federal and state regulations influence best ancillary asset management practices at various state DoTs. The authors' work focused on the development of policy frameworks that are flexible yet comprehensive, enabling adaptation for local needs while ensuring consistent levels of safety and performance.

Despite these developments, ancillary asset management still faces serious issues. The heterogeneity of the ancillary assets makes different needs in maintenance, as well as the requirements for data collection, leading to difficulties in establishing homogeneous management approaches (Nassereddine et al. 2024). Data fragmentation across different transportation departments often results in inconsistent management practices (Ammar et al. 2024a; Khoshkenar and Nassereddine 2024b). Also, budgetary and human resource constraints have hampered the outcome of appropriate data collection and management systems, and many agencies still rely on either outdated or paper-based legacy systems for ancillary asset data management, which hampers data-driven decision-making (Allen et al. 2019; Khoshkenar and Nassereddine 2024a). However, there is an emergence of appreciation for effective ancillary asset data management. Accurate and up-to-date data plays a pivotal role in support of the identification and mitigation of safety risks, the implementation of resource optimization strategies, regulatory compliance, and proactive maintenance aimed to extend asset service life. Efforts toward standardization, centralized data management systems, advanced data capture technologies such as mobile mapping systems, LiDAR, and unmanned aircraft, data integration and interoperability mechanisms, and the development of data governance frameworks are some of the techniques and technologies that have been explored to overcome these challenges (Allen et al. 2019; Ammar et al. 2022; Khoshkenar and Nassereddine 2024c). With ancillary asset management in a state of constant evolution, the necessity for a more complete and updated knowledge of the current best practices from state DoTs remains significantly important. This research seeks to fill that knowledge gap by providing an in-depth look into how state DoTs address various aspects of ancillary asset management, from data collection through to stakeholder access aiming to contribute to even more effective and uniform practices in this crucial area of transportation asset management.

## 3. Methodology

The study adopts cluster analysis, statistical analysis, and semi-structured interviews to thoroughly document and interpret the existing practices among state DoTs on ancillary assets data stewardship and data models. Regarding the cluster and statistical analysis, a detailed survey, based on information derived from the literature review, is prepared and sent to different state DoTs across the United States touching on the following key features:

- Identification of ancillary asset classes managed by state DoTs and associated data collection methods and frequency for inventory and condition data.
- Exploring existing ancillary asset repository management approaches ancillary asset data.
- Exploring the methods and frequency of updating ancillary asset data

The survey is forwarded to the voting membership of the AASHTO committee on maintenance, representing all fifty U.S. state DoTs and the District of Columbia and a total response of 39 is obtained for a response rate of 76%. The dataset contains responses to 10 questions for each of the 38 asset classes. Three questions are statistically analysed asking about "required time needed for new inventory data for ancillary asset to be updated", "divisions responsible for updating ancillary asset data across state DoTs", and "different access methods to ancillary asset data for stakeholders". The other seven questions are analysed through hierarchical clustering method to determine the possible patterns in state DoTs asset management practices across 38 different asset classes. This methodology consists of several steps including data preparation, distance calculation, hierarchical clustering, and optimal cluster determination. The first four questions are investigating ancillary asset classes inventory and condition data collection methods including "manual", "automated", "remote", and "as-built documents from construction" along with the related frequency consisting of "every six months", "annually", and "more than one year". The next three questions ask about how state DoTs manage their repository(s) for ancillary asset classes defining if "the state DoT manages a single repository", "the state DoT manages multiple repositories", or "a third party manages a central repository". Finally, the last question delves into whether state DoTs are using "manual", "automated", or "remote" methods for updating their ancillary asset data. Also, responses such as "unknown/unsure" and "Others" are ignored, as they don't provide insights to the study, to further simplify the analysis. For the questions that have more than one feature to do the cluster analysis, the data is normalized to account for differences in response rates between features and asset types. Let $X_{ij}$ be the raw count for option j of question i. The normalized value $x_{ij}$ is calculated through Equation 1:

