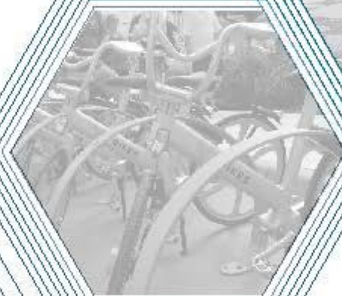

A Multi-asset Transportation Infrastructure Asset Management Framework And Modeling For Local Governments

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FINAL REPORT

Center for Transportation Equity, Decisions & Dollars

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FINAL PROJECT REPORT

by

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Georgia Institute of Technology

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16. Abstract
Local governments (LGs) in the United States are managing 3/4 of 4 billion miles of roadway and more than 1/2 of nearly 600,000 bridges, which are critical transportation infrastructure assets that support the mobility, economy, and homeland security on both the local and national levels. To maintain the aging infrastructure in a state of good repair under shrinking budgets, LGs must adopt a systematic approach to conduct cost-effective maintenance, rehabilitation, and reconstruction (MR&R) instead of relying on subjective individual knowledge and experience. As a result, benefit from the scarce transportation budget could be maximized; and accountability could be demonstrated to the stakeholders. However, many factors can enable or inhibit the success of transportation asset management (TAM) in LGs, including agency size, organization, staff, budget, and technology. To address the above issues, this research aims to analyze the underlying factors that hinder LGs from adopting a well-defined TAM program by conducting and analyzing an online survey. The survey investigates the knowledge gaps in TAM within Georgia's LGs. Based on the survey analysis, a multi-asset management guideline was developed for local governments to implement an asset management system. To better manage multiple assets, this research project also explored an innovative framework for maintaining interdependent assets, in which an objective measure was proposed to quantify the effectiveness of the entire transportation network. To demonstrate the benefit of the proposed framework, an interdependency-based mathematical optimization was developed by incorporating traffic capacity models, deterioration models, and treatment improvement models. The preliminary case study showed promising results of integrating transportation infrastructure interdependency to enhance the objectivity in cross-asset management, improve the efficiency of network-level mobility, and reduce the risk of network failure.

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Executive Summary

Local governments (LGs) are responsible for managing a large portion of the national transportation network, which is vital for the mobility, economy, and homeland security of the country. While state departments of transportation (DOTs) are at more advanced stages of transportation asset management (TAM) practices, local agencies are still behind in maintaining the assets under their jurisdiction in a state of good repair. Many factors contribute to the lack of proper TAM practice on the local level and thus will be highlighted in this report.

This project conducts a comprehensive literature review to explore the basic concept and components of a TAM program, in addition to the current practice at the local and state levels. This review is coupled with the results of an online survey that targeted the local agencies in the state of Georgia in order to validate the status-quo and to identify the gaps in their TAM practice and shortcomings which are affecting the transportation assets' performance and network efficiency. The findings from this survey showed that few LGs are applying proper TAM practices with main weaknesses in organization, staffing, adopted technologies, available funding, and resource allocation. Most local agencies lack a well-structured organizational chart with roles and responsibilities not being clearly set. Also, in addition to the shortage of human resources, the available staff lack the required skill set and training, which also affects the agency's capability of adopting new technologies within its TAM programs. Funding is a major issue facing LGs as their assets' increasing needs are not covered by the shrinking budgets. This is further aggravated by having a simple and subjective decision-making process, which affects the efficiency of resource allocation and contradicts agencies' requests to receive additional funding. No proper communication is being held within the agency itself and with other local and state agencies. Communication with involved stakeholders is also missing as no performance reports are being issued on a regular basis. Thus, TAM programs are still weak in LGs due to many factors which need to be addressed and remedied.

Consequently, an asset management guideline was developed to suit the needs and capabilities of local transportation agencies in general, and those within the state of Georgia in particular. This guideline will assist the local agencies in understanding all the components of a proper TAM program, believing in its effectiveness, and knowing where to begin in case of new adoption or else how to ameliorate and develop the current practice. The guideline presents the TAM framework proposed by FHWA showing its critical components which are discussed in detail throughout the document. It also focuses on the importance of having a well-established organizational structure and the role that an asset management champion or steering committee can play in pushing toward the adoption and application of TAM practices by holding educational workshops, meetings, and information sessions. LGs should also conduct a self-assessment of their current practice in order to identify strengths, weaknesses, and opportunities. Based on that, policies and plans can be clearly set to reflect the agency's goals and roadmap, while taking into consideration legal requirements, stakeholders' expectations, managed assets,

and available resources. The guideline also pushes for having a solid asset inventory that acts as the cornerstone of a successful TAM program, in addition to having a proper data management system to store and manage this inventory. Performance-based asset management, which is supported by the Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Fixing America's Surface Transportation (FAST) Act, is also highlighted in the document. It also discusses the decision-making process that incorporates risk management, through which the agency should allocate its budget in an efficient and beneficial manner to achieve the best network performance. In that context, a well-studied financial plan that includes funding and budgeting affairs on the short, medium, and long term is recommended. Finally, the guideline insists on having an accurate and frequent reporting process for internal purposes and how that helps in updating the TAM program, besides involving the public and all stakeholders in that whole initiative.

Moreover, this project explores a new framework for cross-asset management decision making, in an attempt to improve the objectivity in similar models to reduce the subjectivity in allocating resources among different transportation assets. For that purpose, the mobility of the entire transportation network is used as the performance measure, as a concept from the traffic engineering discipline, with the objective being set to maximize the network mobility. Yet, the decisions are made in the discipline of pavement/bridge engineering, which is the maintenance programming for the asset facilities, i.e. pavements and bridges. To demonstrate the effectiveness of the proposed framework for objectively managing interdependent assets, a case study is performed using an interstate highway network around the City of Atlanta, Georgia, while considering only pavement and bridge utilities.

Chapter 1: Introduction

1. Background and Research Need

The local governments (LGs) in the United States are managing 3/4 of total 4 billion miles of roadway and more than 1/2 of nearly 600,000 bridges, which are critical transportation infrastructure assets supporting the mobility, economy, and homeland security in local communities and the nation as a whole. To maintain the aging transportation infrastructure in a state of good repair under the shrinking budget, the state departments of transportation (DOTs) have adopted transportation asset management (TAM) programs to conduct cost-effective maintenance, rehabilitation, and reconstruction (MR&R). However, most of LGs still rely on individuals' knowledge and experience to manage and make decisions on transportation infrastructure MR&R. The lack of a systematic approach for managing transportation infrastructure assets makes it difficult for an LG to maximize the benefit of the scarce transportation budget and demonstrate accountability to the legislatures, the public, and other stakeholders.

To address the above issues, this project analyzes the underlying factors that hinder LGs from adopting the TAM program. A comprehensive literature review is conducted to identify, collect, and review information on the existing practice of TAM in LGs, including the general framework, implementation, and mathematical modeling. An online survey is then created and distributed to the LGs in Georgia with the help of GDOT's Local Technical Assistance Program (LTAP). The major topics tackled by the questionnaire include the current organization's structure, goals, and policies, condition assessment and data management practices, performance measures and decision-making processes, in addition to funding and budget allocation details and accountability to legislatures, public, and other stakeholders. Then, based on the literature review and the survey results, a multi-asset management guideline for LGs is proposed to include the components of a generic TAM program as a basis, coupled with a focus on LG's particularity. The proposed framework extensively considers the LGs' particularity in the organization, workforce, and funding sources. In the meantime, the similarities to the corresponding state DOTs are also considered in order to wisely leverage their resources. To implement a better practice for asset inventory, condition assessment, and data management, the most up-to-date technologies such as 3D sensing, computer vision, crowdsourcing, cloud computing, GIS/GPS, and mobile and web applications are evaluated and incorporated. The MR&R decision-making process is modeled as a multi-asset, multi-facility mathematical programming in an attempt to improve the objectivity in similar models to reduce the subjectivity in allocating resources among the different transportation assets. Constrained by LGs' goals and policies, and different budget sources, the framework is established using two assets, pavements and bridges, for evaluation and demonstration purposes. Finally, a case study is developed based on a small network in Atlanta, Georgia.

2. Research Approach and Focus

The objectives of this project are: 1) to analyze the underlying factors that hinder LGs from adopting TAM to efficiently and cost-effectively maintain their transportation infrastructure assets in a state of good repair; 2) to propose a multi-asset management framework that considers the LGs' particularity in organization, workforce, and funding sources, and the similarity to the corresponding state DOTs; 3) to incorporate the most up-to-date technologies, such as 3D sensing, computer vision, crowdsourcing, cloud computing, GIS/GPS, and mobile and web applications in asset inventory, condition assessment, and management; and 4) to explore a multi-asset, multi-facility mathematical programming to support the network-level MR&R decision-making. Figure 1.1 illustrates the methodology adopted to accomplish the above research objectives.

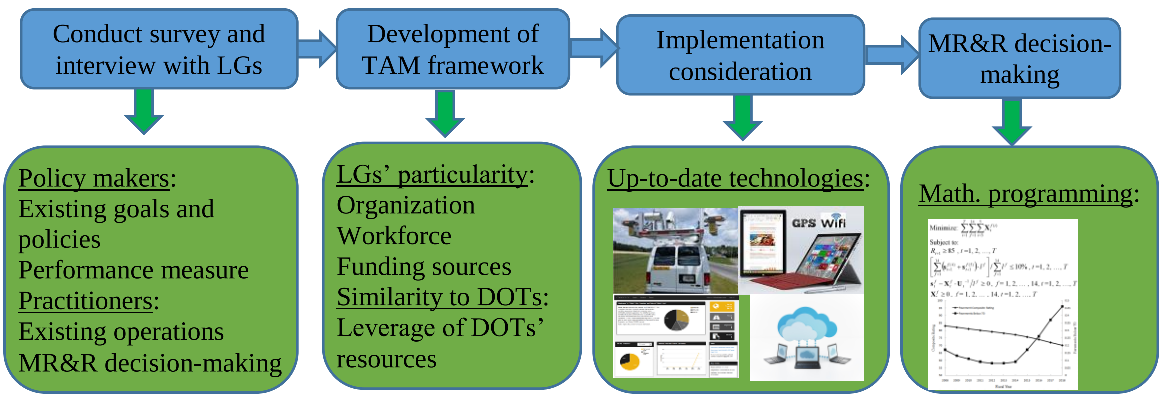


Figure 1.1 Operation Flow of Research Methodology

As shown in Figure 1.1, the first step is to conduct a comprehensive survey and interview with policymakers and practitioners in LGs. Thus, the existing goals, policies, and performance measures can be incorporated and/or enhanced. In the meantime, the existing operations and MR&R decision-making process can be analyzed; and thus, the factors that hinder the adoption of a TAM can be uncovered.

Based on the survey and interview conducted in the first step, a multi-asset TAM for LGs will be developed in the second step. The LGs' particularity in organization, workforce, and funding sources are to be considered. An LG normally lacks resources for an independent management system. Thus, it is important to trim down the unnecessary components and fully leverage the state DOTs' resources through LTAP.

In the third step, implementation consideration will be included in the developed TAM. Asset inventory, condition assessment, and management are the most important components for a reliable TAM. However, they are also the biggest bottleneck because of the need for significant labor and cost. The use of the most up-to-date technologies can be a means to reduce costs and improve data quality. A comprehensive review of these technologies will be performed in terms of their data accuracy, coverage, collecting effort, and cost. Thus, LGs have a broad choice depending on their budget, asset type, and urgency.

Finally, a multi-asset, multi-facility mathematical programming will be explored to support the network-level MR&R decision making. Though "worst first" and "prioritization" have been widely used in LGs to make decisions on MR&R, they are not cost-effective. To address this issue, mathematics programming will be explored to optimize the system performance and resource use. The budget needs to be balanced among different types of assets, such as pavements and bridges.

3. Report Organization

This report is organized into six chapters. Chapter 1 summarizes the research background, need, and approaches; Chapter 2 presents a comprehensive literature review introducing the components of a well-defined TAM program and the concept of cross-asset management while highlighting the current practice of different local and state agencies. Chapter 3 shows the methodology used in conducting the online survey in addition to the key points which were concluded from the response analysis. Note that a detailed survey analysis is presented in Appendix I. Chapter 4 shows the purpose behind the asset management guidelines and the approach through which it was developed. Besides the presented snapshot, the full stand-alone document corresponding to the guidelines formed is found in Appendix II. Chapter 5 explores a framework for cross-asset management decision-making modeling, and dissects its implementation, in addition to a case study for a small network in Georgia. Finally, chapter 6 summarizes the conclusions and makes recommendations for future research.

Chapter 2: Literature Review

A comprehensive literature review is presented below in order to form a clear idea about the concept of TAM, its components, and its current practice among state and local agencies. Moreover, cross-asset management will also be introduced to highlight its advantages compared to dealing with transportation asset groups as silos, independent of one another. This review, combined with the online survey which is presented in the following chapter, will form the basis of the clear, well-defined, and specialized asset management guideline for local governments that was done at a later stage in the course of this research project.

1. Transportation Asset Management

1.1 Overview

AASHTO Subcommittee on Asset Management defines TAM as follows:

"a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives." (FHWA, 2007)

Originating from successful practices adopted in the private sector such as management by objectives, goal-oriented management, risk-based management, and, enterprise resource planning (ERP), TAM concept was introduced in the early 2000s during which AASHTO has established its first TAM Subcommittee (TRB, 2015). Many factors have contributed to the establishment of the TAM practices, such as the limited funds that lead to scarce budgets for the state departments of transportation (DOT), as well as the technological advancements, lack of expert personnel, and public demand for better quality of service and accountability from the people in charge (Flintsch & Bryant, 2006). Moreover, several milestones greatly affected the development of the TAM programs including the Governmental Accounting Standards Board (GASB) Statement No.34, where transportation agencies had to begin recording in their books all their capital and infrastructure assets and all corresponding investments and account for their value by reporting it on a regular annual basis. In 2012, another milestone was marked when the Moving Ahead for Progress in the 21st (MAP-21) was passed (FHWA, 2012b), requiring state DOTs to develop risk and performance-based TAM plans for pavements and bridges in the National Highway System (NHS), and later continued with the 'Fixing America's Surface Transportation Act (FAST Act)' law which was passed in 2015.

Federal, state, and local agencies are developing and implementing TAM to optimize the performance and cost effectiveness of transportation facilities (FHWA, 2007). The specific processes of TAM vary from the federal to the state level, as well as regionally. There is no standard asset management framework that can serve agencies with different resources, political environments, and maturity of their management processes (Wittwer, et al., 2003). In order to maintain consistency and establish a standard basis of understanding, the federal government has issued state asset management requirements for maintaining and improving the conditions of the National Highway System (NHS) by requiring DOTs to develop a TAM plan that includes at least: summary and condition of the State's NHS pavements and bridges, asset management objectives, targets and measures, performance gap identification, life-cycle planning and risk management analysis, financial plan, and investment strategies (GDOT, 2018).

Although asset management techniques will have some overlap at the federal, state, and local levels, management plans should be tailored to serve the interests, financial plans, investment strategies, and available resources of each government individually. The basic asset management guidelines established by FHWA should be used in conjunction with a state or local agency's self-assessment. NCHRP developed a Self-Assessment Tool that can be used by agencies to identify gaps in current methods of asset management. Agencies have found this tool to be a helpful starting position while aiming to strengthen their asset management programs (Wittwer, et al., 2003). Figure 2.1 shows the FHWA's framework for asset management process by showing the critical steps involved and their connection flow. The first step is defining the goals and policies of the system, which must state the agency's mission and reflect the customers' input and expectations. These goals can be later evaluated at the end of the process, as part of the monitoring and feedback mechanism. Establishing a solid and accurate asset inventory is also one of the key factors in that framework, in order to identify all the assets under the agency's jurisdiction, know their value, and track their condition and performance. The condition assessment procedures must be set according to the agency's capabilities and resources to ensure the program's success. An asset performance forecast is then performed based on established models in order to determine the future network performance, and thus identify its needs. Using this data, the network-level program is built by optimizing the available budget to result in the highest network performance possible. Next, projects are selected to be included in short-term plans to be implemented in the next fiscal year or included in the long-term plan (FHWA, 2007).

The successes at the federal and state levels have led to an increased interest in local agencies pursuing similar methods of asset management. The first local agencies that have adopted asset management plans have shown an increase in infrastructure overall condition, as well as more available funding (Bernardin and Durango-Cohen, 2006). Knowing that state DOT TAM programs only address 25% of the nation's roadways, leaving local governments to manage 75% of roadways and 50% of bridges, it is crucial that these agencies have well-established TAM programs to ensure satisfactory performance of the network (Bernardin and Durango-Cohen, 2006). In addition to the pavements and bridges, transportation assets include traffic signs, signals, lane marking, guardrails, culverts, and other assets lying within the right-of-way. The agencies must manage all these assets within the limited funds, which leads them to make trade-offs in the budget allocation process. This concept will be discussed later as part of 'Cross-asset modeling'.

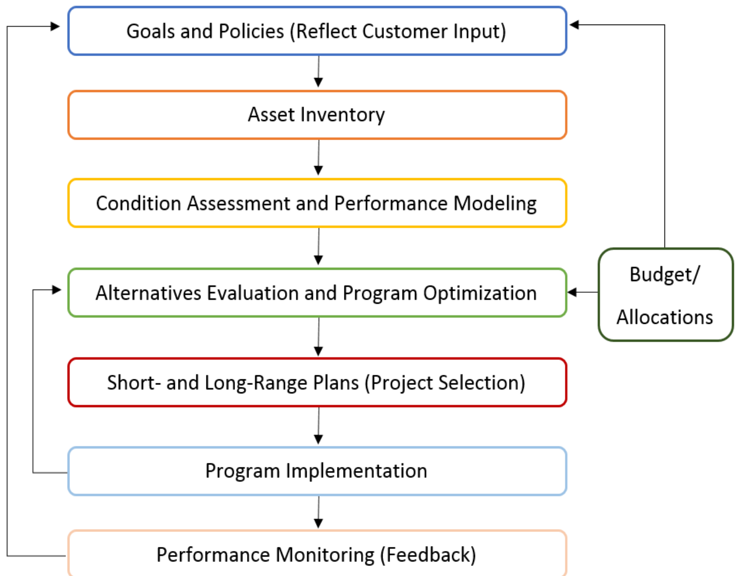


Figure 2.1 FHWA Transportation Asset Management Framework

1.2 TAM Components

1.2.1 Organization

The organizational structure and amount of available resources for local agencies vary. Therefore, the asset management guidelines for each local agency greatly depend on the agency's structure. Organizational culture has proven to be one of the largest obstacles in establishing an asset management program (Wittwer, et al., 2003). Only small agencies with few employees are exempt from this obstacle. Larger agencies with many divisions, such as state DOTs, may have trouble reaching consensus when creating new system processes. Figure 2.2 displays the hierarchical organization within Minnesota's DOT culvert management. The Minnesota DOT has eight engineering districts that participate in asset management (FHWA, 2017).

Regardless of agency size, from the federal to the local level, an important step in achieving efficient asset management is coordination and communication. This shared coordination can benefit single agencies with multiple divisions as well as with neighboring agencies. Larger local agencies may have the resources to have independent divisions for each managed asset, whereas smaller agencies have one division managing all assets.

Top management commitment to implement the goals set by the system is crucial. Moreover, as TAM requires comprehensive coordination and communication among the agency's employees working under different units, it is critical to get them involved so they can appreciate the importance of the management system, and hence create an agency-wide commitment for success. All personnel involved in TAM, as well as other stakeholders, should know the agency's mission, vision, and goals, performance measures and strategies, progress made, and work that still needs to be done. (FHWA, 2007) Agencies must consider having a management position or office that acts as a focal point in guiding the asset management process, where collected information is filtered and synthesized in order to be directed for decision makers. (TRB, 2008) It is also recommended that an agency assigns what is usually identified as a 'champion', who is a senior leader that was involved in defining the agency's strategy and acting as a support for the TAM, ensuring that all appropriate resources are available for its success. (FHWA, 2013a)

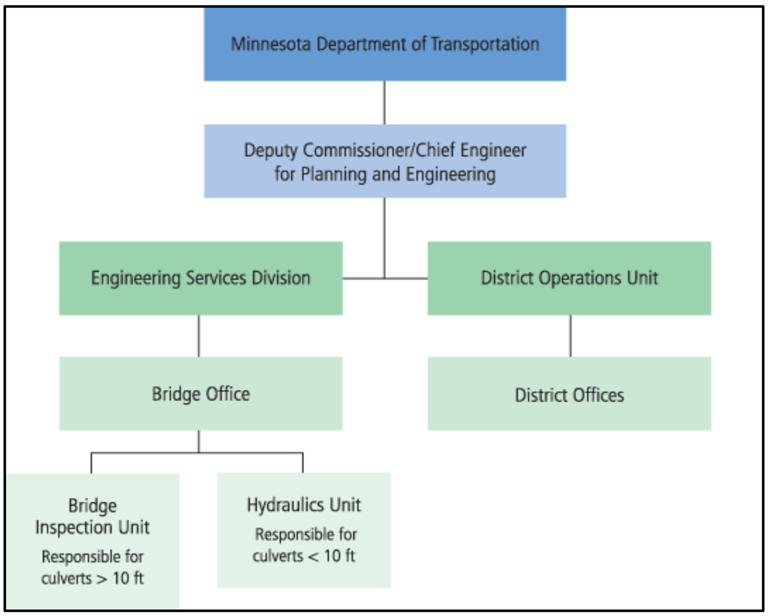


Figure 2.2 Minnesota DOT Culvert Management Organizational Structure

State TAM leaders may have the title of Chief Executive Officer, Deputy Secretary, Director of Public Works, along with many other titles. Although the principles of asset management remain the same, the roles of a TAM leader vary from state to state. However, it is very common to have a TAM champion who initially introduces TAM techniques to a State agency. This individual may be tasked with reporting and communicating with FHWA on the conditions of federally-owned assets. As State TAM divisions become more complex and manage a greater number of assets, the leadership may expand and diversify. Many DOTs have TAM steering or working committees that include staff from various divisions within the State (TRB, 2015).

1.2.2 Strategic Policies and Plans

Agencies must set an asset management policy, either imposed or self-determined, that directs its practice, and defines goals that guide the agency's activities and decisions. The TAM goals must include all the imposed legislative, regulatory, or executive mandates. They must also clarify to the stakeholders, the agency's fundamental responsibilities, and should establish clear priorities among all goals and objectives. Goals must be set to be attainable and well-measured through performance measures in order to evaluate them against performance targets. (Bernardin and Durango-Cohen, 2006)

Organizational goals, policies, and budgets are a means to evaluate the asset management framework. Decision making is mainly driven by goals and performance measures to establish an investment size that reflects service levels and to match the public's needs with the resource allocations. Policies are broad non-engineering, non-economic factors reflecting the transportation agency's values, perceptions, and tendencies which may modify performance-based decisions. Goals can be established based on users' priorities, values, and standards in measurable terms, such as ride smoothness, level of service, travel time, mobility, accessibility, etc. Performance targets are a way to convey to the public how assets are being managed in a logical and fact-based approach since asset management is a customer-focused, goal-driven management and decision-making process. (FHWA, 2007)

After studying the different elements in TAM and based on policies and goals that were set, action plans are formed to identify objectives and formulate tasks, while deciding which elements to include in the plan – assets, types of investments, business functions, and techniques. Tasks identified should have a defined time frame that takes into consideration factors such as the overall priority of each task, the logical sequence of the tasks required to achieve a certain goal, available budget, and the update cycles of policies, data collection and analysis, budget and program development, or delivery of projects and services. (FHWA, 2007)

1.2.3 Asset Inventory

A solid asset inventory acts as the cornerstone of the TAM program, for the agency must know all the transportation assets that fall under its jurisdiction, in addition to basic information concerning the assets' location, type, quantity, and other characteristics pertaining to the corresponding asset item which could help in better managing the system. The following subsections discuss the processes involved in establishing the asset inventory through data collection and management, and how data, tools, and equipment sharing can help agencies in reducing the cost and improving the data quality.

Data Collection

Asset inventory practices can be categorized into different levels based on the effort spent on data collection and the resources being used. The minimum level simply collects basic physical information (e.g., location, size, type, quantity) which may be incomplete or based on assumptions. The core level adds to the minimum level some attributes that can be used in asset valuation such as replacement cost and asset age or installation date, while documenting asset hierarchy, asset identification and asset attribute systems. An intermediate level is characterized as a reliable register of physical and financial attributes that are based on a systematic data collection process, being recorded in an information system with application of data analysis and reporting, while entailing a high level of confidence for critical asset data. For the advanced level, a systematic and fully optimized data collection program is used with a complete database for critical assets and with minimal assumptions for non-critical assets. Information is also collected for work history type and cost, condition, performance, etc. recorded at individual asset component level (Smith, 2013).

As data supports all the activities and decisions of asset management, it should be complete in terms of the assets and its related cost information. It should be current, with regular data collection and updating being performed, and accurate by using standards (metrics, indices or scales and quality control /quality assurance measures) for measurements and by making sure that systems are being used correctly through training the staff responsible for data collection. Finally, data should be accessible by storing data in a form that is ready to use by decision makers. Commercially available computerized management systems are currently being used for that purpose (Bernardin and Durango-Cohen, 2006).

Data Management

Management systems allow agencies to efficiently organize and analyze information. Data management tools help officials assimilate information from existing condition assessments. As agencies often have multiple assets to manage, data integration is an important component of the data management process. Data management can be as simple as compiling existing conditions into one dataset in order to better synthesize and understand existing conditions. Data integration can help connect different components of an agency's transportation assets. Georgia DOT realized its need for data integration in order to establish a common network of spatial data. Data redundancy is common in large agencies that haven't achieve data integration. Agencies are becoming increasingly attracted to the idea of data integration as a means of reducing data collection and storage costs, improve data quality and accuracy, improving data security, and improved accessibility to data. On the other hand, data interoperability improves coordination with multiple agencies at the local, regional and federal levels. It also promotes data sharing and shared learning. (Bernardin and Durango-Cohen, 2006)

Local agencies are relying more on computerized tools to aid in the asset management process. However, evidence has shown that 20% of 70 municipal and county governments surveyed across the United States rely solely on paper data management (Bernardin and Durango-Cohen, 2006). There is a need for a more ubiquitous asset management system for local governments. Computerized tools streamline asset management processes for local agencies and have the capability to improve data collection, resource allocation, and decision-making. The software can range from simplistic spreadsheets to complex software that has the ability to analyze, prioritize, and schedule projects. Another feature of computerized asset management tool is the incorporation of public feedback into the decision-making process. Public input, service requests, and complaints can be recorded into the software system to be reviewed and made part of the decision-making process.