$$x_{ij} = \frac{X_{ij}}{\sum_0^j X_{ij}} \; , \tag{1}$$

This will make each single question sum up to 1.0 from all responses; hence, comparisons across asset types that may have different total responses will be valid. Regarding clustering analysis, the K-means algorithm is applied based on determination of the optimal number of clusters by using the Elbow method and Silhouette score. Moreover, the findings of clustering are validated by using the Cophenetic correlation coefficient that measures how well the hierarchical clustering is preserving the pairwise distances of the original data points versus the distances between points in the hierarchical clustering and performing Silhouette analysis to check the overall quality of clustering. Furthermore, follow-up interviews are implemented to gather further details of the specific state DoT uses of ancillary asset data and their perceptions of collecting and managing that data. The case examples are carried out online through an interview between the research team and MDOT and MnDOT based on their advanced experiences with ancillary asset data. Each state DoT is invited to include those who have had direct experience in the collection and management of ancillary asset classes in developing case examples. Semi-structured interviews often expand into a discussion of unique experiences with each state DoT. The interviewees are informed that the intent of the case example questions is to stimulate thoughts for discussion and that they should provide a narrative and details as they determined appropriate. Finally, focusing on the "what" and "how" of data management, interviews investigate the process of determining what the requirements are for data, developing data models, and quality controlling the data through rigorous measures. The case studies go on to recognize the importance of data stewardship and review resources and methods the state DoTs use to support life-cycle management of ancillary asset data. The interviews lastly conclude by reviewing what was perceived as the most important challenges each state DoT faces to maintain strong ancillary asset inventories and lists the lessons learned, including possible improvement opportunities, particularly in respect to funding and cross-functional coordination. These rich, contextual findings from the front lines of ancillary asset management are captured through the case example interviews, complementing the broader quantitative analysis and providing deep insight into the state of the practice across the transportation industry.

## 4. Results and Discussion

### 4.1 Data Collection Methods and Frequency

The clustering performed for Question 1 reveals that there are clear variations of ancillary assets in their methods of collecting data as depicted in Figure 1. Cluster 0, which consists of assets such as guardrails, pavement markings, and signs, tends towards manual and automated methods of data collection. That indicates these assets are highly critical to road safety and highly visible, thus being prioritized for data collection in a more systematic and frequent manner. Cluster 1 is a more heterogeneous collection of methods for the asset type including drainage systems, noise barriers, and sidewalks. This may indicate that these are all lower-priority assets, or at least that there is less standardization of collection methods across state DoTs for these asset types. Cluster 2 includes culverts, lighting systems, and ITS equipment and regarding to their collection methods, there appears to be a general trend toward the more advanced collection methods such as remote sensing. This may be due to the technical nature of these assets or because they are situated in areas that are not easily accessible for manual inspections. Cluster 3 consists of geotechnical borings, landscaping, and utilities, and shows a tendency towards as-built document use suggesting that these asset types are less frequently updated or do not require regular field inspections.

| Asset inventory and condition data collection method (Total number of responses = 39) | | | | | |
|---|---|---|---|---|---|
| Clusters | Assets | # of responses | | | |
| | | Manual | Automatic | Remote | from As-built documents |
| Cluster 0 | Guardrail; End Treatments | 11 | 6 | 3 | 2 |
| | Guardrail; Impact Attenuator | 12 | 5 | 2 | 1 |
| | Guardrail; Other Barrier Systems | 15 | 6 | 4 | 3 |
| | Guardrail; W Beam | 14 | 6 | 4 | 3 |
| | Pavement Markings /Striping | 8 | 9 | 2 | 2 |
| | Signs; ground mounted roadside signs | 15 | 7 | 5 | 4 |
| | Signs; Overhead panel signs only | 17 | 5 | 5 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| Cluster 1 | Access Control Limits | 5 | 2 | 3 | 2 |
| | Barriers; Noise | 9 | 2 | 2 | 4 |
| | Bike Paths | 7 | 2 | 4 | 3 |
| | Drainage; Curb & Gutter | 9 | 1 | 2 | 1 |
| | Drainage; Ditches | 10 | 1 | 2 | 1 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 14 | 0 | 2 | 5 |
| | Erosion Control; Permanent Structure | 9 | 0 | 1 | 5 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 12 | 0 | 1 | 4 |
| | Parking lots/Park and Ride lots | 8 | 1 | 4 | 1 |
| | Retaining Walls (Earth Retaining Structures) | 14 | 3 | 2 | 5 |
| | Sidewalks | 9 | 2 | 3 | 1 |
| | Signals ; heads and electrical equipment | 14 | 1 | 2 | 5 |
| | Signals; cabinets | 14 | 1 | 1 | 5 |
| | Traffic Management; Network Backbone | 8 | 2 | 1 | 3 |
| | Drainage; Culvert Pipes/ Transverse/Cross Drains | 20 | 0 | 4 | 5 |
| Cluster 2 | Drainage; Inlets and Outlets | 15 | 0 | 4 | 4 |
| | Drainage; Small Structure (culverts <20 ft. total span) | 20 | 0 | 3 | 7 |
| | Drainage; Storm Water Retention Basins/Ponds | 13 | 0 | 4 | 4 |
| | Lighting; High-Mast | 18 | 0 | 4 | 10 |
| | Pedestrian Access Ramps | 18 | 4 | 4 | 9 |
| | Signals; signal supports, pole bases, and mast arms | 16 | 0 | 5 | 8 |
| | Traffic Management; ITS Equipment Only | 18 | 1 | 3 | 7 |
| | Traffic Management; ITS Equipment support structure | 15 | 1 | 4 | 6 |
| Cluster 3 | Geotechnical boring | 5 | 0 | 0 | 4 |
| | Landscaping | 5 | 0 | 0 | 1 |
| | Right of Way Fence | 4 | 2 | 1 | 1 |
| | Rockfall | 6 | 0 | 1 | 0 |
| | Signs; Overhead sign Support Structure | 18 | 3 | 4 | 6 |
| | Survey Monuments or Control Points | 9 | 0 | 0 | 2 |
| | Utilities; Overhead | 1 | 2 | 0 | 1 |
| | Utilities; Underground | 2 | 1 | 0 | 2 |

Figure 1. Asset inventory and condition data collection methods

There are also some interesting trends associated with the periodicity of data capture represented through Questions 2 and 3 shown in Figure 2 and Figure 3 respectively. As a specific example, regarding inventory asset data, assets such as guardrails and pavement markings are more liable to show the collection of inventory data either on an annual or semi-annual basis which also validates their criticality to safety. Further, the condition data collection frequency also depicts a pattern that is quite similar in the way that safety-critical assets such as guardrails and signals are assessed more frequently.

| Asset inventory data collecting frequency (Total number of responses = 39) | | | | |
|---|---|---|---|---|
| Clusters | Assets | # of responses | | |
| | | Semi-annual | Annual | More than one year |
| Cluster 0 | Barriers; Noise | 0 | 4 | 6 |
| | Drainage; Storm Water Retention Basins/Ponds | 0 | 5 | 6 |
| | Guardrail; Impact Attenuator | 0 | 5 | 8 |
| | Guardrail; Other Barrier Systems | 0 | 6 | 9 |
| | Guardrail; W Beam | 0 | 7 | 8 |
| | Pavement Markings /Striping | 0 | 10 | 2 |
| | Signals; signal supports, pole bases, and mast arms | 0 | 5 | 6 |
| | Signs; ground mounted roadside signs | 0 | 7 | 8 |
| | Signs; Overhead panel signs only | 0 | 6 | 9 |
| | Traffic Management; ITS Equipment support structure | 0 | 6 | 5 |
| Cluster 1 | Access Control Limits | 0 | 3 | 3 |
| | Bike Paths | 0 | 3 | 4 |
| | Drainage; Curb & Gutter | 0 | 3 | 4 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 0 | 3 | 5 |
| | Erosion Control; Permanent Structure | 0 | 3 | 3 |
| | Geotechnical boring | 0 | 0 | 1 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 0 | 0 | 2 |
| | Parking lots/Park and Ride lots | 0 | 2 | 3 |
| | Right of Way Fence | 0 | 4 | 1 |
| | Rockfall | 0 | 2 | 3 |
| | Sidewalks | 0 | 3 | 4 |
| | Survey Monuments or Control Points | 0 | 1 | 2 |
| | Traffic Management; Network Backbone | 0 | 2 | 4 |
| | Utilities; Overhead | 0 | 1 | 0 |
| | Utilities; Underground | 0 | 0 | 0 |
| Cluster 2 | Drainage; Culvert Pipes/ Transverse/Cross Drains | 0 | 3 | 13 |
| | Drainage; Ditches | 0 | 3 | 7 |
| | Drainage; Inlets and Outlets | 0 | 2 | 9 |
| | Drainage; Small Structure (culverts <20 ft. total span) | 0 | 2 | 12 |
| | Guardrail; End Treatments | 0 | 3 | 11 |
| | Lighting; High-Mast | 0 | 2 | 10 |
| | Pedestrian Access Ramps | 0 | 4 | 10 |
| | Retaining Walls (Earth Retaining Structures) | 0 | 2 | 7 |
| | Signals; cabinets | 0 | 3 | 7 |
| | Signs; Overhead sign Support Structure | 0 | 2 | 11 |
| Cluster 3 | Landscaping | 1 | 2 | 1 |
| | Signals ; heads and electrical equipment | 1 | 4 | 5 |
| | Traffic Management; ITS Equipment Only | 1 | 6 | 7 |