Data, Tools, and Equipment Sharing

A key finding from the Fifth National Workshop on Transportation Asset Management was that the sharing of data and information is a highly effective method of reducing asset management costs and improving the quality of information management (Bernardin and Durango-Cohen, 2006). Data collection and storage is an essential part of asset management. Local agencies often lack the resources to create and maintain extensive databases, which is necessary for managing existing conditions. Michigan has established a central data storage agency, the Michigan Department of Information Technology (Cambridge Systematics, Inc., 2006). This statewide geographic information system helps to ensure a consistent data storage and collection process. Asset management software can reduce the cost of asset management by sharing resources among multiple agencies. Asset inventories should be maintained in compatible databases in order to reduce maintenance efforts and costs (Bernardin and Durango-Cohen, 2006). Group purchasing can reduce the costs of asset management programs and software.

Collaboration between departments, local agencies, and even state departments can reduce duplicated efforts, increase resources and information, improve access to software and technologies, and reduce costs (FHWA, 2012a). Group purchasing, equipment sharing, and shared software can greatly benefit local agencies with limited resources (Bernardin and Durango-Cohen, 2006).

Equipment sharing is a viable option for local agencies with fewer resources than state transportation departments. Initial equipment costs may be difficult for individual agencies to take on alone. Often times, neighboring agencies require the same materials, tools, and equipment necessary for asset management. Written contracts can be used to formalize and facilitate the sharing of equipment and materials.

Oregon has been practicing software sharing since 1990. The Association of Oregon Counties provides the Oregon Integrated Road Management System to 36 of Oregon’s mid-sized counties. The association has computer programmers developing management tools for managing pavement, vegetation, equipment, GIS, budgeting and financial accounting. The software works with the needs of the counties to continually improve and develop the software’s capabilities over time (Wittwer, et al., 2003).

1.2.4 Condition and Performance Assessment

The initial step in asset management for local agencies includes a current conditions assessment. All agencies, regardless of size, must understand the existing conditions of all managed assets. Agencies may vary in how frequently they update their existing conditions inventory. This depends on the amount of funding and resources that are available to the agency. (Cambridge Systematics, Inc., 2006)

Condition assessment of transportation assets can be done using several methods. The manual collection employs two or more data collectors and a distance-measuring device, who collect data and document it with a pen and a paper, or in most recent cases with handheld computers equipped with GPS. Data is either collected by staff walking on foot and examining the assets carefully, or through their vehicle's windshield while driving. Although this method allows for detailed yet biased data collection, it is labor demanding and requires more time than other advanced methods. The automated collection involves the use of multipurpose vehicle equipped with a distance-measuring device as well as a combination of video cameras (downward or forward-looking), gyroscopes, laser sensors, computer hardware, and GPS antennas in order to capture and store the data and process it through a specifically developed software. High automation and accuracy are achieved using the newest data collection equipment. Widely adopted by transportation agencies is the semi-automated collection which yields comprehensive and accurate data when properly implemented; however, involves a less degree of automation than the previous method. The most advanced is the remote collection method which uses satellite imagery and remote sensing applications to acquire high-resolution images. These images are then used in conjunction with ground information for the transportation assets' location referencing and condition assessment by capturing many of their attributes and characteristics. (Pantelias, 2005)

A condition rating protocol must be chosen by the agency for each asset type. This protocol would include a field assessment procedure to determine the assessment measurement details such as the distress types, severity levels, and extent for pavements, as well as the asset rating computation. Below are some of the most common rating protocols used for pavements and bridges.

Pavements

As for pavement, the largest resource-demanding asset, there are several rating systems that have been developed. Selecting the right pavement rating system depends on the cost-effectiveness achieved, the equipment and personnel needs, and interoperability (incorporating data into TAM software). As local agencies don't have the state DOTs' budgets and workforce that allow them to undertake extensive roadway data collection and analysis, they need to find a rating system that meets their needs while being accurate and cost-effective. (Fitzpatrick, 2016) Of the most adopted rating systems are:

- Pavement Condition Index (PCI)

  Developed by U.S. Army Corps of Engineers and then standardized in ASTM D5340, Standard Test Method for Airport Pavement Condition Index Surveys (ASTM, 2009), it categorizes the pavement condition based on observations in the severity and extent of various pavement distresses, with PCI values ranging from 0 to 100, representing failed and excellent pavement condition, respectively. It helps determine maintenance activities needed by the pavement surveyed; however, it is complex and required extensive data collection. (Fitzpatrick, 2016)

- Present Serviceability Index (PSI)

This system originated from the AASHO Road Test PSR in which raters in a moving vehicle determined pavement condition values based on the quality of the ride. Statistical relationships and correlations were then developed between the panel ratings and pavement distresses such as cracking, rutting, and roughness to determine PSI. Ranging from 0 to 5, for very poor to excellent condition respectively, it is calculated based on slope variance, mean rut depth, cracking, and patching.

Table 2.1 below shows the pavement ride quality breakdown based on PSR values, established by FHWA in 1999 (Fitzpatrick, 2016).

Table 2.1 Pavement ride quality breakdown based on PSR values (Fitzpatrick, 2016).

Ride Quality Condition	PSR Rating		Interstate & NHS Ride Quality
	Interstate	Other	
Very Good	≥ 4.0	≥ 4.0	Acceptable 2.6 - 5.0 Less than Acceptable ≤ 2.5
Good	3.5 - 3.9	3.5 - 3.9	
Fair	3.1 -3.4	2.6 - 3.4	
Poor	2.6 - 3.0	2.1 - 2.5	
Very Poor	≤ 2.5	≤ 2.0	

- Remaining Service Life (RSL)

This system is used in pavement management systems to prioritize maintenance operations with limited available funds. It represents the expected number of years of pavement operation before rehabilitation is required. The pavement life can represent the number of years from pavement construction till first rehabilitation, in case the section is new, or the period between two consecutive construction processes in case the section passed its first cycle. Forecasting the remaining service life of a pavement section is crucial as it predicts when it will require rehabilitation after reaching its terminal condition. The Pavement deterioration curve, as shown in Figure 2.3, plots the change in pavement condition versus time and traffic. It can also determine the criteria for the MR&R trigger points that signal certain treatment strategies, which are all set by the transportation agency according to its goals. (Fitzpatrick, 2016)

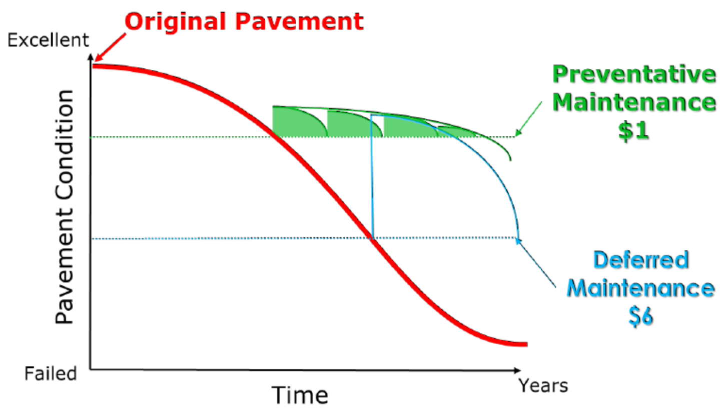


Figure 2.3 Pavement deterioration curve with MR&R trigger points (Fitzpatrick, 2016).

- International Roughness Index (IRI)

This is a numerical rating system of the pavement condition based on the ride quality, formulated based off the longitudinal road profile, measured in inches per mile (in/mile) by a simulated vehicle that monitors wheel paths disturbances (up and down motions). As roughness and thus disturbances increase, the higher the IRI score; whereas a smooth road in good condition has a relatively low IRI score. Table 2.2 below expresses IRI ratings per ride quality category established by FHWA in 1999. (Fitzpatrick, 2016)

- PASER Rating System

This system allows transportation agencies to understand and rate the pavement surface conditions in their jurisdiction, from one to ten, with one being the worst and ten being the best, through a visual inspection of the road. PASER Manual highlights key distresses in pavements when conducting visual inspections; these include: block cracking, drainage issues, edge cracking, fatigue cracking, longitudinal cracking, roughness, rutting, transverse cracking, and utility cuts/potholes. This rating proved to be beneficial for local agencies due to their cost-effectiveness, ease of use, and minimal workforce requirements for data collection. The manual has also developed a score computation sheet with recommended maintenance strategies based on the rating score (see Table 2.3). (Fitzpatrick, 2016)

Table 2.2 Pavement ride quality breakdown based on IRI values (Fitzpatrick, 2016).

Ride Quality Condition	IRI Rating (inches/mile)		Interstate & NHS Ride Quality
	Interstate	Other	
Very Good	< 60	< 60	Acceptable 0 - 170 Less than Acceptable > 170
Good	60 - 94	60 - 94	
Fair	95 - 119	95 - 170	
Poor	120 - 170	171 - 220	
Very Poor	> 170	> 220	

Table 2.3 PASER ratings with recommended MR&R Strategies (Fitzpatrick, 2016).

PASER Rating	Distress Type	M&R Strategy
9 & 10	None	No maintenance
8	Transverse Cracking, Reflection of Pavement Joints, and all cracks are sealed	Little or no maintenance
7	Slight Raveling & Traffic Wear	Routine maintenance, crack sealing, and minor patching
5 & 6	Moderate Raveling, Longitudinal Cracks on Pavement Edges, & Rutting Distortions	Preservative Treatments (Seal Coating)
3 & 4	Severe Raveling, Longitudinal/Transverse Cracking, Patches in fair to poor condition	Structural Improvement and leveling (overlay or recycling)
1 & 2	Alligator Cracking, Rutting 2" deep, Potholes, Patches in poor condition	Reconstruction

Bridges

The most adopted rating system for bridges is FHWA National Bridge Inventory (NBI) General Conditions rating, where the bridge condition is determined as the lowest of the condition ratings of its elements (Deck, Superstructure, Substructure, and Culvert). If the lowest rating is greater than or equal to 7, the bridge is classified as good; if it is less than or equal to 4, the classification is poor. Table 2.4 shows a description of the numeric rating scale (FHWA, 1995).

1.2.5 Decision Making Process

Using the performance measures and existing condition assessment, the next step is to plan for the changing conditions of existing assets. A local agency's asset management approach includes establishing performance targets and allocating funding. The main objective of the decision-making process is to understand the connection between existing conditions and project investment. Agencies striving to maintain a suitable level of service among all managed assets are constrained by funding availability and the competing needs of individual assets.

Table 2.4 NBI element rating system (FHWA, 1995)

<table>
<tr><th>Code</th><th>Description</th><th>Feasible Actions</th></tr>
<tr><td>9</td><td>Excellent Condition</td><td rowspan="3">Preventive Maintenance</td></tr>
<tr><td>8</td><td>Very Good Condition</td></tr>
<tr><td>7</td><td>Good Condition - minor problems</td></tr>
<tr><td>6</td><td>Satisfactory Condition - minor deterioration in structural elements</td><td rowspan="2">Preventive Maintenance and/or Repairs</td></tr>
<tr><td>5</td><td>Fair Condition - Primary structural elements are sound, minor section loss, cracking, spalling, or scour</td></tr>
<tr><td>4</td><td>Poor Condition - Advanced section loss, deterioration, spalling, or scour</td><td rowspan="5">Rehabilitation or Replacement</td></tr>
<tr><td>3</td><td>Serious Condition - Loss of section, deterioration, spalling, or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.</td></tr>
<tr><td>2</td><td>Critical Condition - Advanced deterioration of primary structural elements. Fatigue Cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored, the bridge may have to be closed until corrective action is taken.</td></tr>
<tr><td>1</td><td>Imminent Failure Condition - Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. The bridge is closed to traffic, but corrective action may put back in light service.</td></tr>
<tr><td>0</td><td>Failed Condition - Out of service. Beyond Corrective Action.</td></tr>
</table>

Performance modeling is a crucial step in decision making as it forecasts the asset condition in the future in order to make sound resource allocation choices by identifying proper maintenance and rehabilitation strategies. Several methods were adopted for performance modeling such as regression models, econometric models, heuristic optimization models, and probabilistic models. However, the most currently used is the ‘Markovian chain’, which is a type of probabilistic model, as it was developed from estimates of the probability that a given condition state will either stay the same or move to another state, based on historical field data or the experience of agency personnel. Using the probability transition matrices, an agency can also develop pavement performance models by calculating plotted points based on matrix multiplication. (Li & Sinha, 2004)

Many resource allocation optimization models have been developed previously for cross-asset management that deals with all transportation assets instead of splitting the system into individual systems to be analyzed separately. Some researchers have adopted a macroscopic or network-level approach when formulating their optimization models. These models treat the entire transportation asset network as a whole, and determines the overall condition distribution and budget allocation plan, with the ability to perform long-term analysis on large networks efficiently. However, this approach only allocates budgets among different types of assets without assigning any priority for projects. To deal with that, a microscopic or project-level approach was formulated and takes into account each individual asset unit and generates a specific maintenance and rehabilitation work plan for the asset network. It is implemented using an optimization model, where binary variables are introduced for each individual asset unit (i.e. a pavement segment or a bridge) or project candidate to generate a specific work plan, and a prioritization model where the individual asset units or project candidates are ranked according to a computed index, such as a benefit-cost ratio or a utility score. However, this approach is difficult to implement on large networks due to its high computing requirements. An integrated approach is also formulated to merge the two previously mentioned approaches, by forming a model based on macroscopic that determines the overall condition of the network and distributes budget across different assets and preservation treatment categories, and a microscopic model that is applied to generate a specific project candidates list. The limitation of that model is that it cannot provide optimized solutions and is not flexible enough for practical implementation. (Wang, 2014)

1.2.6 Funding and Budgeting

In order to establish realistic condition targets and implementable projects, local agencies must have a clear understanding of available sources of funding. Some recommendations for local governments include assuming consistent levels of funding, identifying potential variations in funding, and evaluating and targeting new funding (Cambridge Systematics, Inc., 2006).

Federal Funding

Funding availabilities vary for state and local jurisdictions. Federal funding is available for states developing an asset management plan. The federal government has funding available from the National Highway Performance Program (NHPP) and Surface Transportation Program (STP) (FHWA, 2012a). As long as national highways are included in the state’s asset management program, federal funds can be used to maintain the state's entire asset management system. As shown in Figure 2.4, "*Transportation Funding from the Atlanta Region's Plan 2017,"* estimates $23.2 billion dollars in federal funds through years 2018-2040. The FHWA has a variety of funds, some of which are available through competitive application processes. Georgia has a repeated history of receiving one of these competitive funds, the TIGER grant. Competitive funds like the TIGER grant are not factored into anticipated federal funding (Atlanta Regional Commission, 2017).

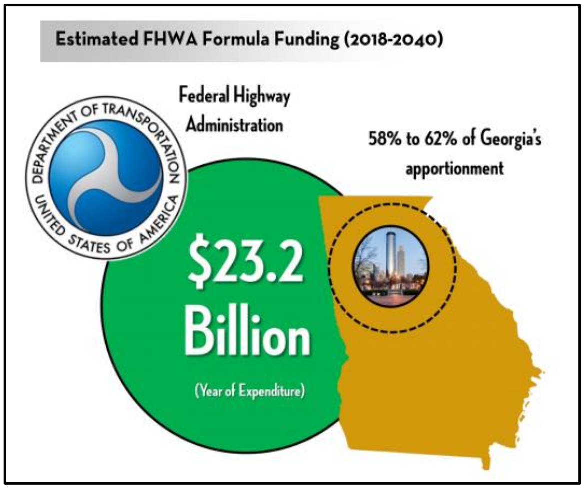


Figure 2.4 Transportation Funding from the Atlanta Region's Plan 2017 (Atlanta Regional Commission, 2017)

State Funding

In addition to federal funds, Georgia receives funding from the state level (Figure 2.5). The Transportation Funding Act (TFA) of 2015 has generated additional statewide revenue and is projected to increase available transportation funds $750-$1 billion annually. Georgia's TFA includes a $0.26 per-gallon state excise tax on gasoline and $0.29 on diesel per gallon. Additionally, the TFA imposes an annual truck and bus highway user impact fee that charges $50-$100, depending on the size of the vehicle. Hotel and motel stay contributes $5 per night to Georgia's transportation funding and electric vehicle owners contribute $200-300 annually (Atlanta Regional Commission, 2017).

Georgia DOT announced an increase for Georgia's 2016 transportation budget to accommodate routine maintenance such as pavement repair, guardrail repair, and upgrading lane striping. Road resurfacing projects resulted in a quadrupled funding allotment during the year 2016. Fiscal year 2018 anticipates funding for bridge repair and replacements that will triple annual transportation investment (Atlanta Regional Commission, 2017).

Local Maintenance and Improvement Grant (LMIG) Program

Georgia's DOT has developed the LMIG Program in order to streamline the process of granting Georgia's cities and counties funding for transportation projects. The program requires local agencies to participate through an application program, with grants ranging from $1,000 to $4 million. Grants will depend on the agency's population and number of miles of roadway (GDOT, 2017).

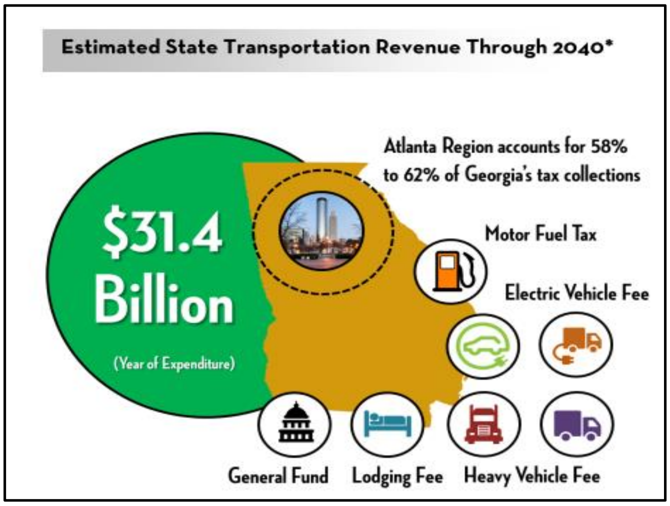


Figure 2.5 State Transportation Funding from the Atlanta Region's Plan 2017 (Atlanta Regional Commission, 2017)

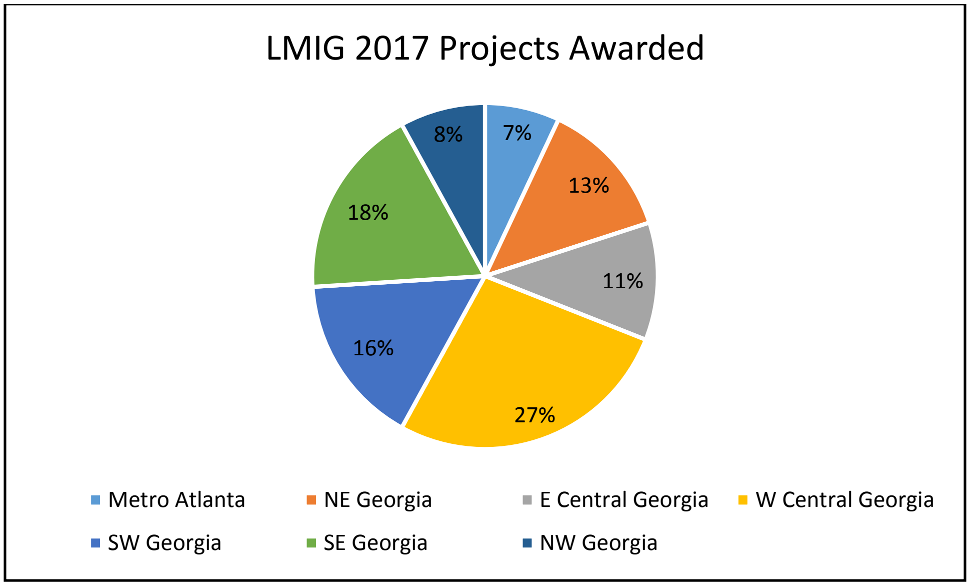


Figure 2.6 Local Maintenance and Improvement Grant Funding by Region (GDOT, 2017)

The LMIG program has helped to give local agencies the resources they need to make improvements to transportation assets. Each region of Georgia, as shown in Figure 2.6, has received grants for a variety of project types. West Central Georgia has received funding for 47 projects in 2017, whereas Metro Atlanta received funding for 12 projects. The awarded amount for each region of Georgia slightly ranges from $1,511,000 to $1,681,800 (GDOT, 2017). Awarded project types for 2017 included striping, signing, shoulder paving, sidewalk installations, crosswalks, ADA ramps, guardrails, vegetation removal, rumble strips, and drainage.

1.2.7 Reporting

Regular quarterly, biannual, or annual reports add accountability, objectivity, and transparency to the processes of asset management. Reports help educate and provide visual progress internally within an agency and externally to the public and larger planning organizations. Several states have conditions reporting legislation such as Michigan and Wisconsin (Bernardin and Durango-Cohen, 2006). Reporting ensures that agencies are tracking expenditures and system conditions. The accumulation of agency reports provides a series of historically recorded reporting that serves as an educational tool that promotes improvement. Reporting can help to improve an agency's efficiency by providing the evidence necessary to adjust future actions based on previous shortcomings. For certain agencies, reporting may be tied to funding. Note that the Governmental Accounting Standards Board (GASB) Statement 34 requires state and local governments to submit annual reports that improve the accountability of local governments.

1.3 State-Level Adoption of TAM

1.3.1 Overview

The number of States implementing TAM has increased in recent years. Most State agencies practice some aspects of TAM, such as pavement or bridge management (FHWA, 2007). Some agencies have implemented more complex TAM programs that analyze, compare, and prioritize policies, programs, and projects. State agencies can benefit greatly by sharing information, experiences, failures, and successes with other state agencies. AASHTO established its first TAM Subcommittee in the early 2000s before TAM was widespread among State agencies (TRB, 2015). MAP-21 was established in 2012 and required state DOTs to develop risk-based TAM for pavements and bridges on the NHS (Transportation Research Board, 2015). This was a substantive contribution to statewide TAM, also knowing that it was followed up by FAST Act in 2015.

1.3.2 Current Status Evaluation

States implementing TAM have found that organizational culture can be one of the most significant obstacles for the success of the system. Moreover, areas where further research needs to be performed were identified. Data collection and integration was identified as one of the areas in terms of maintaining databases, metadata standards, improving data quality, and automated data collection. More research is also required about condition assessment especially for hidden infrastructure, using remote sensing capabilities, warning systems, and finding the link between the assessment and decision-making. Performance modeling also lacks information for capturing the effect of routine maintenance in life value, modeling preventive maintenance, enhancing modeling techniques, and defining proper performance measures. TAM analysis must also be studied in terms of tradeoffs in the decision-making process, asset valuation methods, risk analysis, and treatment selection. Other topics that need research include infrastructure security, applications of emerging technologies, sustainable development and teaching infrastructure management. (FHWA, 2007)

1.4 Local-Level Adoption of TAM

1.4.1 Overview

In order to initiate asset management, it is helpful to have the support of top management. Vermont, for example, established a steering committee as a way to build support and garner volunteers to grow the committee and establish an asset management program. Likewise, Michigan was required by legislation to create an inter-agency committee that consisted of state and local officials. Inter-agency cooperation can be an effective way to pool resources and create a standardized asset management process that is consistent across the state. Local agencies should first look to the basic principles of asset management that have been established at the federal and state levels. Then, guidelines can be developed to help asset management for local governments. Guideline recommendations will vary based on the city or county's population, number and types of assets to be managed, funding sources, the total number of roadway miles, size of available workforce, and coordination among other agencies. Local agencies should establish goals that incorporate all federal, state, and local mandates. Additionally, agencies should address their responsibility to the public and establish clear priorities in alignment with the agency's goals and objectives (Bernardin and Durango-Cohen, 2006).

1.4.2 Current Status Evaluation

Many local governments are being motivated to adopt a well-defined TAM due to budgetary pressures, aging infrastructure challenges, legal mandates, GASB Statement 34 with its corresponding accounting practices, the system success in other state and local agencies, and the desire to take advantage of the new technologies. (Bernardin and Durango-Cohen, 2006)

Due to a large number of local governments in the US, with varying responsibilities and resources, they have established many systems of asset management with different approaches. Some of the challenges faced by local agencies include getting management and staff commitment for the management system adoption, building asset inventory and condition assessment with continuous updating, and the complexity of some asset management tools that prohibit them from being used on the long term (FHWA, 2007). Moreover, ensuring sufficient budget and support for asset management practices is also challenging for local governments knowing the limited resources they have. (Bernardin and Durango-Cohen, 2006)

1.5 Case Studies

1.5.1 State Agencies

Georgia Department of Transportation

In 2012, Georgia DOT adopted and developed a TAM Plan (TAMP) that meets Federal regulations that require the implementation of asset management. Additionally, Georgia DOT has established a TAM Steering Committee to guide the operations of the state's TAMP (GDOT, 2014). The DOT created an Asset Management Self-Assessment that was administered to the TAM task force.

Georgia DOT maintains over 18,000 of Georgia's 123,456 miles of roadway and more than 6,600 of 14,700 bridges. The remaining 85% of the roadway and 55% of bridges are maintained by local governments. Table 2.5 displays assets owned by GDOT. The majority of Georgia's assets are owned and managed by Georgia DOT (GDOT, 2014).

Georgia DOT uses Level of Service (LoS) to measure the public's perception of an asset's condition (GDOT, 2014). Three factors are used to measure LoS, including strategic objectives, department-wide performance measures, and customer feedback. Georgia DOT's

TAMP aligns with its GDOT's vision to enhance Georgia's competitiveness through leadership in transportation.

Georgia DOT creates an objectives table each fiscal year. The table includes each objective with corresponding action steps/strategies, measurements/targets, and the division responsible. An example includes maintaining Georgia's interstates such that 90% or more are in "Fair" or better condition. The action step for this objective includes developing a detailed pavement management implementation process for interstates through the Georgia Asset Management System (GAMS). The measurement/target is a COPACES rating of 75 or more for 90% or more of Georgia's interstates by the end of the fiscal year. The division responsible for this objective is the Division of Permits and Operations (Maintenance) (GDOT, 2014). Each fiscal year will have many objectives. Objectives not fully met may extend into the next fiscal year.

Concerning the pavements, Georgia DOT aims to operate and maintain roads at a level that optimizes safety, efficiency, and reliability. Figure 2.7 shows the distribution of state, county, city, and other public roads in the state of Georgia. Georgia DOT is required to maintain federal transportation infrastructure and often includes state roads. Remaining county and city roads fall under the jurisdiction in which they are located. State agencies are not required to incorporate these roads into state TAMPs.