Figure 2. Asset inventory data collection frequency

| Asset condition data collecting frequency (Total number of responses = 39) | | | | |
|---|---|---|---|---|
| Clusters | Assets | # of responses | | |
| | | Semi-annual | Annual | More than one year |
| Cluster 0 | Drainage; Curb & Gutter | 0 | 4 | 3 |
| | Drainage; Ditches | 0 | 4 | 5 |
| | Drainage; Storm Water Retention Basins/Ponds | 0 | 6 | 5 |
| | Guardrail; Other Barrier Systems | 0 | 5 | 6 |
| | Guardrail; W Beam | 0 | 5 | 6 |
| | Pavement Markings /Striping | 0 | 7 | 3 |
| | Signals ; heads and electrical equipment | 0 | 5 | 3 |
| | Signals; cabinets | 0 | 5 | 4 |
| | Signals; signal supports, pole bases, and mast arms | 0 | 6 | 7 |
| | Signs; ground mounted roadside signs | 0 | 7 | 5 |
| | Signs; Overhead panel signs only | 0 | 6 | 8 |
| Cluster 1 | Guardrail; Impact Attenuator | 1 | 4 | 7 |
| | Landscaping | 1 | 2 | 1 |
| | Traffic Management; ITS Equipment Only | 1 | 5 | 6 |
| | Traffic Management; ITS Equipment support structure | 1 | 5 | 6 |
| Cluster 2 | Access Control Limits | 0 | 2 | 1 |
| | Barriers; Noise | 0 | 3 | 5 |
| | Bike Paths | 0 | 1 | 3 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 0 | 3 | 5 |
| | Erosion Control; Permanent Structure | 0 | 4 | 2 |
| | Geotechnical boring | 0 | 1 | 1 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 0 | 2 | 4 |
| | Parking lots/Park and Ride lots | 0 | 2 | 2 |
| | Right of Way Fence | 0 | 2 | 2 |
| | Rockfall | 0 | 2 | 3 |
| | Sidewalks | 0 | 3 | 3 |
| | Survey Monuments or Control Points | 0 | 1 | 2 |
| | Traffic Management; Network Backbone | 0 | 3 | 3 |
| | Utilities; Overhead | 0 | 0 | 0 |
| | Utilities; Underground | 0 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Cluster 3 | Drainage; Culvert Pipes/ Transverse/Cross Drains | 0 | 3 | 13 |
| | Drainage; Inlets and Outlets | 0 | 3 | 8 |
| | Drainage; Small Structure (culverts <20 ft. total span) | 0 | 3 | 11 |
| | Guardrail; End Treatments | 0 | 4 | 10 |
| | Lighting; High-Mast | 0 | 3 | 12 |
| | Pedestrian Access Ramps | 0 | 2 | 8 |
| | Retaining Walls (Earth Retaining Structures) | 0 | 3 | 9 |
| | Signs; Overhead sign Support Structure | 0 | 2 | 10 |

Figure 3. Asset condition data collection frequency

## 4.2 Repository Management

Questions 4, 5, and 6 provide some insights about the management of the asset data repository. Based on the results, there is variation in how the state DoTs manage data across different asset types as shown in Figure 4, Figure 5, and Figure 6. Several state DoTs manage one repository of safety-critical assets, such as guardrails and signs, which indicates a trend in centralized data management for these critical assets enabling more coordination in decision-making and resource allocation. However, there is a very significant difference in the management of the repositories for different asset types; many state DoTs have more than one repository for different asset types. This may reflect difficulties in the integration of data or the continued existence of legacy systems that have not yet been fully integrated. The diversity in the methodologies of repository management reflects the difficulty of ancillary asset data management and the possibility of standardized, better-integrated systems. Use of third-party managed central repositories, although less prevalent, as indicated by Question 6, it does occur for some asset classes, especially those assets requiring more specialized management and technology. This may suggest a tendency to outsource particularly complex data management or exploit other professional expertise for specific asset classes.

**Assets are being managed in a single repository by the DOT (Total number of responses = 39)**

| Clusters | Assets | # of responses |
|---|---|---|
| Cluster 0 | Barriers; Noise | 11 |
| | Drainage; Culvert Pipes/ Transverse/Cross Drains | 11 |
| | Drainage; Inlets and Outlets | 10 |
| | Drainage; Storm Water Retention Basins/Ponds | 10 |
| | Guardrail; End Treatments | 10 |
| | Guardrail; Impact Attenuator | 10 |
| | Guardrail; Other Barrier Systems | 11 |
| | Guardrail; W Beam | 11 |
| | Lighting; High-Mast | 11 |
| | Parking lots/Park and Ride lots | 11 |
| | Retaining Walls (Earth Retaining Structures) | 9 |
| | Sidewalks | 9 |
| | Signals; cabinets | 9 |
| | Signs; ground mounted roadside signs | 9 |
| | Signs; Overhead panel signs only | 9 |
| | Signs; Overhead sign Support Structure | 14 |
| Cluster 1 | Access Control Limits | 6 |
| | Bike Paths | 7 |
| | Drainage; Curb & Gutter | 6 |
| | Drainage; Ditches | 7 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 6 |
| | Erosion Control; Permanent Structure | 5 |
| | Geotechnical boring | 4 |
| | Landscaping | 3 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 7 |
| | Pavement Markings /Striping | 6 |
| | Right of Way Fence | 3 |
| | Rockfall | 5 |
| | Survey Monuments or Control Points | 7 |
| | Traffic Management; Network Backbone | 3 |
| | Utilities; Overhead | 2 |
| | Utilities; Underground | 3 |
| Cluster 2 | Drainage; Small Structure (culverts <20 ft. total span) | 13 |
| | Pedestrian Access Ramps | 14 |
| | Signals ; heads and electrical equipment | 13 |
| | Signals; signal supports, pole bases, and mast arms | 12 |
| | Traffic Management; ITS Equipment Only | 14 |
| | Traffic Management; ITS Equipment support structure | 9 |