Table 2.5 GDOT Managed Transportation Assets (GDOT, 2014)

ACTIVITY	ASSET COMPONENTS	QUANTITY	MEASURE	FINANCIAL WORTH
Vehicle Network	Road Pavements Road Bridges Freight Track Miles	18,903 6646 540	Miles *(Center Line)* Number Miles	N/A $6,265,500,000.00 $ 27,000,000.00
[1]**Facilities**	Welcome Centers Rest Areas District Offices Area Offices Maintenance Offices Storage facilities TMC's	9 17 7 43 275 482 2	Number Number Number Number Number Number Number	$ 14,617,105.48 $ 21,330,890.60 $ 70,250,000.00 $ 64,500,000.00 $ 93,782,883.85 $ 10,257,761.00 $ 38,973,409.00
Network Control and Management	Traffic Signals *(on State Routes)* Traffic Signals *(State Maintained)* Traffic Signs Road Markings Fiber Optic Communication Changeable Message Signs CCTV Cameras VDS Cameras Ramp Meters	5800 2417 3,000,000 18,903 280 115 620 2800 170	Number Number Number Miles Miles Number Number Number Number	$783,000,000.00 $326,295,000.00 ** ** $ 33,000,000.00 $ 17,000,000.00 $ 12,000,000.00 $ 35,000,000.00 $ 20,000,000.00
Parking	Park n Ride Lots Xpress Stations	93 21	Locations Locations	$ 19,017,435.00 $141,047,315.00
Vehicles and Equipment	Vehicles and Equipment	8874	Pieces	$44,510,000.00
IT Equipment	Server Equipment Network Equipment Workstations Printers VoIP	640 369 5100 684 1,357	Pieces Pieces Pieces Pieces Pieces	$1,544,991.71 $ 682,640.79 $5,387,408.14 $ 237,695.30 $ 450,000.00

In order to maintain its existing road infrastructure, Georgia DOT aims to maintain a COPACES rating of 75 or higher on all interstates and a rating of 70 or higher on all multi-lane and non-interstate state routes (GDOT, 2014). The TAMP includes scheduled inspections, reporting measures, performance reports, and public input. Additional needs for roadway maintenance include potholes, edge ruts, drainage, shoulders, slope repair, and vegetation. In addition to COPACES, Georgia DOT uses concrete surveys and inspections to collect information on existing asset conditions.

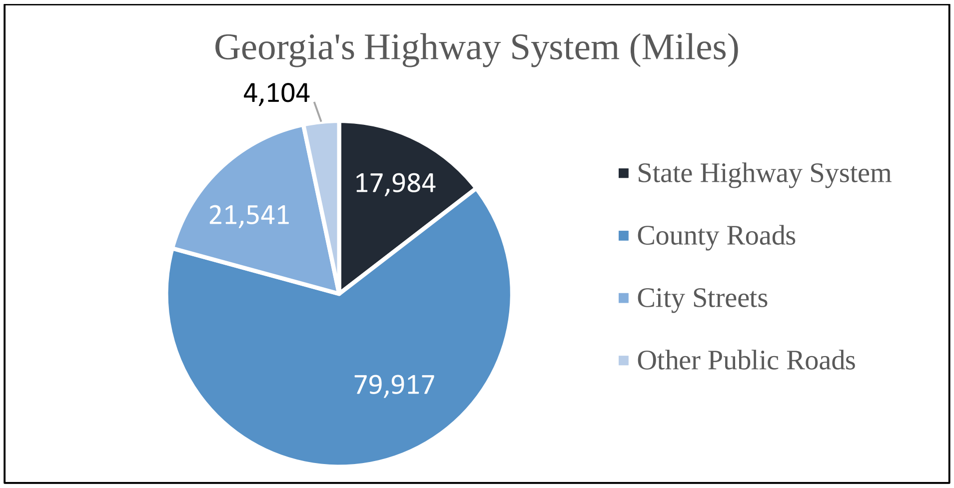


Figure 2.7 GDOT Highway System by Miles of Pavement (GDOT, 2014)

Oftentimes, roads will yield the same COPACES rating. These roads will be entered into the GDOT's Risk Factor Matrix in order to assess the associated risk for each roadway and better allocate the state's limited resources. The Risk Factor Matrix considers a variety of factors, including functional classification of the road, AADT, percent truck traffic, and population of the county the route is located (GDOT, 2014). Once the risk factor is calculated, the COPACES score is divided by the risk factor in order to determine a new rating.

As for the bridge assets, Georgia DOT maintains over 6600 bridge structures and aims to maintain 85% of state-owned bridges to meet or exceed Georgia DOT's standard. The standards include three rankings of good, satisfactory, and fair. Georgia DOT also complies with the National Bridge Inspection Standards (NBIS) that enforces a Code of Federal Regulations (CFR) TITLE 23, PART 650, Subpart C – National Bridge Inspection Standards. The Bridge Maintenance Unit (BMU) is responsible for bridge inspection and for submitting reports to FHWA to prove that all NBIS requirements have been met. Other responsibilities of BMU includes maintaining the Bridge Information Management System (BIMS) which keeps a record of bridge assets under its jurisdiction. It also communicates with local agencies who are responsible for some bridges, to make sure posting and maintenance requirements are met. BMU also ensures mobilizing inspection and maintenance resources to address emergency needs.

Georgia DOT has also established an additional analysis tool which is the Bridge Prioritization Ranking (BPR) formula, which assists in identifying which bridges are candidates for rehabilitation or replacement and when these bridges need to be scheduled in the construction work program. Thus, it concentrates efforts on bridge structures with the greatest combined risk rather than adopting ‘worst first’ approach. The formula is based on structural capacity in terms of the strength of the structure to carry vehicle loads, the condition of the different components of the bridge and the type of structure. It is also based on user demand considering the amount of traffic crossing the bridge, the length of the detour if the bridge is not in service, restrictions on truck weight and classification of the roadway.

Georgia DOT is facing challenging issues as funding limits are not sufficient for bridge maintenance and replacement requirements, knowing that the interstate system is approaching 60 years of age; thus, 88 bridges need to be replaced each year assuming an average maximum life span of 75 years. Therefore, due to budgetary constraints, Georgia DOT is deferring some planned bridge maintenance which increases the risk of greater lifecycle costs.

Ohio Department of Transportation

Ohio has the tenth largest highway system, the fourth largest interstate network, and the second largest inventory of bridges. As Ohio has grown, so has the number of unfunded transportation assets in need of improvement. In an effort to secure funding for transportation projects, Ohio DOT is using asset management to engage policymakers and stakeholders in the process. By effectively communicating goals, accomplishments, and improvements, Ohio was able to win over major funding for transportation investments (Wittwer, et al., 2003).

Michigan Department of Transportation

Michigan is unique in its emphasis on TAM. The state DOT has realized the benefit of understanding the needs of the entire state’s transportation network. Michigan DOT strives to communicate externally with elected officials, stakeholders, the public, and internally within the city’s council and departments (Wittwer, et al., 2003). The state has also developed an advisory group, the Michigan Transportation Commission (MTC), which consists of state and local officials. The MTC oversees and facilitates the state’s asset management. This asset management coordination can help to establish a standardized system of understanding existing conditions and planning for future needs.

1.5.2 Local Agencies

Gwinnett County, Georgia

Gwinnett County is one of the fastest growing counties in America. County officials have experienced an increasing need for more organized management and processes (Wittwer, et al., 2003). Consequently, the county implemented an asset management program that began by creating an inventory of assets. The county’s Department of Water Resources uses asset management to manage its water, wastewater, and stormwater infrastructure. Decisions are made by considering the total lifetime cost of each asset. The county uses information systems, such as mapping and work history, to provide current information to aid in the decision-making process.

Gwinnett County has effectively used asset management to manage and maintain assets at minimal costs while maximally serving the needs to customers (Gwinnett County Government).

Local Michigan Agencies

Michigan has established a Transportation Asset Management Council (TAMC) with the mission to help local agencies implement an asset management approach (Cambridge Systematics, Inc., 2006). The TAMC works with Michigan's State Transportation Commission to coordinate collaboration among state and local transportation agencies. By bringing together local agencies, regional planning organizations, and metropolitan organizations, a direct partnership can develop and function in efficient coordination. The TAMC redefines the asset management policies and guidelines developed at the national and state levels to better fit the needs and capabilities of local agencies. The TAMC has established five basic guidelines for local agencies, which include an assessment of current conditions, establishing program targets and funding, identifying projects, setting priorities and developing a multi-year program, and reporting results (Cambridge Systematics, Inc., 2006).

Kent County, Michigan

Kent County, Michigan has a joint effort asset management plan with the metropolitan planning organization and municipal government agencies within the county (Wittwer, et al., 2003). The county has established a six-step planning process as part of its asset management plan. The process includes surveying one-third of primary roads annually and updating the database of existing conditions by using the MicroPAVER program. The next step is to determine the county's current road needs based on PCI, traffic volumes, and other factors. Staff from multiple departments then identifies potential projects for a five-year period. Staff from the county's Planning, Engineering, and Maintenance departments collaborate to analyze future conditions and forecast future needs and objectives. The staff then updates the county's Five-Year Improvement program and incorporates the proposed plans into the annual budget each year. Considered projects are selected in coordination with other state and local agencies. Many factors are taken into consideration when prioritizing projects, such as the potential for economic development in high growth areas. The county uses the Federal Surface Transportation Program (STP) to fund 80% of pavement maintenance and construction (Wittwer, et al., 2003). An important component of Kent County's asset management program is the monitoring of project performance (Bernardin and Durango-Cohen, 2006).

Ionia, Michigan

The city of Ionia, Michigan has implemented a multi-asset transportation management system that includes streets, water and sewer lines, and fire hydrants (Bernardin and Durango-Cohen, 2006). The city identified issues due to the inefficiencies of data collection and storage. The city made the decision to transfer all data into a Geographic Information System that would connect all department databases. Additionally, the city invested in rating system software to evaluate existing conditions and prioritize project funding and implementation. Education and training led to the successful asset management program in Ionia. Ionia's asset management program has evolved as new needs presented themselves, such as integrating sidewalk repairs and updates into the city's plan. Additionally, the city's parks and trail system is being incorporated into the asset management plan.

Alcona County, Michigan

Alcona County has a population of 11,000 with 32 agency employees. The county benefits from collaboration with larger commissions and the assistance of Michigan's LTAP Center. The LTAP Center has helped many local agencies in Michigan begin successful asset management programs. The TAMC provides local agencies with education and training resources on the use of asset management principles and procedures. An introductory course on asset management is offered by LTAP. Alcona County implemented an asset management plan based on the RoadSoft program and a field data collection system. The RoadSoft program was developed by Michigan's LTAP Center to assist agencies in meeting federal requirements for pavement assets. Using this tool, Alcona developed a management system that measures existing conditions and forecasts future conditions. Deterioration curves are used to plan for maintenance scheduling. The asset management systems helped to create a framework for understanding maintenance alternatives and consequences of actions. The county's program uses information collected from assessments completed by townships. Existing conditions are used to develop cost estimates and needed revenue for asset maintenance (Wittwer, et al., 2003).

Alcona employees have found the asset management system to be an effective tool in promoting public understanding of the county's roadway asset and decision-making processes. Furthermore, this public transparency has helped enhance taxpayer support in Alcona (Wittwer, et al., 2003).

Cole County, Missouri

Cole County, Missouri underwent major asset management improvements as it transitioned from informal, knowledge-based asset management to a more systematic approach (Bernardin and Durango-Cohen, 2006). Cole County identified two main reasons for moving toward asset management practices, with one being dependence on employees' memories to make decisions (Wittwer, et al., 2003). Cole County previously lacked asset management processes that recorded decisions, actions, projects, and funding allocations. Asset management was established in order to capture information from aging and retiring employees. The second reason for moving toward an asset management plan was Cole County's need to comply with the GASB Statement 34 (Wittwer, et al., 2003). Similar to other local agencies, the GASB Statement 34 provided guidance for improving asset management programs at the local level.

Cole County partnered with the University of Missouri at Columbia for assistance. Students helped to create a simple database system using spreadsheets and GPS devices to begin data collection (Wittwer, et al., 2003). Each year, one-third of the county's existing road conditions are re-assessed and rated using a standardized condition rating manual (Bernardin and Durango-Cohen, 2006). The county used this new asset management system to plan for future maintenance projects by evaluating existing conditions and using performance prediction curves. Additionally, the county's asset management plan considered alternative options for short and long-range projects.

2. Cross-Asset Management Modeling

For agencies practicing TAM, individual management systems are being implemented for each type of infrastructures such as pavements, bridges, traffic signs, control devices, and other road furnishings. This practice is preventing agencies from considering the interaction which exists between these individual asset groups that collectively form the transportation infrastructure system. Although each group may be implementing the best optimization model in its decision-making process, these systems prove to be economically unsound and ineffective in terms of management and coordination due to the lack of communication between these interrelated components. For instance, consider a road section undergoing pavement rehabilitation followed by bridge maintenance works a couple of months later. (Zhang et Al., 2002) This will result in user dissatisfaction due to the traffic delays caused by successive construction works in addition to the loss of cost-savings that can be accomplished by the economy of scale. Cross-asset management has been recognized as the next generation of innovation for transportation agencies to improve their decision making on managing multiple transportation infrastructure assets (Proctor & Zimmerman, 2016). Its implementation is more economically efficient and improves the performance of the overall transportation system (Porras-Alvarado et Al., 2016). In light of the need to distribute the available funding among the different components of the transportation system to achieve the best performance, high-level management of agencies is developing an interest in decision support tools which implement cross-asset management to aid in finding an optimal resource allocation plan. Although many methods and tools are present for individual management systems considering the current practice, only a few frameworks exist discussing the cross-asset resource allocation process.

Many challenges and considerations are faced in the development of the cross-asset resource allocation models. The outcome of the model must address the maintenance needs of all assets, the objectives of the individual asset groups, and the objectives of the overall highway asset system in an equitable and optimal manner (Fwa and Farhan, 2012). It should allocate the total budget available among the competing asset components, select the facilities to be maintained and/or rehabilitated, and choose the most suitable treatment strategy for those projects (Sadek et Al., 2003). Thus, the challenge arises in implementing the above concepts which are characterized by the heterogeneity of the assets as well as the multi-objectivity and trade-off analysis required (Dehghani et Al, 2013). This heterogeneity dictates comparing the assets' condition, performance, and superiority while considering the difference in the asset's nature and the scales and methods used. Moreover, the multiple goals set by the agencies' policies and plans are usually in conflict, which makes it a difficult process. These goals include proper functioning of assets, structural integrity, safety considerations, economics, and environmental impacts in addition to other goals which act as the assets' performance indicators.

Due to the involvement of multiple types of assets, e.g., pavements and bridges, different decision-making techniques need to be applied to normalize and compare the benefit of maintaining each of them (Maggiore & Ford, 2015). Some literature focused on the modeling and solution of multiobjective asset management and left the final decisions to users (Chen et al., 2015; Shoghli & de la Garza, 2017). However, there exist infinite sets of optimal solutions, also known as the Pareto frontier, to optimize different conflicting objectives. Though a Pareto frontier provides sufficient information among different solutions, a decision maker still needs to use subjective preference to evaluate different objectives/criteria and achieve a single solution. This process is called multi-criteria decision-making (MCDM). Kabir, et al. (2014) have done a comprehensive literature review by summarizing the MCDM-related literature published from January 1980 to October 2012. Weighted sum model (WSM) and analytical hierarchy process (AHP) are two commonly used methods for transportation infrastructure asset management (Ziara et al., 2002; Ahmed et al., 2017; Farhan & Fwa, 2014). The above MCDM methods provide systematic approaches to decision-makers to deal with conflicting selection criteria and/or objectives. However, decision-makers' subjective preference on the criteria and/or objectives is often needed, which caused a problem for objectively justifying the superiority of a solution over another one. Thus, we need to "be objective wherever possible" in a decision-making process (Buchanan et al., 1998).

Pavements and bridges are the two biggest transportation infrastructure assets. In our literature search, these two types of assets were always included in cross-asset management modeling. Zhang, et al. (2002) developed an integrated asset management system for pavements and bridges, in which priority indexes were used to combine the different objectives. Sadek, et al. (2003) used the weighted sum of the condition of six types of assets, including pavements and bridges, within a utility function in the optimization modeling. The weighting factors indicate the relative importance of different assets. Dehghani, et al. (2013) used a more complex trade-off analysis to come up with a single quality measure for the entire transportation network by considering structure, function, safety, and environment for pavements, bridges, and other safety features. It consists of a cycle of 4 steps including an initial budget allocation among assets based on expert opinion, selection of treatment actions based on the assigned budget, prediction of the performance of each asset, and finally computing the overall performance of the whole corridor. The use of weighing factors among different assets largely relies on decision-makers' preference. Weninger-Vycudil, et al. (2015) used a weighted benefit-cost ratio as a utility function to allocate resources for pavement and bridge maintenance projects. A top-down approach consisting of a 3-stage model was also proposed to generate the optimal network-level budget allocation plan for a large-scale transportation network that considers multiple asset types and to schedule neighboring projects to occur simultaneously (Wang, 2014). The first stage used linear goal programming to allocate the available budget among different asset types by minimizing the weighted deviation of each asset group from its corresponding deficiency target level. Although these weights are assigned using the Analytic Hierarchy Process (AHP), it still involves some subjectivity within that step. AHP is also used in the second stage along with Multiple Attribute Utility Theory (MAUT) to select project candidates with maximum benefit, while choosing the best result among the two methods. In the third stage, selected projects are optimized using constraint and integer programming methods to establish a schedule that combines adjacent projects while considering budget limitations and project timing constraints. Another model is developed using the bottom-up approach to solve the multi-asset, multi-objective network maintenance optimal budget allocation problem using 2 stages to ensure maintenance needs of all assets are addressed, individual asset systems objectives are met in an equitable manner, and the overall highway system objectives are achieved optimally (Fwa and Farhan, 2012). The first stage uses a genetic algorithm to consider each individual asset system independently, and to study the multi-objectivity that establishes the family of optimal Pareto solutions by minimizing the maintenance cost, as well as maximizing the assets' condition. Using these results, the cross-asset tradeoff is performed in the second stage using dynamic programming to achieve the optimal budget solution for the overall network-level objectives. In that stage, the budget is allocated to the individual asset systems by minimizing the difference in their improvement levels above the pre-defined minimum performance threshold for each asset group. This approach can lead to questioning the optimality of the proposed solution and its effectiveness, since the adopted criteria of equal levels of improvement for different assets might not fulfill the maintenance needs of some of these assets. Another framework was also proposed using multi-objective optimization formulation to maximize infrastructure performance while also considering the appropriate distribution of benefits among the assets (Porras-Alvarado et al., 2016). The model introduces the concept of utility and envy to reflect the fairness consideration, by maximizing the first and minimizing the latter, in addition to maximizing the asset efficiency or performance. Therefore, the Pareto optimal solutions are obtained after assigning weights for the different objectives, which also introduce subjectivity in that model.

The use of WSM, AHP or other MCDM methods for cross-asset management is reasonable because of the difficulty to objectively measure the entire network's performance given conflicting criteria or objectives. However, as mentioned above, cross-asset management needs to be objective whenever possible. Using a transportation network consisting of pavements and bridges as an example, they are interdependent assets to provide desired LoS to the public in terms of mobility and safety. To the best of our knowledge, the interdependency between these two assets was seldom considered, if any, in the existing literature. Instead, decision-makers' preference was adopted to determine their relative importance. This strategy has been proved practical and effective. However, if their interdependency can be explicitly considered, the objectivity in the models would be significantly improved.

Chapter 3: Online Survey and Analysis

1. Introduction

After conducting a comprehensive literature review about the concept of TAM, its components, and the current practice among local and state governments, we have created an online survey that targets local agencies of the state of Georgia in order to validate the status quo. This survey will help in identifying the gaps and shortcomings in the local agencies' practice which are affecting the transportation assets' performance and network efficiency. The first section of the survey asks general questions to obtain some basic information about the respondent's name, job title, department, and contact info. It also asks for some highlights about the agency that they work for, such as it being a county, city, or a city-county merged agency, and the departments and number of employees that are involved in TAM. The next section checks for the agency's adoption of a well-defined TAM program, which in the case is present, several questions follow to clarify in detail about the practices of the agency in that subject matter. Condition assessment and data management, a crucial component of TAM, are also tackled in addition to another related section discussing performance measures and decision making. Finally, the questionnaire includes a part related to funding matters facing the agency in addition to their opinion regarding the current status of their TAM practice and how they rate it. Results from the survey helped to highlight the particularities of practice at the city and county level within Georgia. Coupled with the findings from the literature review, the survey results contributed to developing a customized set of guidelines for local TAM practice within Georgia.

2. Methodology

The survey was created and distributed using 'Qualtrics' online tool. It consisted of 35 questions organized into the six sections mentioned above: General Information, TAM Program, Condition Assessment and Data Management, Performance Measures and Decision-Making, Funding, and Rating of Current Status. This questionnaire was developed using elements from the FHWA's Asset Management Data Collection for Supporting Decision Processes and AASHTO's Transportation Asset Management Guide Self-Assessment Exercise, in addition to the reference to surveys conducted by some local and state agencies such as Kansas County Transportation Agencies, and Georgia DOT's Asset Management Self-Assessment Survey. As the survey aims to capture the city and county particularities unique to Georgia, some questions were specific to particularities of Georgia local TAM policies, funding, guidance, and resources, in addition to others being related to more broad and overarching transportation management practice details common to all local transportation agencies in the United States.

The survey was meant to be short and straightforward while maintaining details and specificity. Question types included a variety of single-answer multiple choice, multiple selection, short answer, sliding scales, and Likert scales. The survey included many, "Other," options to allow respondents to expand on their answers. To avoid redundancy and incorrect responses, the survey utilized branch logic, which customizes the respondent's survey experience by allowing different question paths throughout the survey. Depending on how respondents answer certain questions, they receive a slightly varied survey route. For example, the first question in the Transportation Infrastructure Asset Management section defines TAM and asks agencies, "Do you practice a well-defined transportation asset management program within your agency?" The response given for this question then controls the subsequent questions. Respondents who answer, "yes," "somewhat," and "not sure," are directed to complete the remainder of the Transportation Infrastructure Asset Management section. The respondents who answered, "No", skip the remainder of the section and continue to the Condition Assessment and Data Management section. Although agencies responded not having a well-defined TAM program, we assumed that it is likely that these agencies still practice some derivative of transportation management. The survey was designed to capture all nuances of local transportation management within agencies with varying agency size, the number of employees, available budget, etc.

The survey was set to be completed by managers and department and/or division leaders within local city and county agencies as a TAM self-assessment. It was administered to cities and counties within Georgia through several methods. Initially, as shown in Figure 3.1, the research team contacted representatives from Georgia DOT's LTAP and acquired about 400 contacts in cities and counties within Georgia. Additional outreach included contacting the twelve regional commissions in Georgia. The regional commissions had limited response rates, however, some regional commission directors agreed to forward the survey information to their respective counties and cities. The final method of survey outreach was conducted by searching online for county transportation department contact information. By manually researching the website for local governments, a database was created that included the contact information for management positions, such as Public Works Directors, Road Superintendents, etc., within Public Works and/or Road Departments. Once the information was collected, counties were contacted individually either by email, telephone, or both. The contact method was dependent on the information provided on each county's website. There were several limitations in this method, as several counties lacked comprehensive websites or contact information for transportation departments.

Following survey outreach, the data was sanitized for completeness and consistency. To ensure the maximum amount of data could be collected, survey responses were analyzed even if the respondent didn't make it to the end of the survey. If respondents answered the first set of general questions that included name, contact info, and city or county of employment, their response was kept for analysis. The response rates for each question varied from the beginning to the end of the survey.

As a result, sixty-two cities and counties received and began the survey. Some respondents chose not to complete the survey and several cities and counties had multiple survey entries. Of the sixty-two, responses from twenty-seven counties and seventeen cities were selected, in addition to only one consolidated city-county government, and one Georgia Department of Transportation (GDOT) district office. Note that since the category of county-city consolidation didn't receive enough responses, it was discarded in the analysis along with the response of the GDOT district as logical patterns cannot be formed based on one response as a sample space. The selected local agencies covered most areas of the state of Georgia, as shown in the map in Figure 3.2, as well as population size of each county and city survey respondent varying greatly, with the population of responding city agencies ranging between 500 and 102,200, whereas that of responding county agencies ranging between 6,800 and 1,040,000. Therefore, this wide range of population sizes in addition to the variance in asset jurisdiction scale differences as shown in the next section refutes any bias affecting the analysis results.

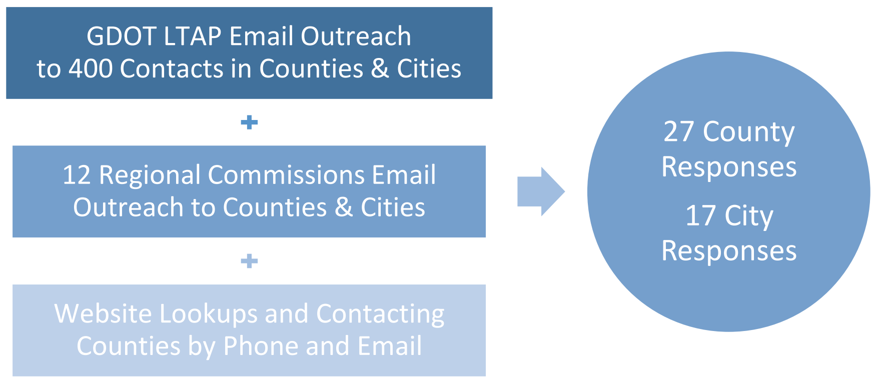


Figure 3.1 Flowchart of Survey Outreach Methods

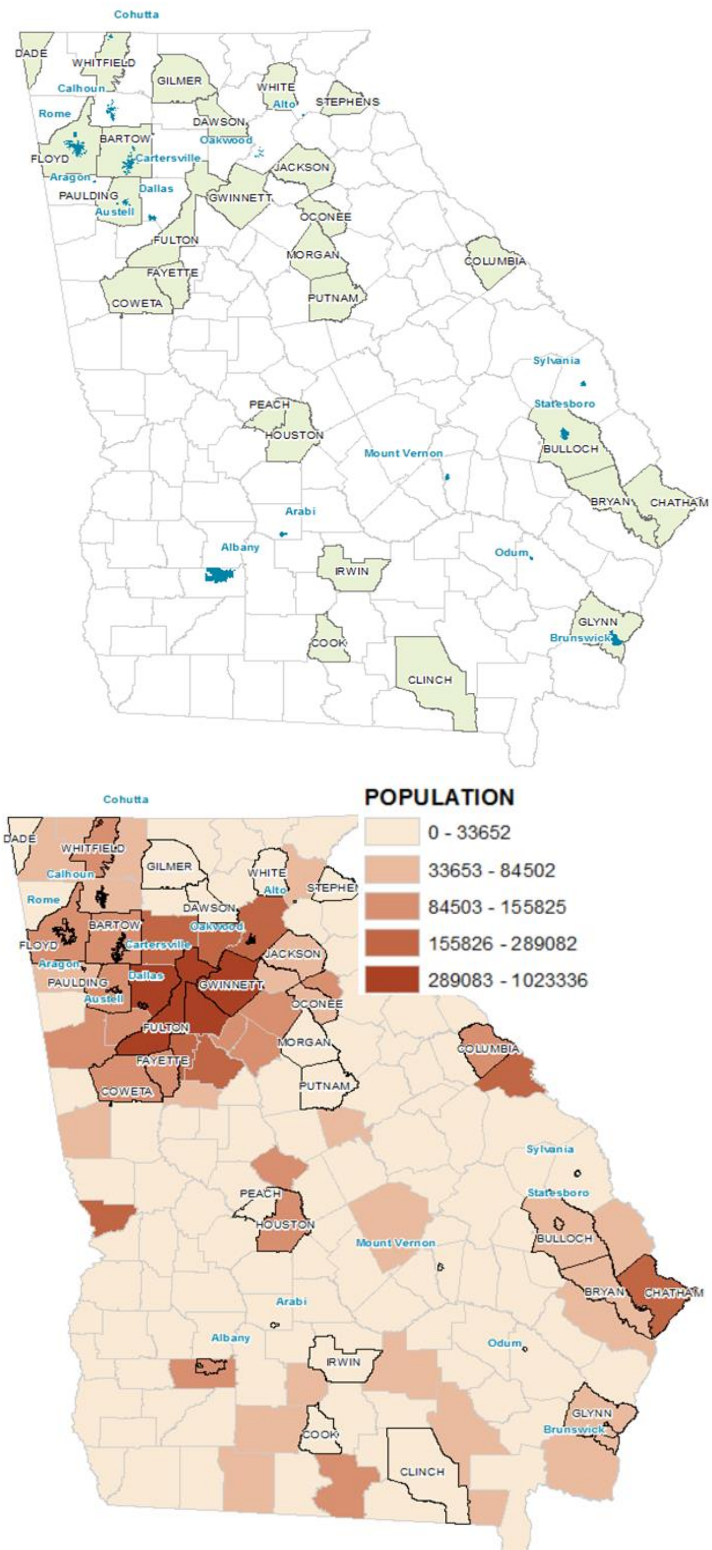


Figure 3.2 Spatial Distribution and Population Size of Respondent Cities and Counties

3. Analysis

The following section highlights the survey results and major findings. The survey analysis served as the critical component that provided previously unknown insights and information about current TAM practices at the local level. Results from the survey helped to highlight the particularities of practice at the city and county level within Georgia. Coupled with findings from the literature review, the survey results contributed to developing a customized set of guidelines for local TAM practice within Georgia. For a more comprehensive analysis with extensive graphical representation, please refer to Appendix I.

The survey data was analyzed using a variety of methods. In addition to the typical responses displayed using charts and tables, the survey data were aggregated into groups called, “Asset Tiers,” according to the quantity of managed assets under their jurisdiction. This helps by cross-analyzing the responses with a significant indicator, which can lead to meaningful conclusions. Asset Tiers have been categorized into four tier levels for both counties and cities, with ranges determined using the natural breaks in the data (Table 3.1). The number of paved and unpaved roadway miles is based on the latest available records from the GDOT Office of Transportation Data issued in 2016 for counties and 2009 for cities, and combined with the responses collected from one of the survey’s questions, as some data from both sources were missing. Most county respondents belong to Asset Tiers 2 and 3, with an asset range of 250 to 1000 miles in each jurisdiction (Figure 3.3).

The purpose of the Asset Tiers is to aggregate the counties and cities into groups to be cross-analyzed with other survey questions. The survey contains many questions that can be explored in numerous ways. This analysis uses the aggregated county and city data to identify key findings and correlations between an LG’s number of managed roadway asset miles with other variables, such as agency organization, TAM origin and establishment, funding, and collaboration. This report highlights the most important findings from the cross-analysis results.

The following sections analyze each of the six survey parts: General Information, Transportation Asset Management Program, Condition Assessment, and Data Management, Performance Measures and Decision-Making, Funding, and Rating of Current Status.

Table 3.1 Asset Tier Groups by Total Number of Paved and Unpaved Roadway Miles

Asset Tiers	County Roadway Miles	City Roadway Miles
1	0 – 250	0 – 50
2	250 – 500	50 – 100
3	500 – 1000	100 – 500
4	1000+	500+

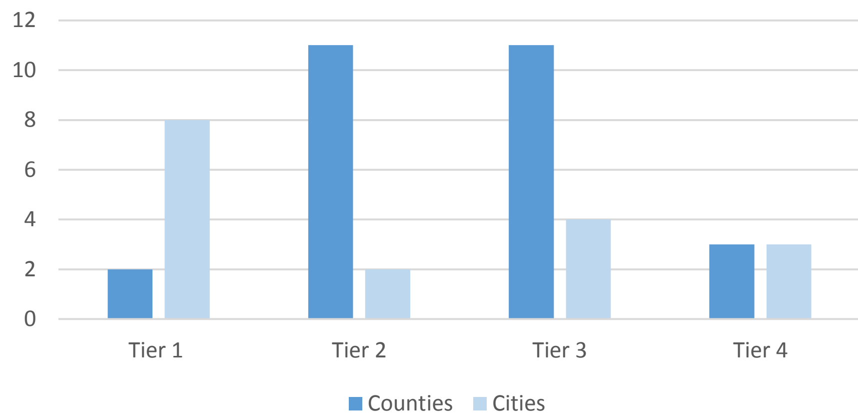


Figure 3.3 Miles of Paved Asphalt Concrete Roadway by Asset Tier Groups

3.1 General Information

Survey respondents began the survey with a general information section, which asked the respondents to record their name, contact information, job title, and the agency they work for, whether it is a county, city, or consolidated city-county. Additionally, this section included general questions about the structure and establishment of transportation infrastructure management within the respondent's agency. In that context, respondents were asked to list the divisions and departments within the agency that are involved in managing transportation infrastructure assets. Public Works Department was the most frequent response, followed by Engineering and GIS departments. Additionally, most counties have over twenty staff employees who are actively involved in managing transportation infrastructure assets, whereas most cities have less than 5 employees. This can be tied to the difference in scale of assets included under the jurisdiction of counties and cities, coupled with the availability of financial resources.

The final question in the general information section asked whether agencies had an established GIS department or GIS Professional (GISP) employees. Most cities and counties confirmed the above, while others either answered no, somewhat, or selected 'Other' and provided further explanation. Some counties indicated having a contract with their regional commission to assist with GIS work. Other counties indicated that they didn't have GIS departments, but GIS duties fell on other agency divisions, such as the public works department. One county indicated that they hire a private company for GIS services. City agencies also responded 'Other', indicating that they obtain GIS assistance from their county agency. One city agency noted that they have a partnership with their county, as well as several other neighboring cities for assistance and collaboration. When cross analyzing GIS utilization and Asset Tiers (Figure 3.4), there is a relationship between the two variables. Agencies that indicated a lack of GIS departments or GIS employees also have less managed roadway miles, with counties belonging to Asset Tiers 1, 2, and 3 and cities of Asset Tier 1 only. Subsequently, all county and city agencies of Asset Tier 4 confirmed having GIS departments and employees. This proves that some agencies with smaller asset jurisdiction are yet to utilize proper asset management tools.

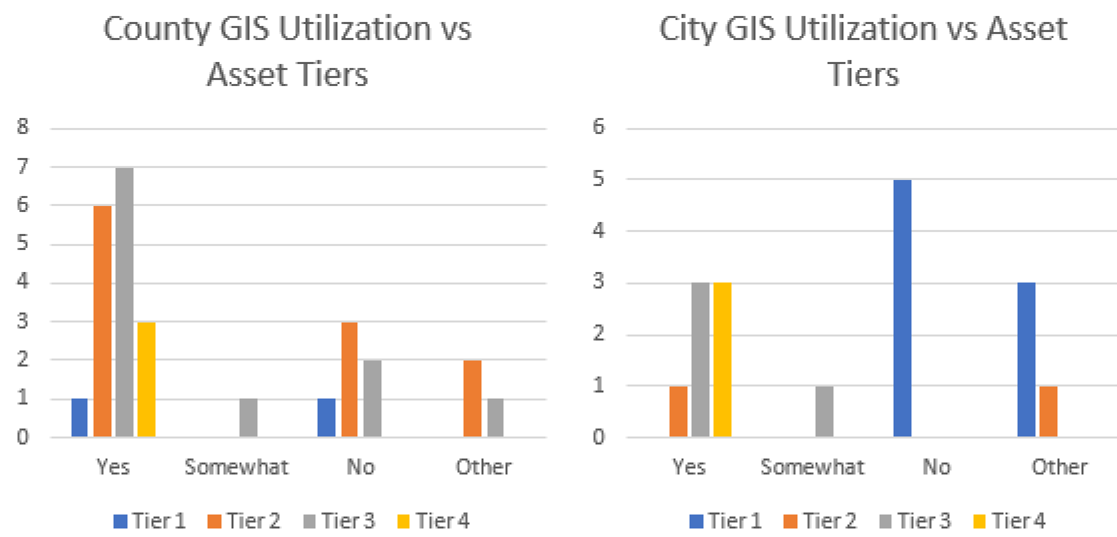


Figure 3.4 Cross-analysis Between GIS Utilization and Asset Tiers

3.2 Transportation Asset Management Program

The section following the general information section has nine questions regarding an agency's TAM program. The first question defines TAM and asks survey participants if they practice a well-defined TAM program within their agency. The answer choices were yes, no, somewhat, and not sure. The participant's response to this question controlled the remaining order of survey questions. If a respondent responded that they don't have a well-defined TAM program, he or she will automatically skip the eight remaining questions in the TAM section that ask for more detail about the agency's TAM program. These respondents will continue to the next section, Condition Assessment & Data Management. The other respondents who selected anything other than 'no' for the first question will work through the remaining questions in the TAM section. The common answer to that question was 'Somewhat' for most agencies (Figure 3.5), noting that all cities in Asset Tier 4 responded similarly. This shows that agencies are still not familiar with the concept of a well-defined TAM program with its known objectives and procedures.

Survey participants are then asked how many full-time and part-time employees are involved in TAM within the agency (Question 7). This question is similar to the question asked in the previous general information section, "How many employees are involved in managing transportation infrastructure assets? (Question 4)". Question 4 precludes the Transportation Infrastructure Asset Management section, where TAM is clearly defined. It was assumed that some counties and cities may be unfamiliar with TAM. Other agencies who are more familiar with TAM are expected to understand the difference between basic TAM and an established TAM program. These agencies will be able to distinguish between full- and part-time employees whose main role is TAM. The majority of cities reported having 0-5 full-time employees working on basic transportation management (question 4) as well as within defined TAM programs (question 7). Counties had a majority of 20+ employees involved in basic transportation management, and a majority of 0-5 employees working strictly within TAM programs. As for the agencies who depend on part-time employees for the TAM program, all respondents indicated using up to 5 of them, either solely or in addition to their full-time employees.

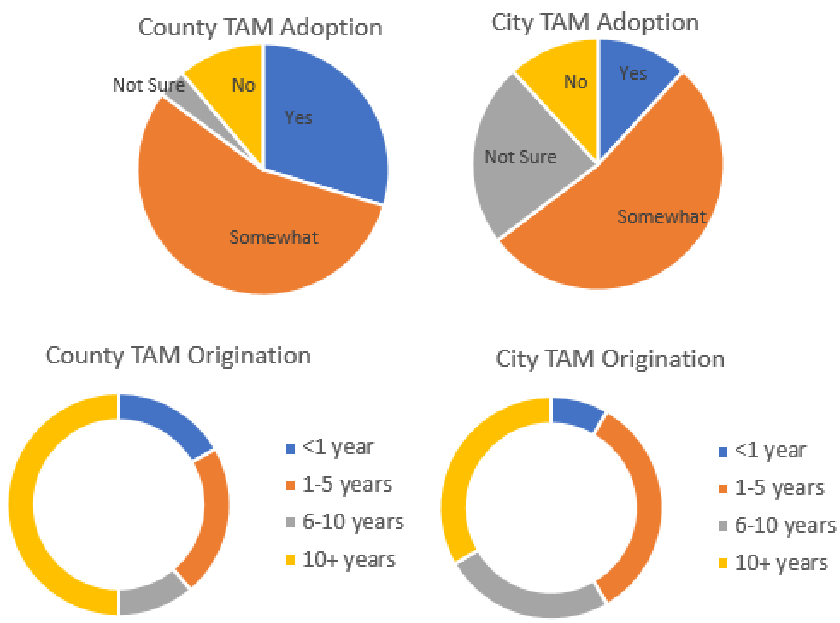


Figure 3.5 TAM Adoption Rate by Agencies and its Origination

Next, survey respondents were asked to indicate the transportation assets managed within the agency. Every city and county agency manages roadway assets and more than 70% of county respondents manage bridges, marking/striping, culverts, guardrails, and signage. However, only 35% of city respondents manage bridges. City agencies reported managing sidewalks more often than county agencies.

Respondents who indicated in the previous question that their agency manages bridges or roadways were asked to go into more detail about the quantities of these managed assets. They were asked to record the number of bridges and miles of roadway (paved asphalt concrete, paved Portland cement concrete, and unpaved). This data was used in setting up another set of asset tiers, in addition to GDOT's reports, due to the incompleteness and variability of these two sources. The survey asked participants to indicate when their agency's TAM program was established. The question gives four multiple answer choices. Half of the county agencies indicated that their TAM programs have been established for more than ten years. The most common response for city agencies was a tie between 1-5 years and more than ten years. This shows there is a lot of variation in the number of years an agency's TAM was established (Figure 3.5).

Survey participants who responded that they practice TAM within their agency, or somewhat practice TAM were asked what software their agency uses. Respondents were given a variety of different software choices, provided in multiple-response format with an additional optional write-in response. City agencies reported using a larger variety of software types. In both county and city agencies, GIS is the most commonly used software used in TAM. Other software used by agencies included COPACES, City Works, and MicroPaver.

When asked about the impact of state or federal laws and initiatives on their TAM practice, most agencies mentioned being affected by the FAST Act and Governmental Accounting Standards Board (GASB) Statement 34. The final question in that section of the survey asked participants about their defined goal(s) for Transportation Asset Management Programs. The question gave the following example, “Keep 80% or more of roadway in ‘Fair’ or better condition.” This question type was a short answer. While many agencies indicated not having a goal, others indicated keeping a certain percentage of the roadway at a specified condition, all the time, or within a defined target period. There were a number of other responses, including: “Repave 10% every five years”, “The goal is to have repaired/rebuilt roadways last at least 20 years without significant follow-up maintenance”, “Maintain all streets in Fair or better condition and upgrade the condition of roads with the lowest ratings insofar as funding allows.” These responses reflect some of the agencies’ strategies that use subjective judgment or ‘Worst-first’ as their decision-making process.

3.3 Condition Assessment & Data Management

The objective of this section is to check the agencies’ current practices and the tools used for assessing the condition of transportation assets and managing data. Around ninety-percent of counties and cities confirmed having a well-established asset inventory, or at least some form of it. However, 50% of both counties and cities were not confident (responding with, ‘Somewhat’, ‘Not Sure’) of the inventory data collection practices at their agencies. This finding may be tied to the previous responses which showed that agencies are not confident about having a well-defined TAM program, knowing that asset inventory acts as the cornerstone of any successful program.

For agencies who responded anything other than, ‘No’ to the previous question, a question followed about the software used for asset inventory, with choices given from which multiple answers could be selected. Results indicated that paper record management systems are still widely adopted by agencies with a high adoption rate of GIS mapping tool and computerized databases, especially by counties. However, cloud computing and mobile/web applications are yet to be used in asset management at the local level.

As for the condition assessment method adopted by counties and cities, as shown in Figure 3.6, most of the agencies use in-house efforts for that purpose, with some using a mix of in-house, contracting, public input, and other methods for specific assets such as GDOT bridge assessment. Note that when cross-analyzed against Asset Tiers, the results showed no connection between the scale of roadway miles and the methods used for assessment, since all tiers used several combinations of methods for that purpose. As for the method used by transportation agencies for data collection, and after explaining each one, the responses showed that the manual method is still the most used by the local agencies, with more than 70% adoption by both cities and counties, and only a few using semi-automated and fully automated methods (Figure 3.7). Note that all county respondents belonging to Asset Tier 4 use the manual method for data collection, proving the inefficiency in their current practice. The remote collection is not adopted by any of the surveyed local agencies, which could be explained by its high technological and financial demands.

The final question in that part is related to the frequency of condition assessment surveys for different asset types. The result of the surveyed agencies shows that the most adopted time interval between asset surveys is a 1-year interval for both county and city agencies, with some exceptions for assets of slower deterioration rates such as sidewalks with a frequency of more than 5-years.

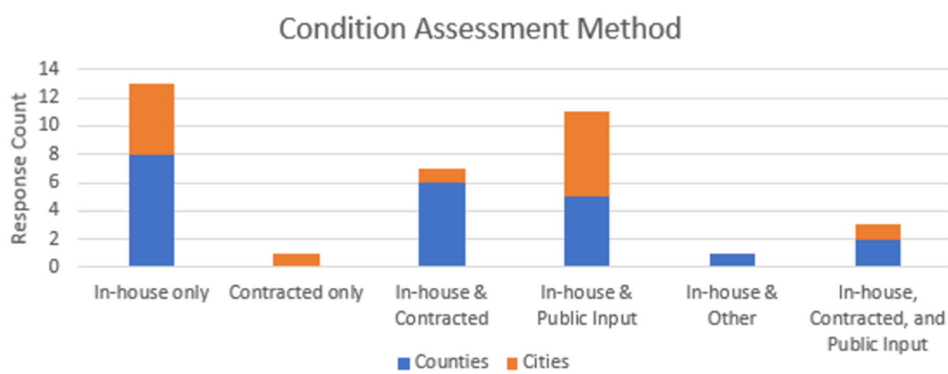


Figure 3.6 Condition Assessment Methods Used by LGs

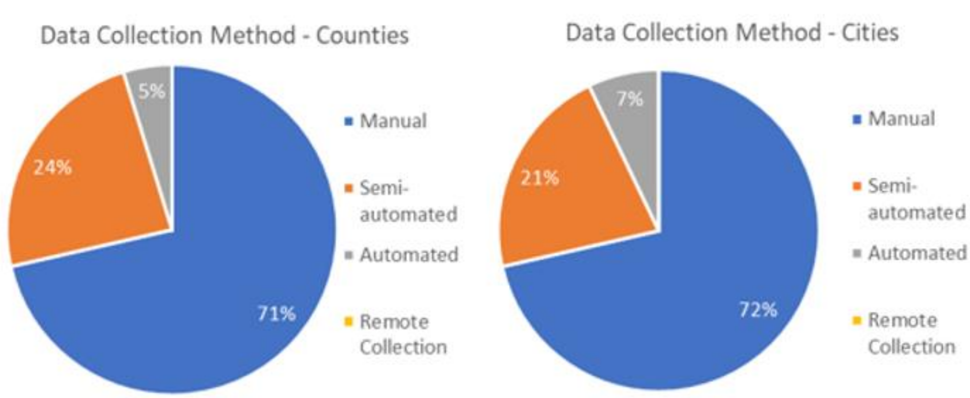


Figure 3.7 Data Collection Methods Used by LGs

3.4 Performance Measures and Decision-Making

The purpose of this section is to evaluate the performance measures and decision-making process adopted by the local agencies. The first question asks the respondent to evaluate some statements related to performance measures used by them, by indicating whether they strongly agree, agree, disagree, strongly disagree, or stand neutral. Most counties expressed a neutral stand for having well-defined performance measures used to track project scope, schedule, and budget, whereas most cities agreed to that statement. As for having planning and programming processes periodically reviewed and updated, both counties and cities either agreed or stood neutral. Regarding responses on well-defined levels of service for system maintenance, both stood neutral, with counties having a tendency towards disagreeing and cities tending towards agreeing. The next question showed that more than 70% of agencies don't regularly publish reports of performance measures to the public and stakeholders. A city agency who chose the 'Other' option mentioned that monthly reports are provided to the elected officials primarily but are also open to the public. Another county agency said that they are working on getting this data on their webpage soon.

The final question in the section was about the method used by agencies to prioritize projects. The results prove that most local agencies adopt simple subjective ranking based on the judgment of their decision-maker, or a ranking based on simple parameters such as level of service or condition (Figure 3.8). None of the responders use mathematical optimization or any type of advanced analysis in their decision-making process.

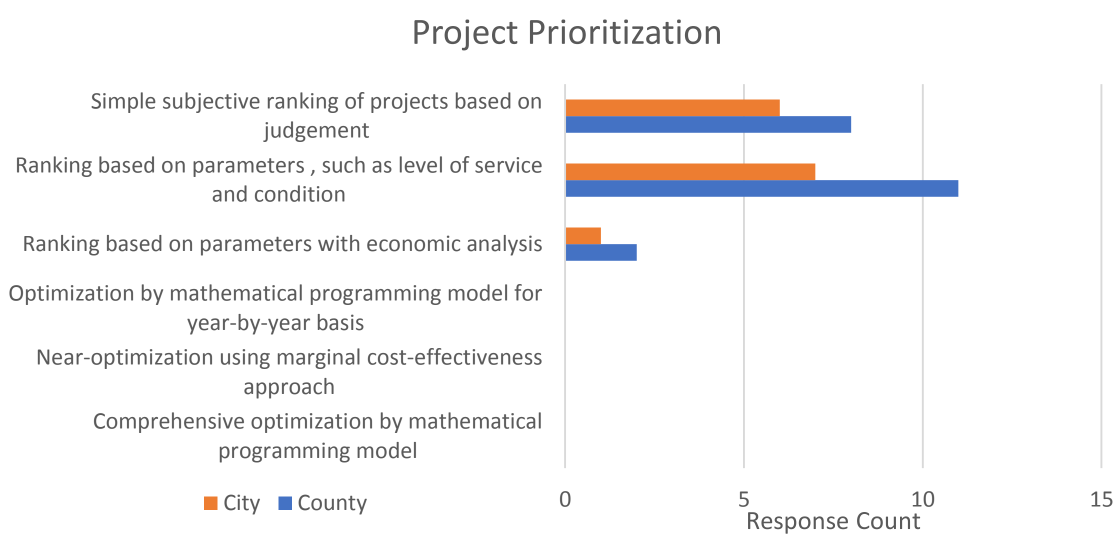


Figure 3.8 Project Prioritization Methods Adopted by County and City Agencies

3.5 Funding

The Funding section contained six questions given to all survey respondents. The first question was a four-part Likert-type question that asked respondents to record their level of agreement on four statements, from strongly disagree to strongly agree. The majority of county and city respondents agreed to all four statements. Thus, they confirmed working with political leaders and other stakeholders to present funding options and consequences and that programs are consistent with realistic projects of future revenues. Moreover, they also confirmed having confidence in their construction cost estimates and in those of the maintenance and rehabilitation works.

The following question was only asked to respondents who previously indicated that their agency has implemented a TAM program. The question asked respondents to select the statement which best describes the agency's TAM program funding, with the following options: "fixed amount each year", "based on need", "based on negotiations", and a blank to fill a customized answer. Most counties indicated that they have a fixed amount each year whereas cities tied the amount to negotiations. Respondents who selected 'Other' as an answer indicated that funding was determined by Special Purpose Local Option Sales Tax (SPLOST) and Local Maintenance and Improvement Grant (LMIG). Another question asks respondents to indicate their agency's annual budget for Maintenance Rehabilitation and Reconstruction (MR&R). The majority of city agencies reported spending less than $100,000 annually on MR&R (Figure 3.9). However, some cities reported spending more than $2,500,000 annually on MR&R, which shows the huge difference in budget allocation among Georgia city agencies. This spending is likely a result of the availability of funding and resources. The majority of county agencies spend more than $500,000 on MR&R annually. It is interesting to note that 5 out 8 counties in Asset Tier 2 responded to that question indicating having a budget above 1 million dollars for MR&R, similar to all Tier 4 responders. Next, respondents were given a sliding scale bar to break down their agency's percentages of spending on routine maintenance, capital investment, and an optional, 'Other,' fill-in the blank. They were instructed to have totaled percentages sum to 100%. Two respondents selected other as an option choice and wrote in, "Labor," and, "Resurfacing." Both city and county agencies spend more on routine maintenance than capital investment, by an average distribution of 80% by 20% with variation among agencies (Figure 3.10).

Similar to the previous question, survey respondents were given another set of assets with sliding scales. The question asked survey participants to indicate the percent of funding allocated for each managed transportation asset. As the previous question stated, the respondent was instructed to ensure that the percentage values sum to 100%. The question gave some asset options, including roadways, bridges, sidewalks, signage, and culverts. The respondent had the option to write-in additional assets as needed. Most county agencies allocated 70% for their roadway assets and less than 10% allocated to each of the other assets. Yet, most cities indicated only a 40% allocation to the roadway assets with the rest distributed among other assets.

The final question in the funding section of the survey asked participants if they received LMIG funding in the past year. All respondents from county agencies that reached this question indicated that they received some amount of LMIG funding. All but one city agency respondent reported receiving LMIG funding. The question then asked the respondents to indicate the amount of funding and the local agency's cost match. Most county and city agencies respondents reported a cost match of 30%, with the exception of two counties reporting 10%, one city reporting 20%, and another city reporting 70%.