Figure 4. Assets being managed in a single repository

**Assets are being managed in multiple repositories by the DOT (Total number of responses = 39)**

| Clusters | Assets | # of responses |
|---|---|---|
| Cluster 0 | Drainage; Culvert Pipes/ Transverse/Cross Drains | 8 |
| | Drainage; Inlets and Outlets | 7 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 5 |
| | Drainage; Small Structure (culverts <20 ft. total span) | 7 |
| | Drainage; Storm Water Retention Basins/Ponds | 5 |
| | Guardrail; End Treatments | 6 |
| | Guardrail; Impact Attenuator | 6 |
| | Guardrail; Other Barrier Systems | 6 |
| | Guardrail; W Beam | 6 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 6 |
| | Pavement Markings /Striping | 6 |
| | Pedestrian Access Ramps | 5 |
| | Retaining Walls (Earth Retaining Structures) | 5 |
| | Signals ; heads and electrical equipment | 8 |
| | Signals; cabinets | 8 |
| | Signs; Overhead sign Support Structure | 6 |
| | Traffic Management; ITS Equipment support structure | 7 |
| | Traffic Management; Network Backbone | 7 |
| Cluster 1 | Access Control Limits | 4 |
| | Barriers; Noise | 3 |
| | Bike Paths | 3 |
| | Drainage; Curb & Gutter | 4 |
| | Drainage; Ditches | 3 |
| | Erosion Control; Permanent Structure | 4 |
| | Geotechnical boring | 2 |
| | Landscaping | 3 |
| | Parking lots/Park and Ride lots | 1 |
| | Right of Way Fence | 2 |
| | Rockfall | 2 |
| | Sidewalks | 3 |
| | Survey Monuments or Control Points | 2 |
| | Utilities; Overhead | 1 |
| | Utilities; Underground | 0 |
| Cluster 2 | Lighting; High-Mast | 13 |
| | Signals; signal supports, pole bases, and mast arms | 9 |
| | Signs; ground mounted roadside signs | 11 |
| | Signs; Overhead panel signs only | 10 |
| | Traffic Management; ITS Equipment Only | 11 |

Figure 5. Assets being managed in multiple repositories

**Assets are being managed by a third party in a central repository (Total number of responses = 39)**

| Clusters | Assets | # of responses |
|---|---|---|
| Cluster 0 | Barriers; Noise | 1 |
| | Bike Paths | 2 |
| | Drainage; Culvert Pipes/ Transverse/Cross Drains | 1 |
| | Drainage; Curb & Gutter | 1 |
| | Drainage; Ditches | 1 |
| | Drainage; Inlets and Outlets | 1 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 1 |
| | Drainage; Small Structure (culverts <20 ft. total span) | 2 |
| | Erosion Control; Permanent Structure | 1 |
| | Geotechnical boring | 1 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 0 |
| | Pedestrian Access Ramps | 2 |
| | Retaining Walls (Earth Retaining Structures) | 1 |
| | Right of Way Fence | 1 |
| | Sidewalks | 1 |
| | Signs; ground mounted roadside signs | 2 |
| | Signs; Overhead panel signs only | 2 |
| | Signs; Overhead sign Support Structure | 2 |
| | Traffic Management; Network Backbone | 1 |

| | | |
|---|---|---|
| Cluster 1 | Access Control Limits | 0 |
| | Drainage; Storm Water Retention Basins/Ponds | 0 |
| | Landscaping | 0 |
| | Lighting; High-Mast | 1 |
| | Parking lots/Park and Ride lots | 0 |
| | Rockfall | 0 |
| | Signals ; heads and electrical equipment | 0 |
| | Signals; cabinets | 0 |
| | Signals; signal supports, pole bases, and mast arms | 0 |
| | Survey Monuments or Control Points | 0 |
| | Traffic Management; ITS Equipment Only | 0 |
| | Traffic Management; ITS Equipment support structure | 0 |
| | Utilities; Overhead | 0 |
| | Utilities; Underground | 0 |
| Cluster 2 | Guardrail; End Treatments | 4 |
| | Guardrail; Impact Attenuator | 3 |
| | Guardrail; Other Barrier Systems | 4 |
| | Guardrail; W Beam | 3 |
| | Pavement Markings /Striping | 4 |