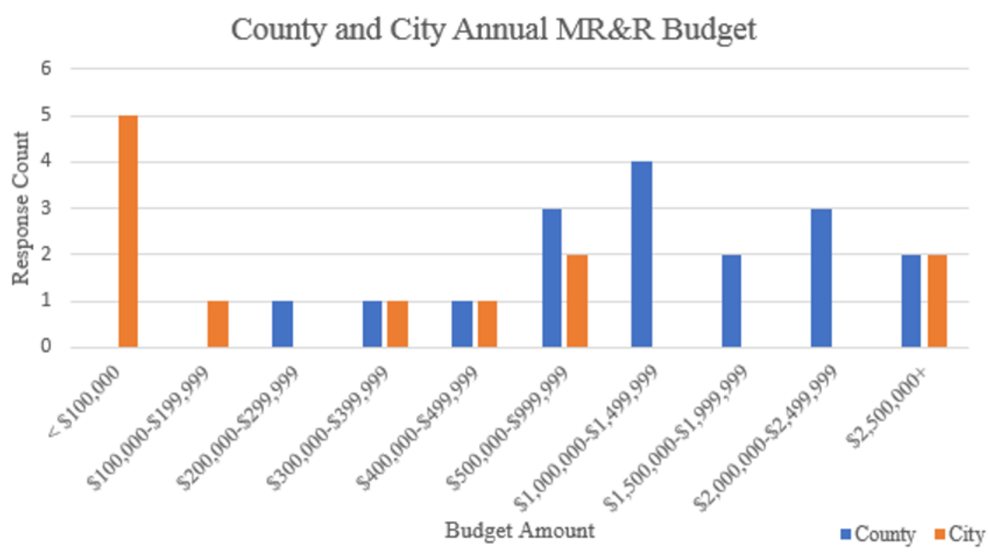


Figure 3.9 Local Agencies Budget

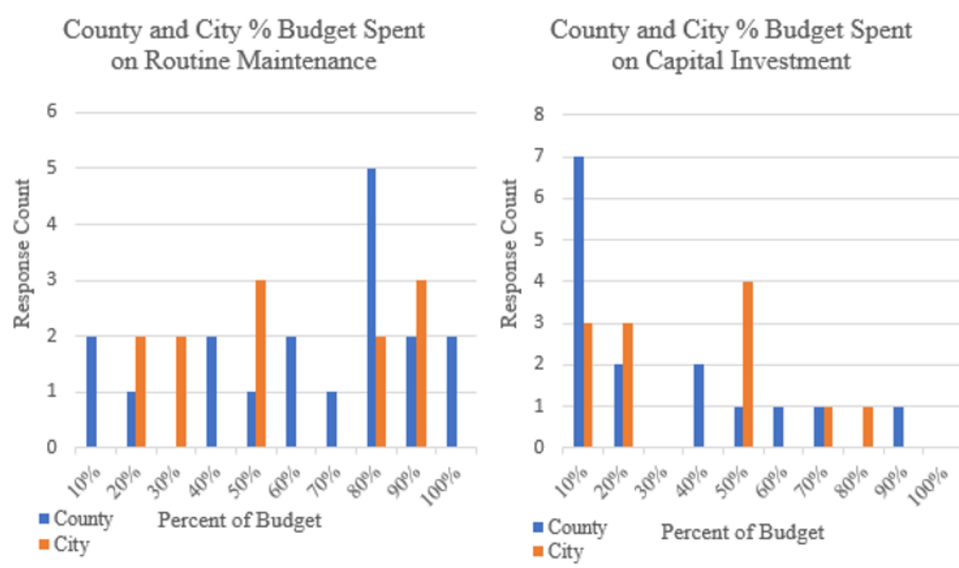


Figure 3.10 Local Agencies Budget Allocation on Routine Maintenance and Capital Investment

3.6 Rating of Current Status

In this section, agencies were asked about their opinion regarding their current practice of the TAM program, how they rate it, and what factors are impeding its development. The first question asked if agencies have access to data and support from regional and state agencies such as GDOT and the Atlanta Regional Commission (ARC). Seventy-three percent of counties and 56% of cities indicated having access to GDOT's support with some indicating access to ARC and other local agencies. Another five-part Likert-type question asked respondents to record their agreement on five statements in order to pinpoint the interests of local agencies in statements regarding actions that could affect positively their TAM practice. Most agencies showed high interest in increased support from GDOT, more collaboration with neighboring local agencies, more funding, better educational programs, and the concept of sharing the purchase of software and technologies with other local agencies (Figure 3.11). Results from the following question indicate that most agencies received some form of aid from LTAP, either as funding or through training programs on equipment, tools, and skills.

Finally, when prompted to rate their current TAM status on a scale of 1 (worst) to 5 (best), most county agencies gave a score of 2, whereas most cities reported a score of 4. When asked about the factors that hinder agencies from applying proper TAM practice, the following answers were recorded: lack of funding, lack of education, training, and experience, need of more personnel and more equipment, and no planning, with only a few exceptions denying the presence of any factors impeding the TAM good practice.

4. Key Findings

The survey responses include cities and counties with a wide range of population sizes and asset scales, representing a diverse distribution of Georgia's cities and counties. While most LGs confirmed having some form of a TAM program, only a few LGs indicated having a proper application of its correct practices. In addition to lacking a clear goal for the TAM program, poor organization is a critical issue as the agencies are not well-structured and lack clear roles and responsibilities. Moreover, the lack of staff, skillset, and training prevent the agencies from coping with today's TAM practice that incorporates new software and technologies. In that context, most LGs still use paper management systems to maintain their asset inventory records. In spite of LGs having a wide array of assets, there are no sufficient resources available to maintain their performance at an acceptable level. This is further aggravated by having a simple and subjective decision-making process, which affects the efficiency of resource allocation and contradicts agencies' requests to receive additional funding. Performance management also appears vague to LGs, which is reflected by a lack of communication with the stakeholders, as only a few agencies regularly publish performance reports. Thus, TAM programs are still weak in local governments due to many factors which need to be addressed and remedied.

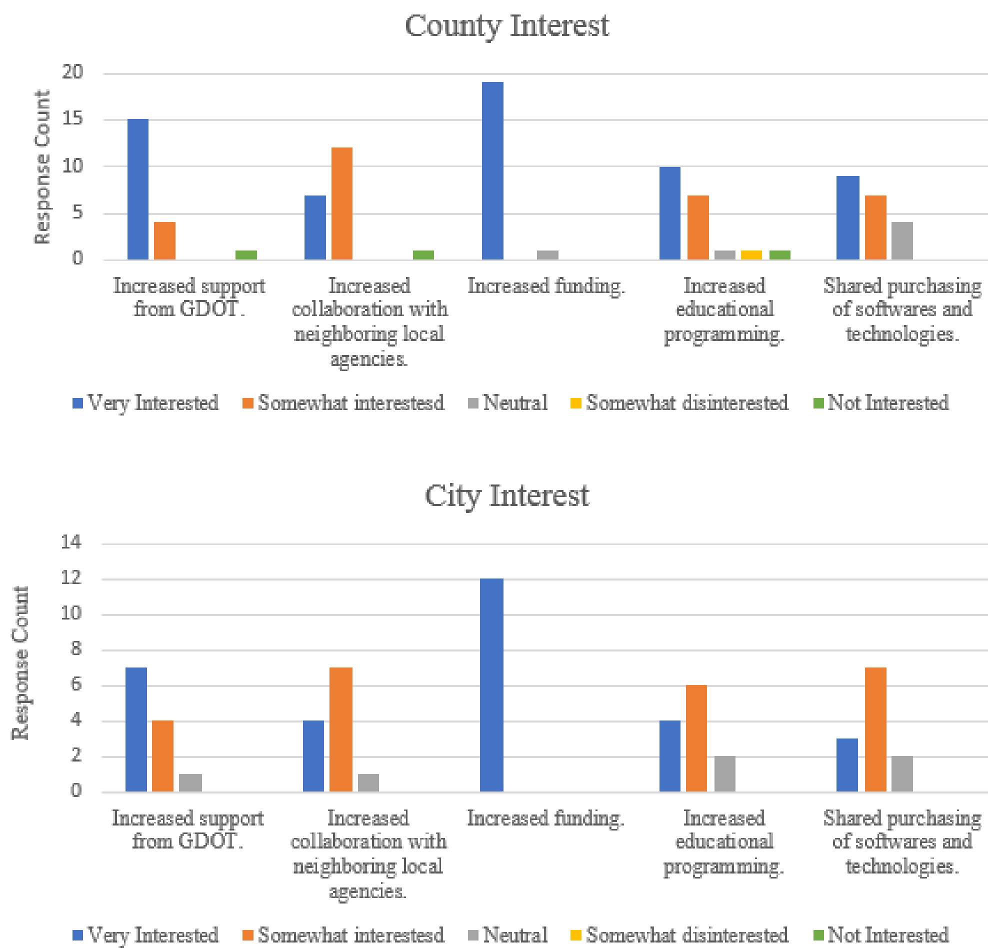


Figure 3.11 Agencies Interest in Actions Affecting the TAM Program

Chapter 4: An Asset Management Guideline

After conducting a comprehensive literature review about TAM and after analyzing the responses of Georgia's surveyed LGs, an asset management guideline was developed to suit the needs and capabilities of local transportation agencies in general, and those within the state of Georgia in particular. This guideline will assist the agencies in understanding all the components of a proper TAM program, believing in its effectiveness, and knowing where to begin in case of new adoption or else how to ameliorate and develop the current practice. The standalone document is organized by chapters, each discussing a certain component of the TAM program, and introduced by a checklist to inform the readers about the chapter's objectives and main topics beforehand. The following is a snapshot of the chapters which are found within the whole document in Appendix II.

1. Introduction

This first chapter introduces the guideline by stating its purpose, providing the common definitions of TAM of several credible organizations such as the American Public Works Association (APWA), FHWA, etc. These definitions help to establish a standard basis and consistency in the understanding of asset management. Federal, state, and local agencies translate these definitions to best fit the resources and methods in place within their agency, as well as the plans which are tailored to serve the interests, financial plans, investment strategies, and available resources of each government individually. For instance, FHWA defines asset management as,

> "a systematic process of maintaining, upgrading, and operating physical assets cost-effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decision-making. Thus, asset management provides a framework for handling both short- and long-range planning."

Moreover, this chapter shows the asset management framework created by FHWA (2007) showing the critical components being connected in a flowchart to depict the process of developing a well-defined TAM program.

The initial step of TAM is to define the goals and policies of the system, which must state the agency's mission and reflect the customers' input and expectations. Agency goals and policies will guide the remaining sections of the TAMP. As the flow chart in Figure 2.1 depicts, both budget allocations and performance monitoring are factored into goals and policies. Performance monitoring is used as a check to ensure an agency's goals and policies are reflective of an agency's performance. An agency's goals and policies should be updated based on feedback gathered from performance monitoring and/or changes to the agency's budget. The following step in asset management is to build an effective asset inventory including infrastructure assets by type, condition, location, function, and value. This critical step in the asset management process allows agencies to maintain a cohesive, accurate, and updated log of managed assets. Additionally, it allows agencies to track and monitor the conditions of managed assets. Condition assessment and performance modeling follow asset inventory. All agencies, regardless of size, must understand the existing conditions of managed assets. The frequency of conducting condition assessments may vary, depending on agency size and budget. The conditions of managed inventory must be properly assessed to determine current performance and forecast future performance. Additionally, local agencies must establish performance measures to assess current conditions. Performance measures help agencies effectively communicate their asset conditions, determine financial need, and target cost-effective solutions. Additionally, performance measures improve external communication and internal operations. Performance measures should be feasible, communicable, and measurable. Then, these three previous components are used to evaluate different maintenance strategies and evaluate project alternatives. The next step is to plan for the changing conditions of existing assets. The main objective of the decision-making process is to understand the connection between existing conditions and project investment. Agencies strive to maintain a suitable level of service among all managed assets but face budgetary constraints that limit decision-making. Many agencies apply a 'worst first' case scenario to their decision-making process. Instead, mathematical optimization can be used to make more informed and calculated decisions. Performance modeling aids in forecasting future asset conditions, identifying proper maintenance and rehabilitation strategies, and allocating funding appropriately. While considering the available budget, projects are selected for short- and long-term plans. Decision-making is followed by project and program implementation. The entire asset management program helps to ensure that projects are implemented and completed on time and budget. Budgeting is a critical component of TAM and must be closely evaluated before other steps of the process can occur. Financial resources may be available at federal, state, and local levels for TAM. This report will explore funding opportunities for local agencies. The final step in the FHWA's asset management flow diagram is performance monitoring, which loops back to the first step in the process, goal and policy setting. Performance monitoring ensures a feedback loop that continually improves an agency's TAMP. Performance monitoring includes regular reporting to keep the public and stakeholders engaged in the asset management process. Additionally, performance monitoring ensures accountability and communication within agencies. Regular meetings and discussion-based workshops encourage collaboration during the performance monitoring stage.

In light of the successes at the federal and state levels in terms of TAM with the increased interest of local agencies in pursuing similar methods, and since many available guides and documents are targeted only towards state agencies, this framework guide is intended to guide local Georgia agencies through the process of creating, implementing, and maintaining an effective and customized TAM. This guide will help fill the knowledge gap present and tackle the factors hindering the agencies from adopting TAM programs while considering their particularity in terms of organization, workforce, funding sources, and other issues.

2. Organization

Georgia has 159 counties and more than 500 cities that vary in geographical size, population, and the number of managed assets. Therefore, there is no one size fits all approach to asset management. The organizational structure of an agency's asset management program is essential for the success and efficiency of a TAMP. Organizational structures of asset management programs vary between federal, state, and local agencies. The number of employees and divisions within local agencies is significantly less than state agencies, therefore resulting in a different organizational structure. However, it is still critical to employ a structured asset management system with clearly defined roles and tasks.

Widespread understanding and agreement are critical to the success of a TAMP. As a first step, if your agency is new to the idea of asset management, an internal workshop can help with visioning within the agency. Georgia DOT has an LTAP that can assist in developing an asset management program. LTAP provides technical assistance to rural and local governments, including workshops and educational seminars. Many local agencies already take advantage of this assistance to conduct on-going training, classroom sessions, and seminars. Additionally, the National Highway Institute (NHI) has training courses that demonstrate asset management principles and techniques to agency managers to enable them to begin the process within their own agencies.

Smaller agencies may have fewer resources and therefore more integration between departments. It is common that smaller agencies share roles and responsibilities between departments. Steering committees may not be feasible for smaller agencies with already stretched job roles. Instead, it may be best to redefine roles for employees that more explicitly integrate the practice of TAM. In this case, a leader should be selected who will spend the majority of his or her time implementing the TAMP and guide others. This individual should be a senior leader or manager involved in defining the agency's strategy, goals, and priorities. TAM leaders may have the title of chief executive officer, Deputy Secretary, Director of Public Works, etc. The leader should partake in training courses and be well-informed on the practice of TAM before introducing the program to his or her agency. Although the program will be led by an individual, it is critical to educate the entire agency on the major principles of TAM. TAM is not a single-division practice. Asset management practices should involve a variety of departments or divisions within an agency. As the TAMP grows and becomes more complex, the champion may opt to diversify and expand to a TAM committee. Smaller agencies may create part- or full-time positions to work on TAM.

As for larger agencies, they are encouraged to establish TAM steering committees. Organizational culture has proven to be one of the largest obstacles in establishing an asset management program (Wittwer, et al., 2003). Larger agencies with multiple divisions may have trouble reaching consensus when creating new system processes. Steering committees, in that case, can improve communication and build consensus within agencies. Steering committees should consist of mostly senior managers from each agency department or division. These individuals can serve as liaisons between their departments and the TAM steering committee. The steering committee will serve to ensure that the program is working together as a unit. Larger agencies may also benefit from selecting an asset management champion to lead and guide the steering committee. TAM requires comprehensive coordination and communication among the agency's employees working under different units, therefore it is critical to get all agencies involved and understanding the importance of the TAM. Additionally, steering committees are responsible for educating the public and stakeholders on the agency's mission, vision, goals, performance measures, strategies, and progress. Agencies should focus on creating a management position or TAM office that acts as a focal point for guiding the asset management program, where information is filtered and analyzed to be directed for decision makers (Transportation Research Board, 2008). Figure 4.1 depicts an example of a steering committee's organizational structure. The steering committee is composed of several division managers and a TAM champion. The division managers represent each of the agency's departments/divisions. This cross-disciplinary support helps to build consensus within the agency and can reduce duplicated efforts and inefficiencies.

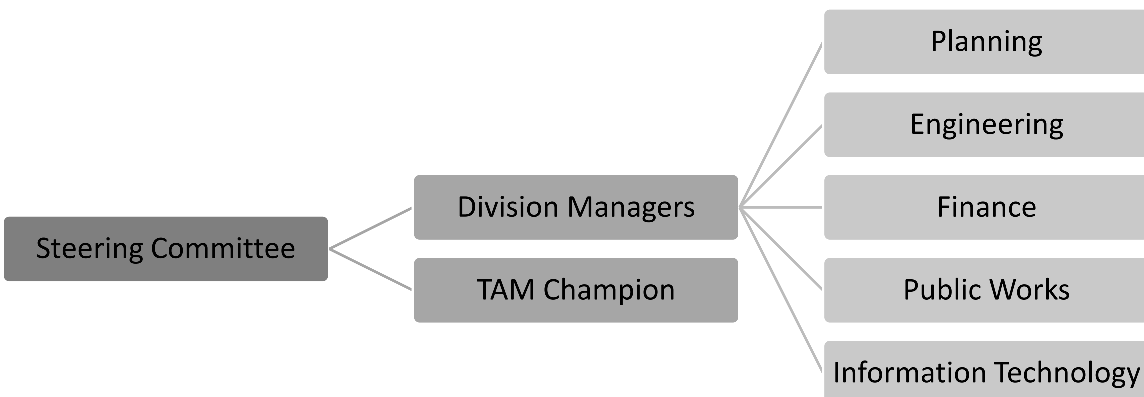


Figure 4.1 TAM Organizational Chart

The number of part- or full-time employees working on TAM will depend on the resources available within the agency. Smaller agencies may opt to combine roles and employ one or two individuals to work on TAM part-time. Whereas larger agencies who opt to develop steering committees may also employ several part-time or full-time employees as resources allow. The agency should establish workload requirements, responsibilities, and actionable items for each TAM employee to promote accountability and reporting. Educational sessions and workshops can be helpful when establishing a TAM workforce. Additionally, regular meetings are essential in maintaining the success of a TAMP.

3. Policies and Plans

Many agencies practice elements of a TAMP, but lack formalized TAM processes. Therefore, agencies are encouraged to conduct asset management self-assessment. The self-assessment will aid in understanding an agency's current decision-making processes and identifying strengths and weaknesses in existing processes. An analysis can lead an agency to identify opportunities for improvement and can guide an action plan for setting and achieving agency goals. The results from the self-assessment can be used to clearly define the scope of a TAMP. During the assessment, the agency can determine which assets should be included in the TAMP, the types of investments (preservation, capital, operational), and common principles and approaches. Table 4.1 displays AASHTO's descriptions for levels of TAM Maturity. This table can begin to help guide local agencies in understanding their current level of TAM and identify the next steps in the process. The table displays five levels of maturity. This table is intended to be used in conjunction with the AASHTO Self-Assessment tool.

Table 4.1 AASHTO Description of TAM Maturity Levels (AASHTO, 2013)

TAM Maturity	Generalized Description
Initial	No effective support from strategy, processes, or tools. There can be a lack of motivation to improve.
Awakening	Recognition of a need and basic data collection. There is often a reliance on the heroic effort of individuals.
Structured	Shared understanding, motivation, and coordination. Development of processes and tools.
Proficient	Expectations and accountability drawn from asset management strategy, processes, and tools.
Best Practice	Asset management strategies, processes, and tools are routinely evaluated and improved.

Following the self-assessment tool, an agency must define an appropriate TAM practice. The agency must consider its current practice, strategic goals, legislative requirements, public and stakeholder expectations, managed assets, available resources, and budget. Organizational goals, policies, and budgets should be used to evaluate the asset management framework. Policies are broad, non-engineering, non-economic factors that reflect the transportation agency's values, perceptions, and tendencies. Goals can be established based on users' priorities, values, and standards in measurable terms, such as ride smoothness, level of service, travel time, mobility, and accessibility. Performance targets are a way to convey to the public how assets are being managed in a logical and fact-based approach, since asset management is a customer-focused and goal-driven management and decision-making process (FHWA, 2007).

After studying the different elements in TAM, action plans should be formed to identify objectives and formulate tasks. Identified tasks should have a defined time frame that considers factors, such as the overall priority of each task and the logical sequence of the tasks. AASHTO defines several key components to consider when initiating change within an agency:

- Communicate the need for and benefit of change
- Establish a guiding team – TAM Champion or TAM Steering Committee
- Develop a vision of change and strategies to achieve that vision
- Involve employees in the process, assign roles, and delegate tasks
- Maintain progress and hold regular meetings to update staff on successes
- Implement a feedback loop to improve the system

Similar to the state agencies which are legally bound to abide by certain legislations issued by federal agencies, policies formed by local agencies must also abide by legislations issued by state and federal governments. For instance, the Governmental Accounting Standards Board (GASB) Statement 34 establishes financial reporting requirements for state and local governments, including states, cities, towns, villages, and special-purpose governments such as school districts and public utilities (GASB Statement 34 Summary, 1999). GASB Statement 34 requires agencies to report the value and condition of transportation capital assets in accordance with stated standards. GASB Statement 34 has been in effect as early as June 1999. Smaller agencies, such as towns and school districts, are required to complete basic financial statements as listed in GASB Statement 34 Appendix C.

Agencies should develop a complete and comprehensive TAMP that includes a summary of the agency's policy goals, objectives, financial targets, and performance targets. The FHWA states that agencies must, "examine exactly where they are, what information they have available, and where they want to go before determining an approach to implementing asset management" (FHWA 2017). The guide should include detailed instructions for financial, accounting, and administrative tasks to adhere to in future decision-making processes. Local agencies in Georgia can modify GDOT's strategic goals and adapt them to best fit local goals and performance targets. Additionally, local agencies are encouraged to partner with neighboring or other similar local agencies to discuss transportation needs and priorities and identify where interests overlap. After identifying policies and goals for the TAMP, it is important to establish quantifiable performance measures that support agency goals. Agency goals and initiatives should be updated regularly to reflect changes in policy, technology, and emerging issues.

AASHTO developed a TAMP outline that is useful to help guide the development of a new local agency TAMP. Finally, asset management can be implemented and accomplished in stages. Thus, agencies must determine what is feasible given existing budgets and resources. Establishing short, medium, and long-term goals can help keep attainable objectives.

4. Asset Inventory and Condition Assessment

A solid asset inventory acts as the cornerstone for a successful TAM program as it compiles all the infrastructure assets under the jurisdiction of a certain agency in a well-established, up-to-date, accurate, and accessible record (FHWA, 2007). These assets are tied to relevant spatial and physical characteristics such as the location, quantity, type, size, function, AADT, age, replacement cost, maintenance history, etc. The effort put to collect attributes for the surveyed assets, its accuracy especially for the critical assets, and completeness characterizes the inventory as either basic, intermediate, or advanced (Smith, 2013). The more attribute data is collected for the assets surveyed, the more supported the agency's decisions will be. However, agencies should plan ahead their data collection to take into consideration their available resources and should avoid collecting data that is not used in the decision-making at later stages. Therefore, a routinely-revised data collection plan is crucial for a complete and accurate asset inventory record. In addition to assets' basic identification characteristics, condition assessment data should also be added to the agency's records and updated continuously according to a certain rating system. This condition assessment should be performed consistently to characterize the current status of the managed assets in order to predict their future conditions and to find the most cost-effective and beneficial MR&R decisions based on the data collected (FHWA, 2013[b]).

Therefore, the plan should clearly define what data needs to be collected, what methods will be used, and how often will the information be updated. As data requires time, effort, and money to collect, store, retrieve and use, a decision should be made to indicate what data is actually required to enable the agency to manage its assets. This is a key point since it leads to a long-term commitment by the agency, knowing that this data needs to remain current and valid by performing continuous updating. Therefore, agencies should try to minimize their planned data collection by setting realistic and sustainable goals, without affecting the quality of their decision-making process. Pilot studies are very useful for that purpose as a way to test the data collection scope, effort, and cost in order to evaluate and modify the plan accordingly. (World Bank, 2007)

The frequency of conducting a condition assessment varies between agencies based on the available funding and resources (Cambridge Systematics, Inc., 2006). The survey is usually done either using in-house resources, subcontractors, public input, or a combination of more than one methodology. Several tools and methods are currently being used among state and local agencies for data collection while noting a remarkable technological evolution whose goal is to collect large volumes of asset condition data quickly and efficiently.

Condition Assessment Rating System

Choosing an asset rating system or protocol is a critical step in the condition assessment process as it defines the asset's deterioration characteristics and distresses according to a certain scale of extent and severity levels. It is a scoring system that calculates the rating of the overall condition of an asset according to well-defined criteria, thus leading to information-based decision making at later stages of the asset management program. Many rating systems exist for different types of assets, some of which are adopted by different state and local agencies on the national level, and others that were set by certain states to fit their own resources, strategies, and assets' requirements. As for the pavement, the most popular rating systems on the national level include 'Pavement Condition Index (PCI), 'Pavement Surface Evaluation and Rating (PASER)' and the Present Serviceability Rating (PSR). Concerning the bridges, the most adopted rating system for bridges is AASHTO National Bridge Inventory (NBI) General Conditions rating. Other transportation assets also have specific rating protocols while some agencies adopt the remaining service life (RSL) system for assessing the condition of these assets by representing the expected number of years of operation based on the asset's life (the period between construction/installation to first maintenance) before maintenance or rehabilitation is required. Road signs, traffic signals, pavement markings, and other similar traffic control assets are usually managed according to Manual on Uniform Traffic Control Devices (MUTCD).

When it comes to choosing a rating system that the agency should follow when assessing their assets, several considerations should be taken into account. First of all, if the agency has adopted a certain protocol for a long period of time during which it has accumulated sufficient history of condition data, then it is logical to continue using that system as the data available is valuable when building the asset's deterioration models. The agency should also evaluate its resource capabilities as some rating systems require a certain level of accuracy that can only be obtained through the use of specific tools and equipment, whose costs should be assessed. Some rating systems may also require expert staff that may not be available at the agency. In that context also, agencies should try to aim to adopt systems that are used by their state's and nearby local agencies, as this will allow the possibility for staff transfer, especially those who retire from state agencies with high accumulated expertise. In addition to the benefit accrued from the assistance programs provided by state agencies which may help the local agencies in both training and resources, adopting systems similar to the neighboring agencies might pay-off sometime in the future if a merger takes place at the county/city level or even at the state level.

Condition Assessment Tools and Methods

Concerning pavements condition assessment, the following lists the methods in the order from the most basic to the most advanced (technologically): (FHWA, 2013[b])

- Manual surveys which employ two or more trained staff collecting data and documenting it with a pen and a paper, or in most recent cases with handheld computers equipped with GPS.

- Automated collection involves the use of a multipurpose vehicle (Figure 4.2) equipped with advanced camera, laser, and computer equipment that captures at highway speeds digital images for the transverse and longitudinal road surface profiles. Based on the method used for data processing, this type of assessment can be categorized as either semi-automated or fully automated.

- Remote collection is the most advanced method as it uses satellite imagery and remote sensing applications to acquire high-resolution images.