Figure 6. Assets being managed in a central repository by a third party

### 4.3 Data Updating Methods and Frequency

Question 7, as shown in Figure 7, outlines the update patterns for asset data, which can be linked to the observations drawn from Questions 8 and 9. Cluster 0, which hosts access control limits and utilities, is updated more along manual lines. This may be because the assets in this cluster change less often or are cumbersome when automating their updates. On the other hand, cluster 1 containing safety-critical assets such as guardrails and signs, demonstrates a mix of subjective manual and automated updating methods which highlights a move to higher efficiency in updating these frequently monitored assets, balancing the need for human oversight with benefits derived from automation. Clusters 2 and 3, which host the more technical assets, including drainage systems and traffic signals show a higher tendency towards automated and remote updating. This is in line with the increased utilization of smart technologies obtained from these asset types. It reflects that critical infrastructure elements can be updated in real-time or near-real-time.

| Asset data updating method (Total number of responses = 39) | | | | |
|---|---|---|---|---|
| Clusters | Assets | # of responses | | |
| | | Manual | Automatic | Remote |
| Cluster 0 | Access Control Limits | 9 | 1 | 0 |
| | Erosion Control; Permanent Structure | 6 | 2 | 0 |
| | Geotechnical boring | 5 | 0 | 0 |
| | Landscaping | 6 | 0 | 0 |
| | Parking lots/Park and Ride lots | 10 | 0 | 0 |
| | Right of Way Fence | 5 | 1 | 0 |
| | Rockfall | 7 | 0 | 0 |
| | Survey Monuments or Control Points | 9 | 0 | 0 |
| | Utilities; Overhead | 2 | 1 | 0 |
| | Utilities; Underground | 2 | 1 | 0 |
| Cluster 1 | Barriers; Noise | 11 | 4 | 0 |
| | Bike Paths | 8 | 4 | 1 |
| | Drainage; Curb & Gutter | 8 | 4 | 1 |
| | Drainage; Ditches | 8 | 4 | 1 |
| | Guardrail; End Treatments | 12 | 8 | 1 |
| | Guardrail; Impact Attenuator | 12 | 6 | 1 |
| | Guardrail; Other Barrier Systems | 14 | 8 | 1 |
| | Guardrail; W Beam | 12 | 8 | 1 |
| | Pavement Markings /Striping | 9 | 6 | 0 |
| | Retaining Walls (Earth Retaining Structures) | 12 | 6 | 1 |
| | Signs; ground mounted roadside signs | 15 | 7 | 2 |
| | Signs; Overhead panel signs only | 13 | 6 | 2 |
| | Signs; Overhead sign Support Structure | 15 | 6 | 1 |
| Cluster 2 | Drainage; Culvert Pipes/ Transverse/Cross Drains | 17 | 2 | 2 |
| | Drainage; Inlets and Outlets | 15 | 2 | 2 |
| | Drainage; Longitudinal Drain (e.g., Underdrain; pipes) | 11 | 0 | 2 |
| | Drainage; Small Structure (culverts <20 ft. total span) | 17 | 3 | 2 |
| | Drainage; Storm Water Retention Basins/Ponds | 13 | 2 | 2 |
| | Lighting; High-Mast | 20 | 2 | 2 |
| | Lighting; Roadway Other (e.g., luminaire; flashers) | 11 | 1 | 1 |
| | Sidewalks | 12 | 3 | 2 |
| | Traffic Management; Network Backbone | 9 | 2 | 2 |
| Cluster 3 | Pedestrian Access Ramps | 18 | 3 | 1 |
| | Signals ; heads and electrical equipment | 19 | 0 | 0 |
| | Signals; cabinets | 16 | 1 | 1 |
| | Signals; signal supports, pole bases, and mast arms | 18 | 1 | 0 |
| | Traffic Management; ITS Equipment Only | 20 | 3 | 1 |
| | Traffic Management; ITS Equipment support structure | 14 | 2 | 0 |

Figure 7. Asset data updating methods

These are contextualized and supported by question 8 results, represented in Figure 8, where 34% of the respondents update their inventory data on an annual basis, while 20% perform immediate updating. These indicate a mixed real-time and periodic updating strategies at state DoTs. However, the 17% who do not update on a regular basis is concerning and may reflect resource constraints or challenges in data management.