Figure 4.2 Georgia Tech Sensing Vehicle (GTSV)

As for the methods used for bridge inspection, it can only rely on the visual evaluation of professional and experienced staff, or it can use several tools and technologies which provide a more accurate assessment. Below are some of the most adopted methods by state and local agencies: (Omar, T. & Nehdi, M., 2016)

- Visual inspection is conducted according to certain guidelines and standards, mainly using the ‘National Bridge Inspection Standards (NBIS)’. New technologies are incorporating special drones (Figure 4.3) in the inspection of bridges as an easier and safer way to assess the condition of the bridges, especially those whose location and physical characteristics act as obstacles for a proper condition assessment.

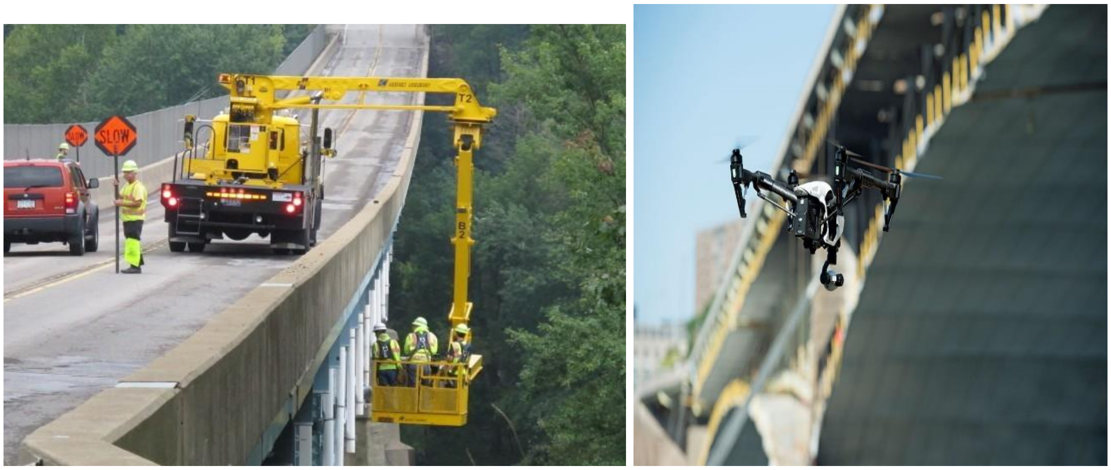


Figure 4.3 Bridge Visual Inspection through Crane and Drone (*Source: Agile Assets*)

- Load testing response method involves loading the bridge with static or dynamic loads and recording the bridge's critical components' responses using strain transducers.
- Non-Destructive evaluation (NDE) methods provide objective and accurate surveys that detect bridges' deterioration behavior at an early stage and tracks its development, if performed periodically.
- Structural Health Monitoring (SHM) technique incorporates sensor and instrumentation installations embedded on a bridge's structural components for either a short-term or a long-term assessment, in order to evaluate its structural performance and to detect signs of deterioration.

The main concern for road signs' condition is maintaining a minimum retro-reflectivity or illumination. The Manual on Uniform Traffic Control Devices (MUTCD) issued by the FHWA in 2009 presents two common assessment methods to evaluate the performance of road signs along with other management strategies to make the right decisions: (FHWA, 2009)

- Visual nighttime inspection involves a 60-year or older trained inspector conducting the assessment through the windshield of a moving vehicle in dark conditions, and identifying visually the signs that don't meet the minimum retro-reflectivity requirement.
- Measured sign retro-reflectivity method uses a hand-held retro-reflectometer and then compares the recordings to the minimum retro-reflectivity levels. (Figure 4.4)

Figure 4.4 Road sign contact retro-reflectometer (*Source: Roadvista*)

- Management methods may include comparing the existing sign's age to its expected life which in turn is location-dependent as it is based on the experienced retro-reflectivity degradation at each geographical area. Blanket replacement method replaces all signs in a certain area at a fixed interval of time that is based on the signs' life expectancies, and thus eliminating the need for periodic assessment. Another method involves placing sample control signs representing some field signs, and monitoring their condition over time to determine the end of the retro-reflective life of the associated signs.

Other road furnishings include many assets that contribute in a way to a safe, fast, and comfortable transportation system. These include but are not limited to road signals, culverts, curbs and gutters, sidewalks, etc. Agencies should review the successful management strategies and guidelines for each type of asset and choose the most suitable one according to their own resource capabilities.

5. Data Management

As the asset inventory data is highly critical and valuable, data management systems should be set up to efficiently organize and analyze the information. That information should have certain attributes when being incorporated within a database in order to fulfill the purpose of its collection and act as a solid foundation for the asset management program. The data collected must be complete and with minimal assumptions, as an incomplete database will result in fabricated decision-making strategies as an output. Data must also be current and valid by performing continuous updating to the agency's information for its assets. The frequency of the inspections must be clearly defined in the policies and plans and may vary between the various types of assets due to the difference in their deterioration rates and safety priority considerations. Data accuracy, precision, and consistency are also important factors for a well-established database. Quality control and assurance programs should also be considered within the agency's plans as a means to evaluate the collection methods and the inspectors' performance. Finally, data should easily accessible by the agency's departments dealing with asset management as data that is not at hand cannot be helpful. However, good security measures should also be implemented to protect the agency from any breach.

Agencies usually adopt one or a combination of management systems such as simple paper record systems, data spreadsheets with basic or complex functions, GIS mapping, mobile and web applications, cloud computing, and other commercial software. Computerized tools streamline asset management processes for local agencies and have the capability to improve data collection, resource allocation, and decision-making. As agencies often have multiple assets to manage, data integration is an important component of the data management process. Data integration can help connect different components of an agency's transportation assets and prevent data redundancy, which is common in large agencies. Agencies are becoming increasingly attracted to the idea of data integration as a means of reducing data collection and storage costs, improving data quality and accuracy, improving data security, and improving accessibility to data. On the other hand, data interoperability improves coordination with multiple agencies at the local, regional and federal level, and also promotes data sharing and shared learning. (Bernardin and Durango-Cohen, 2006)

A GIS department is recommended for TAMPs. GIS departments are responsible for creating and managing a standardized, accurate, and consistent information database of agency assets. However, GIS departments can be expensive and require licensing and education. Agencies can seek GIS assistance from their regional commission and collaborate with neighboring cities and counties to reduce overall costs.

6. Performance Measures

Performance-based asset management program, supported by both MAP-21 and FAST Act, aims to preserve transportation assets by translating policy objectives into system performance measures with realistically set targets. Performance measurement is a way to monitor the efficiency of the asset management program using the performance measures' target compliance as a benchmark. This approach allows the agency to track and forecast the impact of the system investments and resource allocations on the system's performance. In addition, it achieves greater accountability to the policy-makers and better communication of information among the stakeholders, increases the organizational efficiency by setting targets for the staff to focus on and the effectiveness through achieving measurable objectives, allows for better understanding of the impacts of different investment strategies, and encourages an on-going improvement of the business processes. (NCHRP, 2006)

As an example on the application of the above approach, consider the preservation of assets as the goal set in the agency's policies. The measures for that goal may include pavement condition index, bridge health index, remaining life of another asset, etc. The next step involves setting a proper and realistic target for those defined measures. For example, the agency may decide to aim for an X percentage of the pavement to be above a certain condition Y for a certain fiscal year Z.

These performance goals and targets should be updated periodically by the agency to reflect changes in policy or priorities or the emergence of new information that was not previously available.

7. Decision-Making and Risk Assessment

Initial project scoping, option evaluation, and selection can be the greatest opportunities for reducing project costs within a local agency (AASHTO, 2013). Selecting the right projects and completing the right work at the right time helps to improve agency spending. Agencies must instill a proactive approach to asset management by choosing the best time in a facility life cycle to intervene.

Many agencies apply a 'worst first' case scenario to their decision-making process. Instead, project prioritization processes can be used to make more informed and calculated decisions. Project performance modeling plays a critical role in forecasting future asset conditions by identifying proper maintenance and rehabilitation strategies and allocating funding appropriately.

By using asset inventory, conditions assessment, and performance measures, an agency has the tools needed to evaluate risks and prioritize transportation projects. An effective way to conduct project prioritization is to establish a formalized process for project proposals. Agencies should develop a standardized form that includes a nominated project's description, a justification for nomination, anticipated cost, anticipated construction duration, projected funding source(s), impact upon completion, and user benefits. Agencies should then organize a candidate project review committee that consists of division managers and county engineers that will evaluate the project proposals. The committee will review project nominations based on accuracy in predictions, eligibility for funding, and alignment with agency goals and objectives, then make revisions as necessary. After reviewing projects, the committee can develop a ranked list of prioritized projects. The projected costs of maintenance projects are based on labor, equipment, and materials. In addition to economic benefits, rankings should consider environmental protection, network connectivity, equity, accessibility, and cultural preservation. As an agency's budget, scope, or priorities change, the ranked list of projects should change to reflect new information (AASHTO, 2013).

There are several spreadsheet workbooks and database applications that assist with tradeoff and decision-making analyses. The FHWA has developed the Highway Economic Requirements System State Version (HERS/ST) that assists state agencies in tradeoff analyses. HERS/ST determines the most economically desirable combination of projects given specified funding levels. The program determines minimum spending that satisfies specified performance targets.

Another component of decision-making includes hiring in-house or outsourced contracting. Agencies should weigh the cost-effectiveness of outsourcing for specific maintenance and capital projects. In case of outsourcing, it is necessary to develop methods of conducting quality assurance and compare costs of service providers.

Risk Assessment

Local governments can utilize risk assessments and risk management as tools for identifying and evaluating sources of risk. Risk management aims to incorporate mitigation strategies into daily agency operations. The process of risk management should be viewed as a core business driver that influences all activities in an agency (AASHTO, 2013).

Any risk associated with an agency's asset is a risk associated with a local agency. There are several sources and types of risk that might affect local agencies, including natural events and hazards, external impacts, physical asset failures, and operational risk events (AASHTO, 2013). Figure 4.5 displays AASHTO's flowchart for risk management processes. The flowchart emphasizes the importance of monitoring and reviewing during each stage of the process.

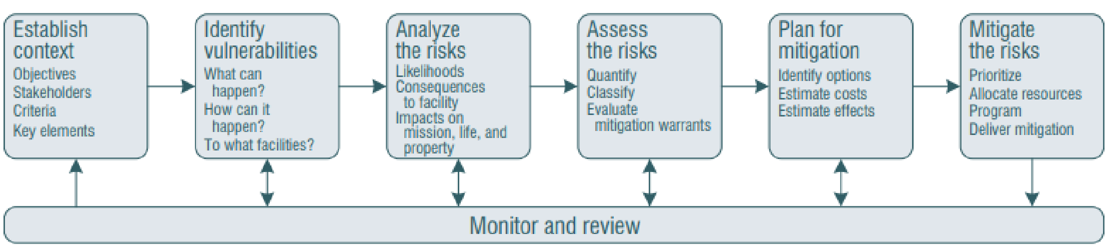


Figure 4.5 Risk Management Framework (AASHTO, 2013)

8. Funding and Budgeting

Local agencies must have a clear understanding of available sources of funding to establish realistic condition targets and implementable projects. Some recommendations for local governments include assuming consistent levels of funding, identifying potential variations in funding, and evaluating and targeting new funding (Cambridge Systematics, Inc., 2006). Funding varies at the federal, state, and local levels. State DOTs receive federal funding for developing, implementing, and maintaining a TAMP. As long as national highways are included in the state's asset management program, federal funds can be used to maintain the state's entire asset management system. The federal government allocates funding from the National Highway Performance Program (NHPP) and the Surface Transportation Program (STP) (FHWA, 2012[b]). However, state DOTs are the recipients of these funds, not LGs.

Funding is often the number one limitation to transportation agencies at federal, state, and local levels. Limited budgeting and resources increase the importance of effective TAM systems. Georgia Congressional Funding is enforced by Georgia law to require GDOT to distribute 80% of its state and federal transportation improvement funds equally among Georgia's fourteen congressional districts over a five-year period (GDOT, 2011). Additionally, the Transportation Investment Act (TIA) allocates a 1% regional sales tax to fund transportation improvements. LG’s can also choose to apply for Georgia's Local Maintenance Improvement Grant (LMIG), which was created to streamline the process of granting Georgia cities and counties funding for transportation projects. Local agencies apply for LMIG through an application program, with grants ranging from $1,000 to $4,000,000, depending on the agency’s population and number or roadway miles.

In addition to identifying potential funding sources, agencies should strive to reduce costs. Intergovernmental agreements can significantly reduce TAM costs. Collaborations with neighboring agencies or regional commissions can improve the efficiency and cost-effectiveness of maintenance and capital investments. Intergovernmental agreements may consist of shared purchasing of tools, software, equipment, or technology. Bundling projects can also be an effective measure for reducing expenditures.

Another component of an effective TAMP is to maintain a log of historical expenses and expenditures. Budgets should be planned and updated annually at minimum. Budgets should be specific and allocate funding for both capital investment projects and maintenance rehabilitation and reconstruction (MR&R). Maintaining accurate cost tracking records will improve budgetary planning and forecasts. Activity-based costing (ABC) is a strategy used to set annual budgets. First, an agency must define a set of activities that cover the entire scope of project work anticipated in the upcoming fiscal year. Then, labor costs, material costs, equipment costs, operating costs, depreciation costs, and salvage values are calculated for each individual activity. Overhead costs are then calculated for each activity, including operations, finance, administrative costs, and oversight costs. All calculated costs are combined into a full activity cost by dividing by the number of output units to calculate the unit cost for each activity. Additionally, budgets should be detailed to allocate among asset types. Allocating budget among assets will depend on an agency's size and number of federal and state-owned assets (FHWA, 2015[a]).

Developing a financial plan is also a critical component of TAM, as an agency’s financial plan validates the ability to deliver the agency’s established goals and initiatives (FHWA, 2015[b]). A financial plan will clearly establish the revenue needed to sustain the desired conditions and enable more accurate projections for future project work. Additionally, a financial plan will inform the public and stakeholders about anticipated levels of service and future projects and maintenance plans.

Short-term financial planning may accommodate 1-5 years into the future, whereas long-term planning typically covers ten to twenty years. Financial plans can be edited and amended as necessary. Financial plans should include the following projections:

- Current and projected revenue sources
- Expenditure needs (operations, maintenance, and capital expenditures)
- Expenditures categorized by asset type
- Asset conditions and rate of deterioration
- Inflation
- Population and growth projections
- Anticipated gaps or surpluses
- Risks

An effective TAM financial plan will anticipate the amount of investment required annually for planned maintenance, rehabilitation, repair, and capital investment projects. The financial plan should identify areas where additional funding is needed as well as projects to consider if excess funding is secured. The FHWA does not recommend creating a financial plan for a period shorter than 10 years (FHWA, 2015[b]). Agencies should begin by drafting a financial plan outline that highlights the agency's goals, strategies, and current status.

9. Reporting

Asset management systems include accurate and frequent reporting processes. Agencies with TAMPs conduct system monitoring and performance tracking to monitor and report project schedules, costs, and quality of work. Reporting helps agencies identify potential improvement areas and ensure more accurate future project timeliness, quality, and delivery. However, reporting is often only required for State DOTs asset management programs. The federal legislature requires state agencies strict reporting measures. As a result, reporting is more common within state agencies than LGs.

GASB Statement 34 requires agencies to submit financial reports regularly. Additionally, agencies can set their own reporting measures to maintain accountability and progress. Reports allow the public and stakeholders to remain educated and informed on the past, present, and future projects. Reporting can also be implemented within departments or divisions of local agencies. Internal reporting helps to build consensus within an agency. Agencies can hold regular meetings with involved staff to discuss project performance and execution. Reports can be scheduled as frequently as an agency prefers and should be used to the advantage of the agency.

Reporting allows for a standardized record of asset management that includes cost tracking, maintenance and operations, budget, and summaries of work performed. A standardized reporting document can be created to help agencies streamline the process of reporting practices. Reports should include the following items:

- Predicted conditions of assets
- Final conditions of assets
- Predicted budget
- Actual budget
- Funding allocations
- Project overbudget/underbudget
- Project timeline
- Unanticipated costs
- Updated project prioritization list

Additionally, agencies can opt to include anticipated future projects and expenditures, multi-year progress and projects, as well as reevaluations of project goals and targets. This feedback cycle is critical to the continual improvement to an agency's TAMP.

Chapter 5: Cross-Asset Modeling and Case Study

Decision-making is the main goal behind the whole TAM program, as all the previous stages act as supporting tools for that step. This project tackles the decision-making process from a new point of view by incorporating two disciplines, traffic engineering, and pavement/bridge engineering, into the developed cross-asset management model. This model considers the interdependency between the transportation assets, say pavement and bridge in that case, and builds a new framework, aiming to reduce the subjectivity in resource allocation. A supporting case study is then presented using a small interstate highway network around Atlanta, GA, to demonstrate the effectiveness of the proposed model.

1. Proposed Framework

In our attempt to improve the model's objectivity, this framework explores a new methodology to reduce the subjectivity in allocating resources among different interdependent transportation assets. Note that pavement and bridge assets are used as an example to demonstrate the advantages of the proposed method.

To explicitly consider the interdependency between pavements and bridges, the mobility of the entire transportation network can be used as the performance measure. In the existing literature, the structural and/or functional asset conditions were normally used as a performance measure, in which different assets were essentially independent. Thus, decision-makers' preference is needed when resources are allocated among them. In contrast, if a performance measure, e.g., mobility, inherently integrates different interdependent assets, resources can be objectively allocated. Nevertheless, maintenance programming is in the discipline of pavement/bridge engineering while mobility is in traffic engineering. To link these two disciplines, further research is still needed.

Figure 5.1 proposes a framework for managing interdependent pavements and bridges. Because pavements and bridges work together to provide mobility, there is no need for decision makers' preference on each of these two types of assets when maintenance programming is being planned. The framework consists of models and methods from the two disciplines, traffic engineering, and pavement/bridge engineering. The performance measure and objective are set in the discipline of traffic engineering, which is to maximize the network mobility, while the decisions are made in the discipline of pavement/bridge engineering, which is the maintenance programming for both pavements and bridges. The relationship between the pavement/bridge conditions and their traffic capacity bridges these two disciplines.

The mobility of the entire transportation network is used to measure the benefit of maintenance programming on interdependent assets. As an example, the interdependent pavements and bridges are used to demonstrate the advantages of the proposed method.

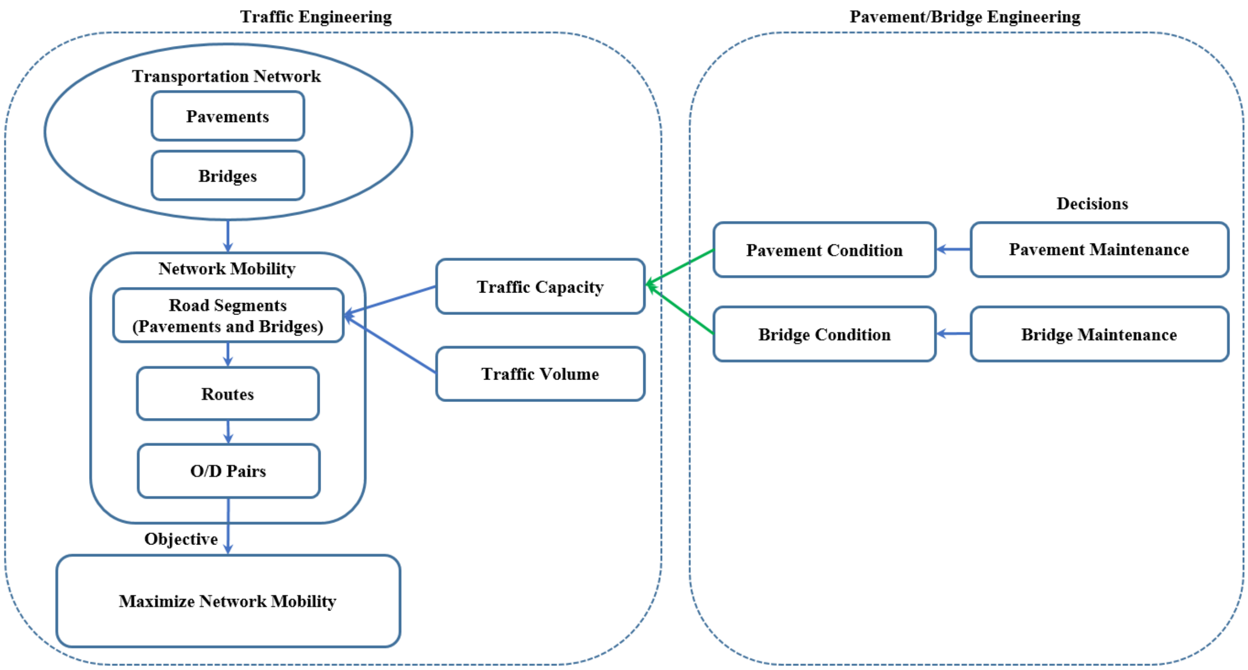


Figure 5.1 Framework for Managing Interdependent Assets

To implement the above framework, the following models need to be determined:

- Transportation network model. To quantify the mobility of a transportation network, a network model is needed to integrate pavements and bridges, which is normally a directed graph;
- Mobility quantification. Because mobility is used as the performance measure, it needs to be quantified. Normally, a bottom-up method can be used from the computation of the travel time of each road segment. Then, the travel time for each route and O/D pair can be computed. Finally, the travel time of the entire network can be evaluated.
- Relationship between asset condition and traffic capacity. This relationship model is the key to linking the two disciplines. The pavement/bridge condition affects its traffic capacity, and thus, affects the mobility given the actual traffic volume.
- Asset condition deterioration model. Pavement/bridge deterioration model tells how its condition drops over time without any treatment. The accuracy of the deterioration model affects how well the network-level pavement/bridge condition can be predicted and the maintenance programming can be planned over a given time horizon, e.g., 5 or 10 years.
- Treatment cost, performance and selection criteria. The final decision of an asset management system is when, where, and what to treat a pavement/bridge. Thus, the knowledge about treatments and cost is very critical. The local market and economy are factors of treatment cost. Its prediction needs economic analysis. The performance of a treatment determines the preference for selecting a candidate treatment. In pavement/bridge engineering, the candidate treatments are normally determined in terms of pavement/bridge conditions. Thus, treatment selection criteria are needed.

- Mathematical optimization. To acquire the optimal treatment solution that maximizes network mobility, a mathematical optimization model is needed. Because the solution is to determine when, where, and what to treat a pavement/bridge, an integer programming is often needed.

2. Implementation

To demonstrate the advantages of the proposed framework, the following illustrates an implementation based on the knowledge from the existing literature and/or reasonable assumptions.

2.1 Transportation Network and Travel Time Computation

A transportation network can be modeled as a directed graph $G = (V, E)$, where V is the set of all nodes and E is the set of all arcs (i.e. road segments). For convenience, bridges can be associated with pavements instead of being midpoints. A normal node has no limitation on traffic capacity. Use bp_j to indicate the pavement id where bridge j is associated as shown in Eq. (1).

$$bp_j = i, where\ i \in (1, 2, \dots, N^p), j = 1,2, \dots, N^b \quad (1)$$

Where N^p is the total number of pavement segments and N^b is the total number of bridges. When a pavement segment i consists of one or more bridges, its traffic capacity C_i^p is equal to the minimum value of pavement and bridges as shown in Eq. (2).

$$C_i^p = \min(C_i^p, (C_{bp_1}^b, C_{bp_2}^b, \dots, C_{bp_j}^b, \dots, C_{bp_{N^b}}^b; where\ bp_j = i)) \quad (2)$$

The interdependent pavements and bridges provide the mobility of the entire transportation network. In traffic engineering, transportation network mobility refers to the required travel time and costs. Normally, the average travel time and reliability are used as the measure of mobility. In this implementation, the mobility measure developed by Leng, et al. (2017) is used, as shown in Eq. (3).

$$T_{gi} = \eta \left(\frac{T_i}{t_i}\right) + (1 - \eta) r_i, i = 1, 2, \dots, N^p \quad (3)$$

where T_{gi} is the generalized travel time. It consists of two parts: the first part is the ratio of actual travel time T_i to the free-flow traffic t_i; the second part is the probability that a road segment doesn't meet the reliability requirement. These two parts are summed using two weighting factors, η and 1-η, which can be determined by Stated Preference (SP) survey. The detailed computation of T_{gi} can be referred to the work done by Leng, et al. (2017), in which T_i is a function of traffic volume, TV_i, and traffic capacity, C_i^p.

Eq. (3) only measures the mobility of one pavement segment, i. To measure the mobility of the entire transportation network, the average travel time for each origin-destination (OD) pair is first defined. Then, the travel time for the entire network can be evaluated based on the mobility of all OD pairs.

The shortest path (st) for each OD pair from node s to t is used to compute the travel time, $T_{g,st}$, which is a weighted average travel time of all pavement segments on this path. TV_i on each segment is used as the weighting factor.

$$T_{g,st} = \sum_{i=1}^{N^p} \delta_{i,st} \cdot TV_i \cdot T_{gi} / \sum_{i=1}^{N^p} \delta_{i,st} \cdot TV_i \quad (4)$$

Where

$$\delta_{i,st} = \begin{cases} 1, \ pavement\ segment, i \in (st) \\ 0, pavement\ segment\ i \notin (st) \end{cases} \quad (5)$$

The travel time of the entire network, T_g, is then defined as the weighted average of all possible OD pairs. The length, l_{st}, of each OD pair is used as the weighting factor.

$$T_g = \sum_{s\in V, t\in V, s\neq t} l_{st} \cdot T_{g,st} \,/\, \sum_{s\in V, t\in V, s\neq t} l_{st} \quad (6)$$

T_g also measures the accessibility of the road network. If an OD pair is inaccessible, the entire road network has an infinite travel time, and therefore, is not connected.

2.2 Traffic Capacity and Asset Condition

As shown in Figure 5.1, the relationship between traffic capacity and pavement/bridge condition links traffic engineering and pavement/bridge engineering. Normally, a pavement or bridge's traffic capacity will decrease when its condition degrades. Condition improvement due to maintenance will increase its traffic capacity.

To the best of our knowledge, there is not much research in this interdisciplinary area in literature. Chandra (2004) has studied the two-lane roads in India by correlating road traffic capacity to pavement roughness, which is measured by the international roughness index (IRI).

$$C_i^p = 93{,}312 - 113.3 \cdot IRI \quad (7)$$

In Eq. (7), the unit of C_i^p is passenger car unit per day (PCU)/d) and the one for IRI is inch per mile (in/mi). This is an empirical equation, in which 93,312 is the design capacity. In the following case study, this equation is modified to fit in with the test road network.