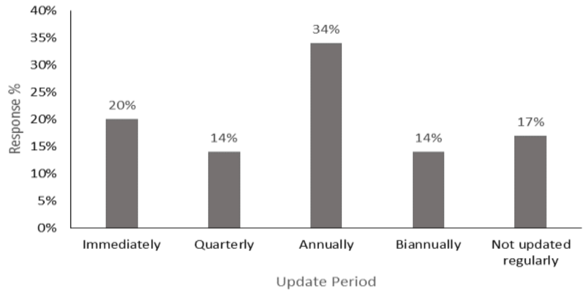


Figure 8. Asset data update frequency

### 4.4 Responsibilities and Access

Questions 9 and 10 offer insights into the organizational aspects of ancillary asset management. As shown in Figure 9, the high involvement of divisions such as Maintenance/Preservation (86%) and Asset Data Management (77%) in updating ancillary asset data indicates that the asset data management is being extremely operationally focused. Moreover, the involvement of other divisions, such as Geographic Information (49%), Construction (40%), and Highway Design (40%), indicates a broader cross-functional approach to asset data management. On the other hand, the rather low engagement in Upper Management at only 6% may further indicate a need for greater strategic alignment in ancillary asset management which can potentially raise barriers against fully integrating asset management practices with broader organizational goals and resource allocation decisions.

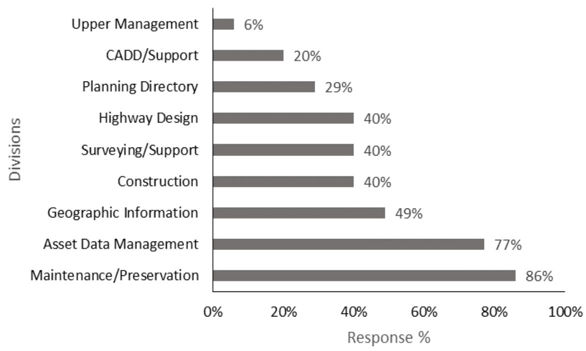



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Figure 9. Responsible divisions involved in asset management

Furthermore, based on the results of Question 10 about data access in Figure 10, it is noted that there is a balancing act which state DoTs pursue between data availability and security concerns, as indicated by high individual requests with 69% and password-protected access with 60%. 49% of state DoTs that publicly publish their ancillary asset data, indicates a trend towards more transparency, and independently enabling greater use of that data by researchers and the public.

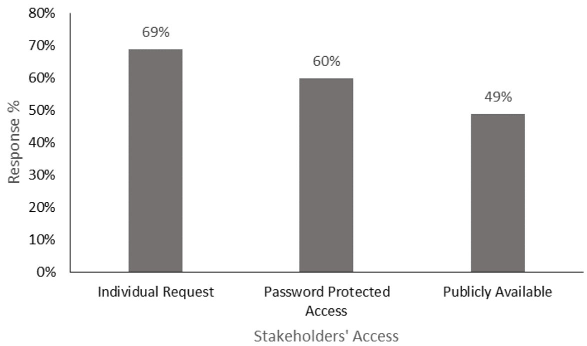


Figure 10. Asset data access methods by stakeholders

### 4.5 Case examples of State DoT Ancillary Asset Management Practices

Building upon the cluster analysis and statistical findings, in-depth case examples of two state DoTs renowned for their advanced ancillary asset management practices are conducted: the Michigan Department of Transportation (MDOT) and the Minnesota Department of Transportation (MnDOT). These case examples provide crucial context to the quantitative results, offering insights into the practical implementation of ancillary asset management programs and illuminating the challenges and best practices in the field.

**4.5.1 Michigan Department of Transportation (MDOT):** MDOT's ancillary asset management journey characterizes the evolution in the asset management strategies from reactive to proactive. Initiated as an outcome of a tragic incident in 1990 due to the failure of a sign structure, till today, MDOT's approach has grown into a comprehensive risk-based asset management program. The department emphasizes the maintenance of safety-critical assets by prioritizing assets such as sign structures and culverts which also aligns with the cluster analysis results. In addition, the step-by-step process of adding ancillary assets is very consistent with the cluster analysis findings on how different asset types are managed with varying levels of sophistications across state DoTs.