Pertaining to bridges, no relative research was found in the literature to correlate bridge capacity to its condition. For demonstration purpose, a step function is assumed based on the definition of the National Bridge Inventory (NBI) score as shown in Table 5.1. Given the design traffic capacity, a bridge's capacity is discounted by the NBI score. For example, when NBI is 5 in fair condition, the capacity is 85% of the design value. When NBI is in critical or imminent failure, its capacity is 0 because the bridge needs to be closed for corrective action.

2.3 Asset Deterioration and Treatment Improvement

The deterioration model is a key component in an asset management system. When a pavement or bridge deteriorates, its traffic capacity will also decrease. Ouyang & Madanat (2004) proposed a deterministic deterioration model. It is a simplification based on the model developed by Paterson (1990).

$$s(t+1) = (s(t) + f^*) \cdot \exp(\beta), \ t = 0, 1, 2, \dots, T \quad (8)$$

Where t is the discretized time starting from 0. According to the pavement survey interval, time is normally discretized as years. T is the total analysis horizon. f^* is a constant representing the average deterioration trend and β is a small constant. Pavement condition, $s(t)$ is measured by roughness, i.e., IRI.

Table 5.1 Bridge Condition and Traffic Capacity

NBI	Percentage of Design Capacity (%)	Description (FHWA, 2018)
9, 8	99	Excellent or very good condition
7	95	Good condition: some minor problems
6	90	Satisfactory condition: minor structural element deterioration
5	85	Fair condition: minor section loss, cracking, spalling or scour
4	50	Poor condition: advanced section loss, deterioration, spalling or scour
3	40	Serious condition: loss of section, deterioration, spalling or scour affects primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present
2, 1	0	Critical or imminent failure condition: bridge should be closed for corrective action

When pavement maintenance is applied, pavement condition will be improved. For simplicity, three categories of treatments, including "do nothing", "minor preventive maintenance", and "major rehabilitation" are used as shown in Table 5.2.

Table 5.2 Treatment Criteria for Pavement

Pavement Condition (IRI)	Do Nothing	Minor Preventive Maintenance	Major Rehabilitation
Good (IRI < 95in/mi)	X		
Acceptable (95 <IRI < 170 in/mi)	X	X	
Poor (IRI > 170 in/mi)	X		X

As shown in Table 5.2, pavement condition is categorized as good, acceptable, and poor based on a different range of IRI. Minor preventive maintenance, e.g., microsurfacing, can only be applied to "acceptable" pavement; and major rehabilitation, e.g., milling and overlay, can only be applied to "poor" pavement. The effectiveness of each treatment is defined as follows:

- Do nothing: no condition improvement
- Minor Preventive Maintenance: pavement condition remains the same for the next 2 years
- Major rehabilitation: pavement condition becomes good (IRI < 95in/mi)

For bridges, a Markov transition probability matrix (TPM) is used as shown in Table 5.3 (Morcous & Hatami, 2011). Though different components, e.g. deck, superstructure, or substructure, of a bridge has different deterioration characteristics, for simplicity, only the one for substructure is used in this implementation.

Table 5.3 Bridge Deterioration Probabilities

NBI	9	8	7	6	5	4	3	2	1
9	0.85	0.15	0	0	0	0	0	0	0
8	0	0.95	0.05	0	0	0	0	0	0
7	0	0	0.95	0.05	0	0	0	0	0
6	0	0	0	0.93	0.07	0	0	0	0
5	0	0	0	0	0.95	0.05	0	0	0
4	0	0	0	0	0	0.91	0.09	0	0
3	0	0	0	0	0	0	0.89	0.11	0
2	0	0	0	0	0	0	0	0.94	0.06
1	0	0	0	0	0	0	0	0	1.0

Similarly, for treatment purpose, bridge condition is categorized as excellent, good, fair, and poor based on a different range of NBI scores. Minor preventive maintenance can only be applied to "good" or "fair" bridges, and major rehabilitation can only be applied to "poor" bridges. The effectiveness of each treatment is defined as follows:

- Do nothing: no condition improvement
- Minor Preventive Maintenance: bridge condition remains the same for the next 2 years
- Major rehabilitation: pavement condition becomes excellent (NBI = 9)

Please note that the above models, treatment selection criteria, and treatment performance are only used for demonstrating an implementation of the proposed framework. For real-world applications, these models and criteria need to be modified or refined according to the actual pavement and bridge characteristics and treatments.

2.4 Interdependency-based Mathematical Optimization Model

With the above models established, the mathematical optimization can be developed. Without loss of generality, let U^p and U^b be the interdependent sets of all pavement segments and bridges, respectively. $x_{i,t,k}$ is the decision variable for pavement segment *i* taking treatment *k* in year *t*. Similarly, $y_{i,t,k}$ is the decision variable for bridge *i* taking treatment *k* in year *t*. $x_{i,t,k}$ and $y_{i,t,k}$ are two 0-1 variables as follows.

$$x_{i,t,k} = \begin{cases} 1, & if\ treatment\ k\ is\ applied\ to\ pavement\ i\ in\ year\ t \\ 0, & if\ treatment\ k\ is\ not\ applied\ to\ pavement\ i\ in\ year\ t \end{cases} \quad (8)$$

$$y_{i,t,k} = \begin{cases} 1, & if\ treatment\ k\ is\ applied\ to\ bridge\ i\ in\ year\ t \\ 0, & if\ treatment\ k\ is\ not\ applied\ to\ bridge\ i\ in\ year\ t \end{cases} \quad (9)$$

The objective is to minimize the network travel time in all analysis years, which is equivalent to maximize the network mobility.

$$\text{Objective: minimize } \sum_{t=1}^{T} T_{gt} \quad (10)$$

where T_{gt} is the generalized travel time for the entire transportation network in year t, which is the function of the transportation network, and the traffic volume and traffic capacity of each pavement segment and bridge as introduced in the above subsection.

The following constraints are applied.

- Annual budget, B_t.

$$\sum_{i \in U^p} \sum_{k=0}^{K^p} (1+d)^t \cdot c_{i,k}^p \cdot x_{i,t,k} + \sum_{i \in U^b} \sum_{k=0}^{K^b} (1+d)^t \cdot c_{i,k}^b \cdot y_{i,t,k} \le B_t \quad (11)$$

where K^p and K^b are the numbers of available treatments (including "do nothing") for pavements and bridges, respectively. $c_{i,k}^p$ and $c_{i,k}^b$ are the cost if treatment k is applied for i^{th} pavement segment and bridge, respectively. d is the discount rate, which is assumed to be a constant.

- Intrinsic constraints: one and only one treatment should be applied to a pavement segment or a bridge in one year.

$$\sum_{k=0}^{K^p} x_{i,t,k} = 1, \forall t \in \{1, 2, \dots T\}, i \in U^p \quad (12)$$

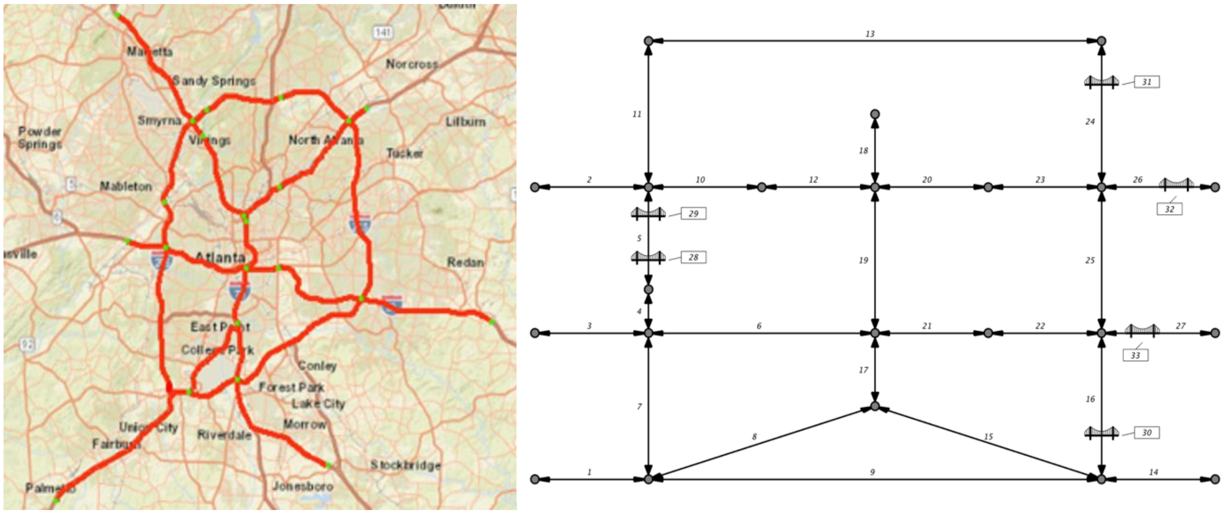
$$\sum_{k=0}^{K^b} y_{i,t,k} = 1, \forall t \in \{1, 2, \dots T\}, i \in U^b \quad (13)$$

- Functions to relate pavement/bridge condition to traffic capacity (see Eq. 7 and Table 5.1)
- Deterioration functions (see Eq. 8 and Table 5.3)

The above optimization model is an integer programming. For a large transportation network, the exact solution is hard to be found. Thus, a heuristic method is often needed. In the following case study, a genetic algorithm (GA) is applied.

3. Case Study

To demonstrate the effectiveness of the proposed framework for objectively managing interdependent assets, a case study is performed using an interstate highway network around the City of Atlanta, Georgia, shown as the thick red lines in Figure 5.2 (a). Figure 5.2(b) shows the equivalent directed graph. The selected network contains 33 utilities, i.e., 27 pavement segments, and 6 bridges. The ID of each utility is shown in Figure 5.2(b).



(a) Map **(b) Directed graph**

Figure 5.2 Interstate Highway Network Around Atlanta, Georgia

The utility characteristics and initial conditions are listed in Table 5.4. Please note that the initial conditions for pavements and bridges are not the actual values, which were modified on purpose to facilitate the case study.

3.1 A WSM-based Optimization Model for Comparison

To assess the effectiveness of interdependency-based asset management, a weighed-sum-model (WSM)-based optimization model is also developed. In a normal WSM framework, pavements and bridges are considered as two independent assets. When decision makers allocate funds between these two assets, a common strategy is to use a multiobjective optimization model, i.e., to maximize the overall conditions of pavements and bridges with given constraints. The overall condition of pavements can be the length-weighted roughness; the one for bridges can be traffic-volume-weighted NBI scores. To make a decision based on these two conflicting objectives, WSM is the most commonly used method, by which a multiobjective optimization can be converted to a single-objective counterpart. Before that, the rating for pavements and bridges need to be scaled for a fair comparison. Assuming the range for pavement IRI is (90, 240), Eq. (14) converts pavement roughness to a score, *PR*, ranging between 0 and 100 (0 indicates the roughest pavement; 100 indicates the smoothest one). Similarly, Eq. (15) convert bridge NBI score to another score, *BR*, ranging between 0 and 100, too.

Table 5.4 Utility Characteristics and Initial Condition for Case Study

Pavement ID	Length (mile)	IRI (in/mile)	AADT	Bridge ID	NBI	Bridge ID	NBI
1	13.05	90	233,400				
2	9.46	90	321,610				
3	2.95	90	208,030				
4	3.33	200	231,290				
5	6.30	130	184,080	28	9	29	5
6	6.43	90	208,030				
7	11.65	200	231,290				
8	6.42	130	233,400				
9	3.89	200	231,290				
10	1.32	90	321,610				
11	1.31	130	184,080				
12	6.67	130	349,450				
13	5.89	200	231,290				
14	9.73	90	214,710				
15	3.95	130	349,450				
16	11.42	200	270,750	30	2		
17	4.10	130	349,450				
18	0.44	90	233,400				
19	4.18	130	349,450				
20	3.39	90	233,400				
21	2.39	90	208,030				
22	7.60	200	192,910				
23	7.12	130	268,870				
24	5.94	200	270,750	31	2		
25	12.94	200	270,750				
26	1.53	130	268,870	32	8		
27	9.97	200	192,910	33	3		

$$PR = \frac{240 - IRI}{240 - 90} \times 100 \tag{14}$$

$$BR = \frac{NBI - 1}{9 - 1} \times 100 \tag{15}$$

When a WSM method is used, the above two objectives are converted to maximizing the composition rating, *CR*, that is the weighted sum of *PR* and *BR*, where *w* is the weighting factor for pavements and l_i is the linear length of i^{th} pavement segment.

$$\text{maximize: } CR = w \cdot \frac{\sum_{i=1}^{N^p} PR_i \cdot l_i}{\sum_{i=1}^{n_p} l_i} + (1-w) \cdot \frac{\sum_{j=1}^{N^b} BR_j \cdot TV_j}{\sum_{j=1}^{n_b} TV_j} \quad (16)$$

For a fair comparison, the constraints for this WSM-based optimization model are exactly same with the ones of interdependency-based counterpart.

3.2 Objectivity vs. Subjectivity

Buchanan, et Al. (1998) had a comprehensive discussion about the distinction between objectivity and subjectivity. "The rule is: subjective pertains to elements which belong to the mind; elements that are outside the mind and which can be shared by other people are objective." Based on this definition, all "elements" in the interdependency-based optimization model are "outside the mind", and "can be shared by other people". On the other hand, the weighting factor, *w*, in the WSM-based optimization model is purely a decision maker's preference. This preference belongs to the mind, and cannot be shared.

To quantify the impact of the subjectivity, a sensitivity study is conducted by changing the weighting factor, *w*, from 0 to 1. Table 5.5 lists the generalized network travel time, T_g, and composite rating, *CR* along with different weighting factors after the first year's treatments.

Table 5.5 Sensitivity Study of MCDM-based Optimization Model

w	0	0.1	0.2	***0.3***	0.4	0.5	0.6	0.7	0.8	0.9	1
T_g	1.301345	1.324606	1.300769	***1.154443***	1.300769	1.300769	1.300769	***Inf***	1.300769	1.432098	1.432098
CR	61.26	62.01	61.00	***60.00***	58.99	56.75	56.98	55.97	54.96	54.83	55.84

Due to the use of decision makers' preference, the *CR*s in different cases are not comparable. However, the measurement of mobility, i.e., T_g, can be used for comparison because it is objective. From Table 5.5, there is no apparent correlation between *w* and T_g, which means the preference-based decisions on cross-asset management are not related to the mobility-based performance measure. Thus, though T_g is the best when *w* is 0.3, it is only applied in this case study. When *w* is 0.7, T_g is infinite, which means the entire transportation network is not connected and some nodes are inaccessible.

From Eq. (3), T_g is the weighted sum of the ratio of actual travel time to free-flow travel time, and the unreliability of travel time. The weighting factor can be determined by SP Survey. Thus, the greater T_g is, the worse traffic condition is. Figure 5.3 shows an example relationship between T_g and traffic capacity of a pavement segment given the traffic volume and the weighting factor. It can be seen that the asymptotic value of T_g is equal to η that is 0.44 in this case study when traffic capacity increases. From Figure 5.3, T_g is sensitive to capacity change when it is greater than 1.0. However, when T_g is less than 0.75, it becomes very insensitive to capacity change. As a comparison, the T_g is 0.519460 when the interdependency-based optimization model is applied. Thus, the maintenance strategy from any case of the WSM-based model is not close to the interdependency-based model.

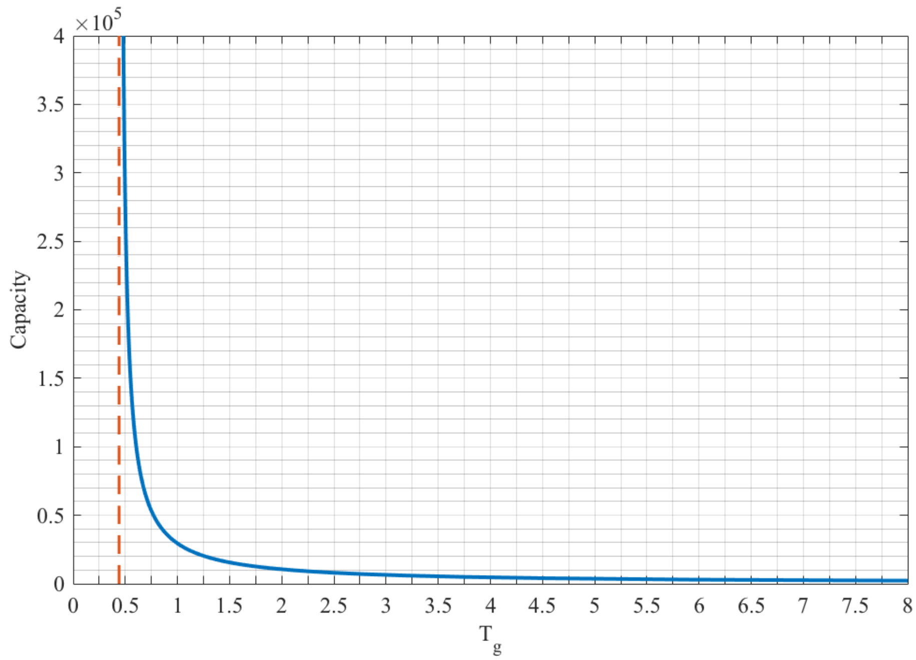


Figure 5.3 Relationship between T_g and Traffic Capacity

The above sensitivity study shows that the WSM-based cross-asset management is subjective, and heavily relies on decision makers' preference. The resulting transportation network might not be optimal in terms of mobility.

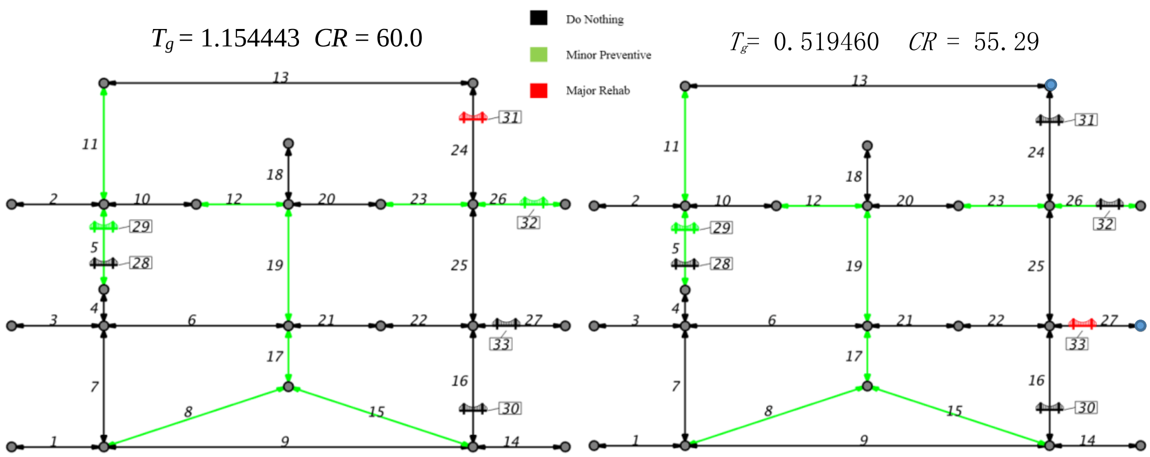
3.3 Maintenance Strategy Comparison

To illustrate the difference of maintenance strategy using the above two optimization models, the conditions of three bridges, (#30, #31, and #33), are set in poor (NBI values are 2, 2, and 3, respectively). Based on the above sensitivity study, *w* is chosen as 0.3, which yields the best performance for traffic operations. A five-year programming is presented in this case study with a yearly $5 million budget.

As shown in Figure 5.4, different colors illustrate different treatment methods, i.e., "Do Nothing," "Minor Preventive," and "Major Rehab" for the first year. Because the available budget is only $5 million, only one bridge in poor condition can be rehabilitated. The remaining budget can then be applied to other utilities for minor preventive maintenance. It can be seen that the WSM-based model chose bridge #31 for rehabilitation while the independency-based model chose #33.

Apparently, after bridge #31 is rehabilitated, the *CR* is maximized as 60.0; it is higher than the strategy when bridge #33 is selected, which is 55.29. However, from the point of view of mobility, this strategy results in a T_g of 1.154443, which is much higher than the one from the strategy of the independency-based model.

Though the initial NBI scores for bridges #30 and #31 are 2s that are worse than the score of 3 for bridge #32, bridge #33 is more critical than the other two in order to maximize the performance of mobility. The upper highlighted node has two degrees entering the network, while the lower one has only one degree, if bridge #33's NBI drops to 2 without treatment, it would lead to network disconnection. Clearly, bridge #33 is more critical than the other two.



(a) MCDM-based model **(b) Independency-based model**

Figure 5.4 Comparison of Maintenance Strategy

Table 5.6 list the five-year performance of two models. It can be seen that the interdependency-based model has much more stable yearly mobility performance because the critical bridge #27 is rehabilitated in the first year. In contrast, the critical bridge is treated in the third year by using the WSM-based model because the other two poor-condition bridges are treated in the first two years. The results show that WSM-based model is unreliable to take into the consideration of network mobility.

Table 5.6 Comparison of T_g in Five-Year Programming

Model	Year 1	Year 2	Year 3	Year 4	Year 5
Interdependency	0.519460	0.516198	0.513843	0.513864	0.514400
WSM	1.154443	1.015754	0.513843	0.513868	0.514404

4. Summary

Cross-asset management in transportation agencies often adopts MCDMs that involve subjective engineering judgment. To enhance the objectivity and reduce the risk of failure of the transportation network, we proposed a new cross-asset management framework based upon the optimization of the efficiency of network mobility. Under this framework, the interdependent pavements and bridges, the two biggest transportation infrastructure assets, can be seamlessly integrated for network-level maintenance programming. To demonstrate the benefit of the proposed framework, an interdependency-based optimization model was developed by incorporating traffic capacity models, deterioration models, and treatment improvement models. In the meantime, for comparison purposes, a WSM-based optimization model was also developed by adopting the commonly used engineering-judgment-based MCDM method.

A case study was conducted using the interstate highway network around Atlanta, Georgia. The results demonstrated that WSM-based maintenance programming and the resulted performance of traffic operations heavily relies on decision makers' preference. In contrast, the interdependency-based counterpart can achieve the best maintenance programming that maximizes the efficiency of traffic operations without the need of decision makers' judgment. More importantly, the maintenance programming based on engineering judgment cannot coincide with the requirements on maximizing the efficiency of network mobility and, therefore, minimizing the risk of network failure.

This research showed promising results of integrating transportation infrastructure interdependency in cross-asset management to enhance the objectivity in multi-criteria decision making, improve the efficiency of network-level traffic operations, and reduce the risk of network failure. The usefulness of the proposed cross-asset management framework lies in the removal of the boundary among different transportation assets; and thus, the issues stemming from "silo" management could be solved. The case study illustrated the benefit of the proposed framework. However, given the limited resource of this research project, this study is just an initial exploration. More research is needed. First, in the proposed framework and case study, road traffic was assumed to be independent of its condition, which is normally not true. For a more precise prediction, traffic should be reassigned when the condition of a road is changed. Second, to the best of knowledge, the interdisciplinary research between traffic engineering and pavement/bridge engineering has not been well performed. For example, little research has been found in the literature to study the relationship between traffic capacity and asset conditions. In this project, we made assumptions about the relationship in order to demonstrate the usefulness of the proposed framework. However, for real-world implementation, the actual relationship needs to be established. Finally, the optimization of network-level transportation asset maintenance programming is very computationally expensive. Even though a GA was used in this study, it could be difficult to solve a problem with a large-scale transportation network. Thus, we need to explore the use of a more efficient approach, such as parallel computing.

Chapter 6: Conclusions and Recommendations

1. Conclusions

TAM practice at the local level is still at its early stages of development and that is reflected upon the condition and performance of the transportation assets under the jurisdiction of its agencies, thus requiring immediate action to improve the current status. As a result of a comprehensive literature review and a targeted online survey for Georgia's local transportation agencies, some factors have been identified to have a crucial role in hindering a proper TAM practice within those agencies. The factors include lacking a well-structured organizational chart with no roles and responsibilities being clearly set in addition to a shortage in sufficient human resources, with the available staff lacking the required skill set and training, which also affects the agency's capability of adopting new technologies within its TAM programs. Funding is a major issue facing LGs as their assets' increasing needs are not covered by the available shrinking budgets, which is also aggravated by having a simple and subjective decision-making process that is affecting the efficiency of resource allocation and contradicting the agencies' requests to receive additional funding. Another issue facing LGs is the lack of proper communication within the agency, with other local and state agencies, and with the stakeholders. All these factors contribute to the gaps present in the LGs' current practices and signals the necessity of addressing and solving these issues.

Consequently, an asset management guideline was drafted to suit the needs and capabilities of local transportation agencies in general, and those within the state of Georgia in particular. This guideline will assist the agencies in understanding all the critical components of a proper TAM program by showing the FHWA framework. It also focuses on the importance of having a well-established organizational structure and the role that an asset management champion or steering committee can play in pushing toward the adoption and application of TAM practices by holding educational workshops, meetings, and information sessions. LGs should also conduct a self-assessment of their current practice in order to identify strengths, weaknesses, and opportunities. Based on that, policies and plans can be clearly set to reflect the agency's goals and roadmap, while taking into consideration legal requirements, stakeholders' expectations, managed assets, and available resources. The guideline also pushes for having a solid asset inventory that acts as the cornerstone of a successful TAM program, in addition to having a proper data management system to store and manage this inventory. Performance-based asset management which is supported by MAP-21 and FAST Act is also highlighted in that document. It also discusses the decision-making process that incorporates risk management, through which the agency should allocate its budget in an efficient and beneficial manner to achieve the best network performance. In that context, a well-studied financial plan that includes funding and budgeting affairs on the short, medium, and long terms is recommended. Finally, the guideline insists on having an accurate and frequent reporting process for internal purposes and how that helps in updating the TAM program, besides involving the public and all stakeholders in that whole initiative.

In an attempt to improve the objectivity in cross-asset management decision-making models, this project presented a new framework to reduce the subjectivity in allocating resources among different interdependent transportation assets. For that purpose, the mobility of the entire transportation network is used as the performance measure, as a concept from the traffic engineering discipline, with the objective being set to maximize the network mobility. Yet, the decisions are made in the discipline of pavement/bridge engineering, which is the maintenance programming for the asset facilities, i.e. pavements and bridges. To demonstrate the effectiveness of the proposed framework for objectively managing interdependent assets, a case study was performed using an interstate highway network around the City of Atlanta, Georgia, while considering only pavement and bridge utilities. This framework showed promising results by enhancing the objectivity in multi-criteria decision making, improving the efficiency of network-level traffic operations, and reducing the risk of network failure.

2. Recommendations

The following are some areas where further research and studies can be done:

- More research needs to be performed concerning TAM practices at the local level in order to transfer the state agencies' expertise in that field to local agencies, thus helping in the improvement of the condition and performance of our critical transportation network.