The Ancillary Structures Unit, managing 16 asset types, established in 2020 demonstrating a trend toward centralization of multiple asset classes which is also identified by the cluster analysis as an important strategy for those state DoTs whose current data management practices are fragmented. Also, the patterns observed in data collection frequency across different asset types is also consistent with the department's risk-based approach to data collection and inspection prioritization. Their aim to inspect all assets within five years of construction strikes a balance between the annual updates reported by 34% of the survey respondents and the less frequent updates reported by others. The vigorous QA/QC procedures and inspector training programs of MDOT have a strong impact on the critical need aroused by this study which is the importance of data quality in asset management systems. Having this program has allowed MDOT to not only track existing inventory and identify deterioration but also identify common things that are overlooked in the construction inspection process. Their emphasis on construction inspection to identify and address installation issues proactively tackles a gap in many state DoTs' data collection practices. Integration of design, construction, and maintenance data on a closed-loop system within MDOT epitomizes the advanced applied practice of data integration which is not sporadic across the state DoTs based on the survey results. Such integration coupled with live data updates in their GIS system points toward the prospect of real-time, cross-functional asset management, which many of the state DoTs in this study are presently working toward. There are valuable lessons offered by MDOT for other state DoTs tackling the complexities with ancillary asset management including flexibility in collecting and managing data and the workforce development opportunities created through their consultant partnerships.

**4.5.2 Minnesota Department of Transportation (MnDOT):** MnDOT's ancillary asset management approach constitutes a gradual, step-by-step progression. Their progression from incidental collection of as-built data to implementation of an asset management strategy appears to essentially capture the incremental steps many state DoTs are now making in ancillary asset management. Departmental focus on underground assets, signals, lighting, drainage, culverts, and signs as early digital as-built pilot projects causes the sole support of the prioritization of safety-critical and highly visible assets, closely aligned to the cluster analysis results. Also, the implementation of mobile LiDAR data acquisition for above-ground assets in 2022 represents the trend toward advanced, automated data collection methods.

MnDOT's development of a Transportation Asset Management Plan (TAMP) in 2014, first focusing on safety and risk-based asset selection, then expanding to additional assets based on data availability and subsequent expert input, demonstrates the iterative nature of asset management program development that many state DoTs are experiencing. This structure of managing most assets at MnDOT using the Transportation Asset Management System (TAMS) aligns with the trend towards centralized data management that has been identified as a potential area of enhancement in many state DoTs. MnDOT's ongoing data dictionary work as part of TAMS development supports the standardization needs discerned from the cluster analysis in the current practices regarding data collection and management.

Moreover, their mature data governance structure, staffed with dedicated data stewards and subject matter experts, represents an advanced implementation of the organizational responsibilities. Based on the survey results, the involvement of the Maintenance/Preservation divisions in updating ancillary asset data at 86%, and Asset Data Management divisions at 77% across state DoTs would suggest that MnDOT's approach could serve as a model for other state DoTs seeking to improve their data governance practices. Also, MnDOT mentioned that the high number of assets and the resource-intensive data entry brought out the importance of efficient methods of automated data collection- a trend observed in the cluster analysis as an increased usage of automated and remote methods for collecting data for certain asset types. The integration of all data into one database within MnDOT's TAM system addresses the challenges of data fragmentation that the analysis uncovered in many state DoTs. Their current efforts to more closely integrate asset data with design and construction phases including Building Information Modelling and Asset Information Models, represent the cutting edge of data integration practices they are pursuing.

## 5. Conclusion

This research comprehensively examines ancillary asset management practices across U.S. state DoTs using cluster analysis and statistical evaluation of survey data from 39 states, supplemented by in-depth case examples of Michigan and Minnesota DOTs. This approach provides valuable insights of the current practices, challenges, and opportunities lying within ancillary asset management. The research, focusing on "what" and "how" questions about ancillary asset data, envelops key aspects such as data collection methods, frequency, repository management, practices for updating, responsibilities distribution, and data access by the stakeholders. Results indicate a complicated setting showing different levels of sophistication by asset class and by state DoT. Cluster analysis demonstrates significant variation in data collection and management practices for different ancillary asset classes, with safety-critical assets generally receiving more advanced and frequent attention. The statistical analysis of updating frequencies shows a mix of proactive and periodic strategies, with 34% of state DoTs updating inventories annually and 20% updating immediately, while 17% lack routine updates due to resource constraints or data management challenges. Case examples of the best practices implemented by MDOT and MnDOT show how agencies have advanced from reactive to proactive strategies emphasizing risk-based approaches with strong data quality assurance. Some important concepts emanating from the research include:

- The need for providing a balance between standardization and flexibility in ancillary asset management
- The importance of providing robust data governance and quality assurance
- The probable potential use of advanced technologies to increase efficiency
- The importance of organization buy-in
- The value of risk-based approaches that enable the organization to prioritize activities and resource allocation.

Although this study sets a foundation for more effective and standardized techniques in managing critical infrastructure components for state DoTs, future complementary research should analyse the long-term performance and cost impact of different strategies and the potential of emerging technologies in ancillary asset management. To conclude, this research brings significant value to improving ancillary asset management practices through the definition of best practices, areas of improvement, and opportunities for standardization supporting the maintenance of safe, efficient, and sustainable transportation systems.

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