- Cross-asset management is still a new approach to TAM, through which all transportation assets are combined in a single framework while using one decision-making model to allocate the budget among the competing facilities. This area can be further studied and developed for better management systems that consider all assets in the network.

- In the context of the model presented earlier, more interdisciplinary research is needed to bridge the gap between the two disciplines adopted, traffic engineering and pavement/bridge engineering, in order to add confidence to the model's internal structure. An example of such research could be the study of the relationship between traffic capacity and asset conditions.

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Appendix I: Online Survey Results

A survey was created to gather information about transportation asset management from counties and cities in the state of Georgia. The survey consists of 35 questions, utilizing branch logic, which customizes the respondent's survey experience by allowing different question paths throughout the survey. Depending on how respondents answer certain questions, they receive a slightly varied survey route. The survey contains six sections, including general questions (5 questions), transportation asset management (9 questions), condition assessment and data management (6), performance measures and decision-making (3), funding (6), and rating of current status (6). This section will explore the information gathered from the survey responses. A total of sixty-two responses were received. Several responses were excluded from the analysis due to incompleteness and insignificance. Additionally, some counties and cities submitted multiple entries from different employees. Only one entry for each city or county was included in the final analysis. Of the sixty-two responses, twenty-seven counties, seventeen cities, one consolidated city-county government, and one Georgia Department of Transportation (GDOT) district were filtered from the collected data for further analysis to be done. The distribution of survey respondents' job titles is shown in Figure I.1 and Figure I.2 below.

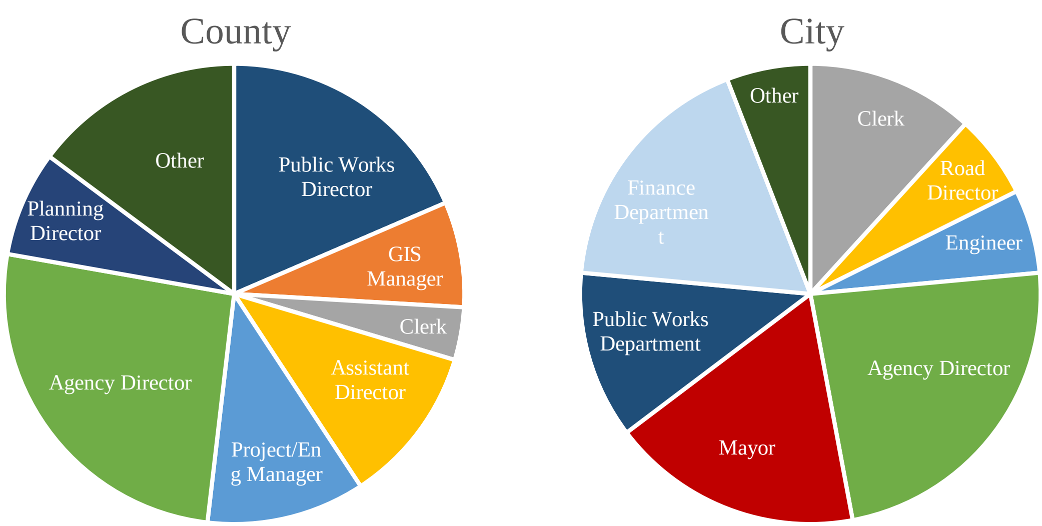


Figure I.1 Survey Respondent Job Titles by County and City

The size and populations of each county and city survey respondent varied greatly. The populations of responding city agencies range from 500 to 73,800. The populations of responding county agencies range from 6,800 to 1,020,000.

General Questions

Survey respondents began the survey with a general information section, which asked the respondents to record their name, contact information, job title, and county or city of employment. Respondents were instructed to specify whether they were from a county, city, or consolidated city-county (i.e. Macon-Bibb County). Additionally, this section included general questions about the structure and establishment of transportation infrastructure management within the respondent's agency.

Each agency's transportation infrastructure management structure varied in both the number and types of involved divisions/departments, as well as the number of employees. Survey participants were asked what agencies/divisions are involved in managing transportation infrastructure assets. Public Works Department was the most frequent response, followed by Engineering and GIS departments. Additionally, most cities and counties had over twenty staffed employees who are actively involved in managing transportation infrastructure assets. Figure I.2 below displays the responses from Counties, Cities, and Consolidated City-Counties.

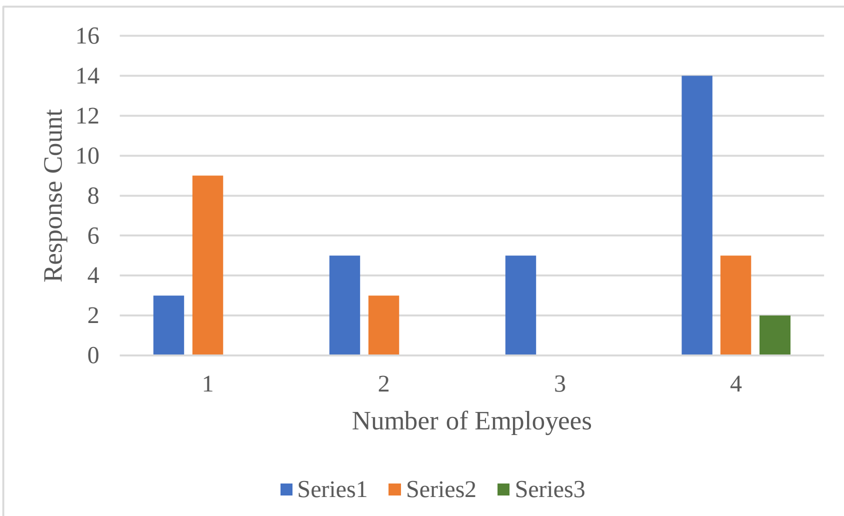


Figure I.2 Number of Employees involved in Transportation Infrastructure Asset Management (Question 4)

The responses to this question yielded some uncertainty by respondents. In some cases, multiple employees from a single city or county completed the survey and had differing responses for this survey question. There may be some ambiguity in the question, "How many employees are involved in managing transportation infrastructure assets?" The management of transportation infrastructure may be interpreted in several ways, which should be taken into consideration upon further analysis.

GIS in Local Agencies

Respondents were asked if their agencies have established GIS departments or GISP employees. Respondents had answer choices yes, no, somewhat, and other (write-in option). As shown in Figure I.3, a majority of cities and counties have established GIS departments.

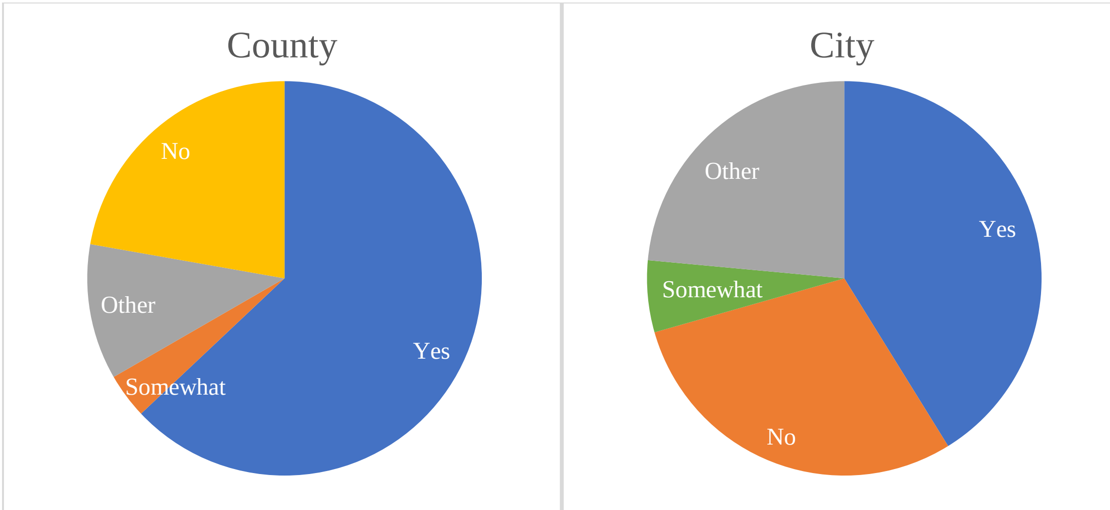


Figure I.3 Agency Presence of GIS Departments

Several respondents selected other as an answer and included more information about their agency's GIS department. Some counties indicated having a contract with their regional commission to assist with GIS work. Other counties indicated that they didn't have GIS departments, but GIS duties fell on other agency divisions, such as public works. One county indicated that they hire privately for GIS services. City agencies also responded other, indicating that they obtain GIS assistance from their county agency. One city agency noted that they have a partnership with their county, as well as several other neighboring cities.

Transportation Asset Management Program

The section following the general information section has nine questions regarding an agency's transportation asset management program. The first question defines transportation asset management and asks survey participants if they practice a well-defined transportation asset management program within their agency. The answer choices are yes, no, somewhat, and not sure. The participant's response to this question will dictate which questions the respondent receives consequently. If a respondent responds that they don't have a well-defined transportation asset management program, he or she will automatically skip the eight remaining questions in the transportation asset management section that asks for more detail about the agency's TAM program. These respondents will continue to the next section, Condition Assessment & Data Management. The other respondents who selecting anything other than 'no' for the first question will work through the remaining questions in the TAM section.

Survey participants are then asked how many full-time and part-time employees are involved in Transportation Asset Management within the agency (Question 7). This question is similar to the question asked in the previous general information section, "How many employees are involved in managing transportation infrastructure assets? (Question 4)" Question 4 precludes the Transportation Infrastructure Asset Management (TAM) section, where TAM is clearly defined. It was assumed that some counties and cities may be unfamiliar with Transportation Asset Management. Other companies who are more familiar with TAM are expected to understand the difference between basic transportation management and an established transportation asset management program. These agencies will be able to distinguish between full- and part-time employees whose main role is TAM. Figure I.4 displays the different responses from counties and cities for survey questions 4 and 7.

The majority of cities reported having 0-5 full-time employees working on basic transportation management (question 4) as well as within defined TAM programs (question 7). Counties had a majority of 20+ employees involved in basic transportation management, and a majority of 0-5 employees working strictly within transportation asset management programs.

Survey respondents were asked to indicate the transportation assets managed within the agency. The results are shown in Figure I.5. Every city and county agency manage roadway assets. More than 70% of county respondents manage bridges, marking/striping, culverts, guardrails, and signage. However, only 35% of city respondents manage bridges. City agencies reported managing sidewalks more often than county agencies.

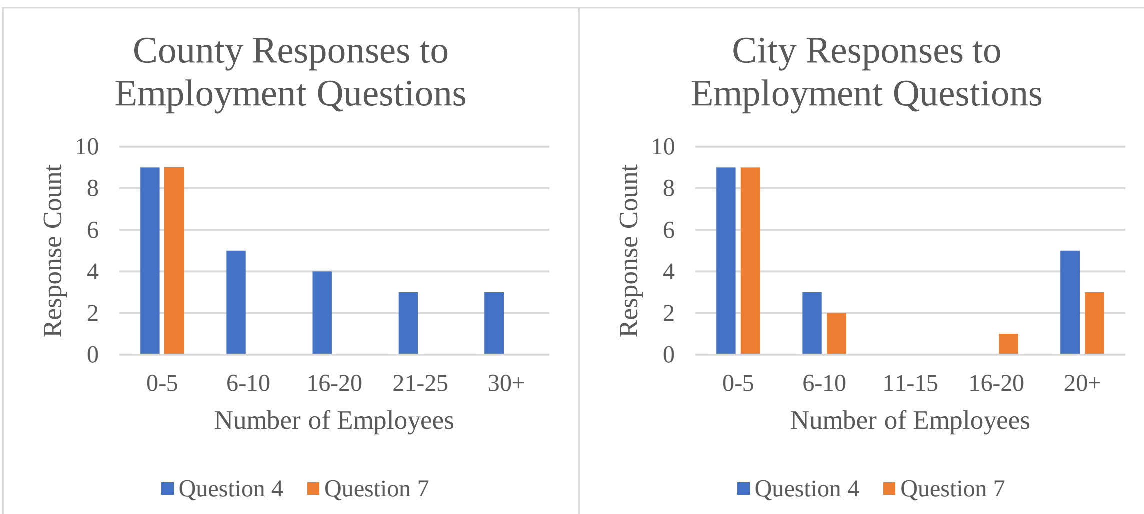
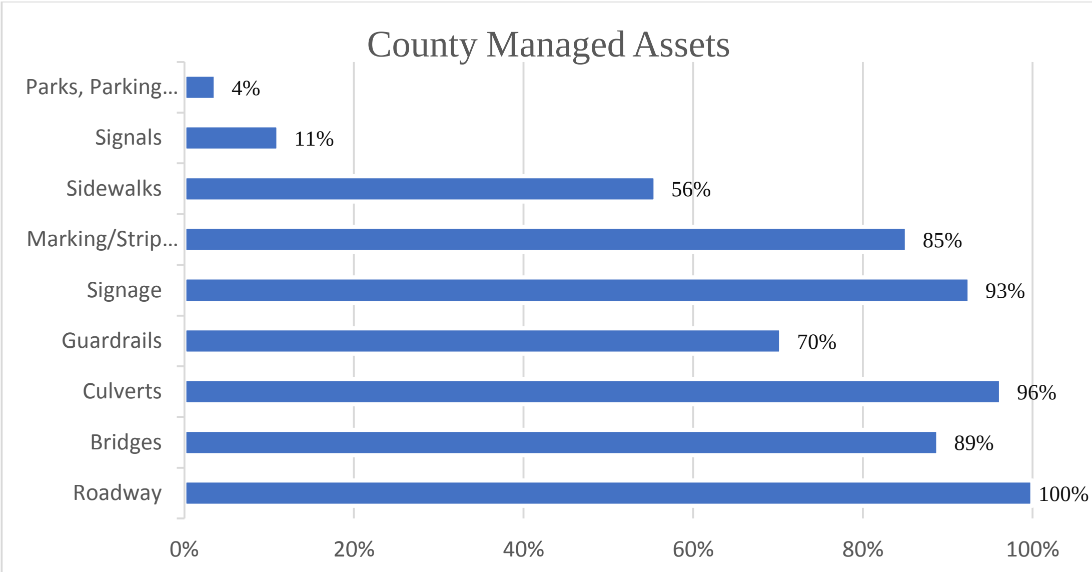


Figure I.4 County and City Responses to Employment Questions 4 and 7



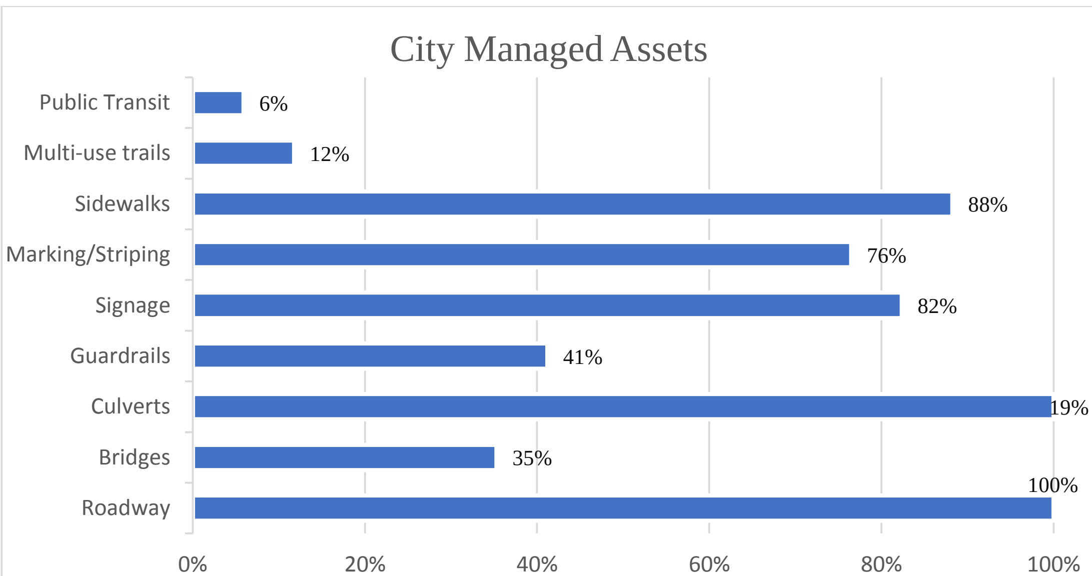


Figure I.5 City and County Managed Assets

Survey respondents who indicated in the previous question that their agency manages bridges or roadways were asked to go into more detail about the quantities of these managed assets. Respondents were asked to record the number of bridges and miles of roadway (paved asphalt concrete, paved Portland cement concrete, and unpaved). Table I.1 and Table I.2 display the responses from county and city agencies.

Table I.1 County Managed Assets – Bridges and Roadway

# Bridges	Count	Miles Paved Roadway – Asphalt Concrete	Count	Miles Paved Roadway – Portland Cement Concrete	Count	Miles Unpaved Roadway	Count
0	5	0	6	0	21	0	7
1-5	1	1-199	1	1-199	1	1-199	14
6-10	3	200-299	5	200-299	0	200-299	1
11-15	2	300-399	3	300-399	0	300-399	1
16-20	1	400-499	3	400-499	2	400-499	0
21-30	1	500-799	3	500-599	0	500-599	0
+30	4	800+	3	600-699	0	600-699	1

The survey asks participants when their agency's TAM program was established. The question gives four multiple answer choices. Half of the county agencies indicated that their TAM programs have been established for more than ten years. The most common response for city agencies was a tie between 1-5 years and more than ten years. As shown in Figure I.6, there is a lot of variation in the number of years an agency's TAM was established.

Table I.2 City Managed Assets – Bridges and Roadway

# Bridges	Count	Miles Paved Roadway – Asphalt Concrete	Count	Miles Paved Roadway – Portland Cement Concrete	Count	Miles Unpaved Roadway	Count
0	10	0	1	0	13	0	9
1-5	1	1-199	10	1-199	2	1-199	5
6-10	1	200-299	1	200-299	0	200-299	0
11-15	1	300-399	0	300-399	0	300-399	0
16-20	0	400-499	1	400-499	0	400-499	0
21-30	0	500-599	0	500-599	0	500-599	0
+30	2	600-699	0	600-699	0	600-699	0
		700-799	0	700-799	0	700-799	1
		800+	2				

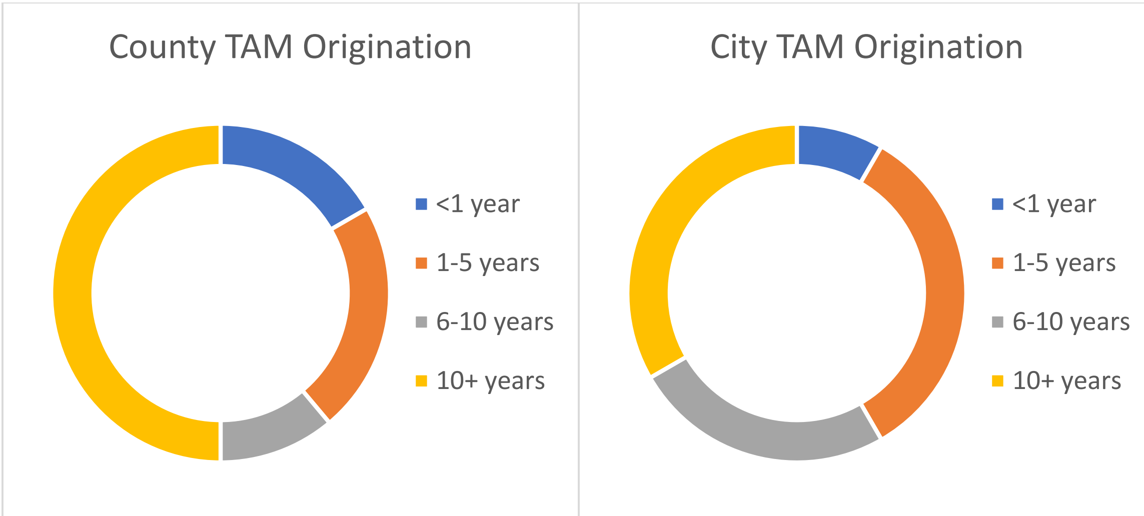


Figure I.6 City and County TAM Origination

Survey participants who responded that they practice TAM within their agency, or somewhat practice TAM were asked what software their agency uses. Respondents were given a variety of different software choices, provided in multiple-response format with an additional optional write-in response. Figure I.7 below displays the results. City agencies reported using a larger variety of software types. In both county and city agencies, GIS is the most commonly used software used in TAM.

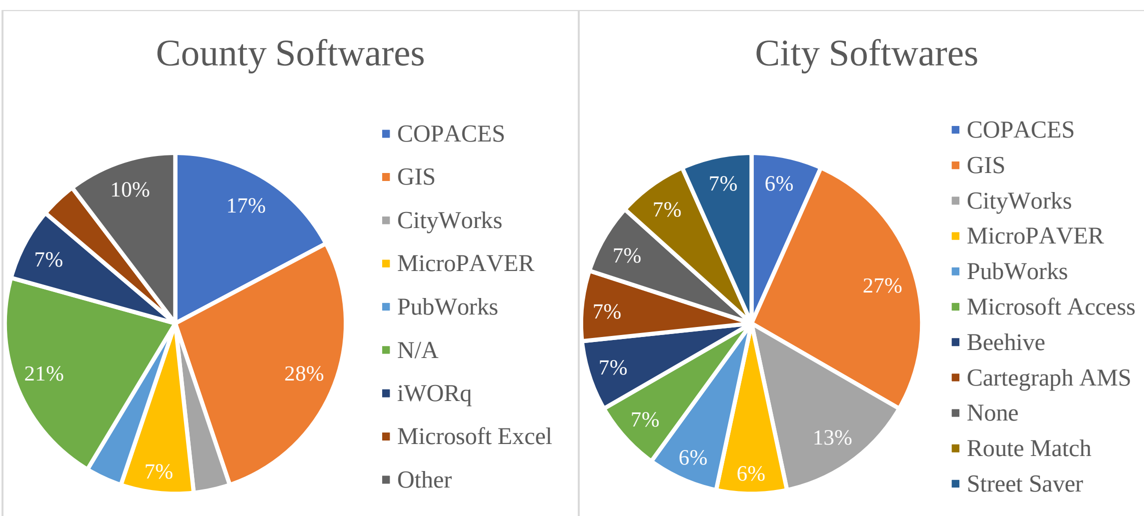


Figure I.7 City and County Software Used

Several county and city agencies indicated that state or federal laws/initiatives impact their agency's TAM practices. The answer choices given for this survey question included Fixing America's Surface Transportation (FAST) Act and Governmental Accounting Standards Board (GASB) Statement 34, as well as an 'Other,' write-in option choice. Figure I.8 shows the distribution of responses.

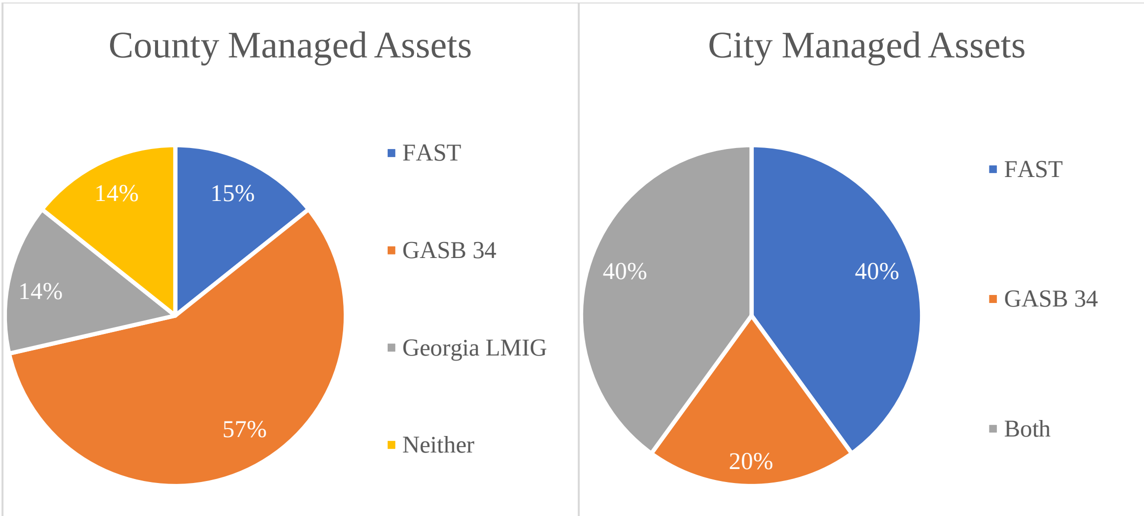


Figure I.8 City and County impacted by state or federal laws/initiatives

The final question in the Transportation Asset Management section of the survey asked participants what is their defined goal(s) set by the agency for the Transportation Asset Management Program? The question gave the following example, "Keep 80% or more of roadway in 'Fair' or better condition." This question type was a short answer. Table I.3 shows the responses from county and city agencies.

Condition Assessment and Data Management

The objective of that section is to check the agencies' current practices and the tools used for the transportation assets' condition assessment and data management. Most counties and cities confirmed having a well-established asset inventory, or at least some form of it. However, around 45% of both counties and cities were not confident ('Somewhat', 'Not Sure') of the inventory data collection practices at their agencies (Figure I.9).

Table I.3 County and City Defined TAM Goals

County Goals
Keep arterials and collectors about 60 on a scale of 0-100 within 5 years.
At this point to bring at least 50% of our road system up to Fair or better condition
Currently working on this stated goal
Keep 80% or more of roadway in 'Fair' or better condition.
Keep 90% or more of roadway in "good" or better condition.
No goal adopted; department goals is: complete assessment, have adopted goals FY 18
None/ Not Specified/Not well defined
Not yet set. Awaiting completion of Asset Inventory
Presently there is not a clear goal. We are paving gravel roads and trying to resurface paved roads as needed.
Repave 10% every five years

The goal is to have repaired/rebuilt roadways last at least 20 years without significant follow-up maintenance.
Use available resources to maintain and improve the County transportation system.
City Goals
100% in fair or better condition
90% in Good to Very Good; average PCI of 80 or greater
Build out infrastructure that was previously ignored by the county. This includes paving streets, installing street scapes and sidewalks, bike paths, and lighting
keep 75% of roads in good condition
keep all City streets in good condition
Maintain all streets in Fair or better condition and upgrade the condition of roads with the lowest ratings insofar as funding allows.
We completed a roadway inventory rating each road from 1 (good) to 4 (very bad). We are working to pave those with a rating of 3 and 4. We are also replacing our road signs to meet the new FHWA sign reflectivity policy.

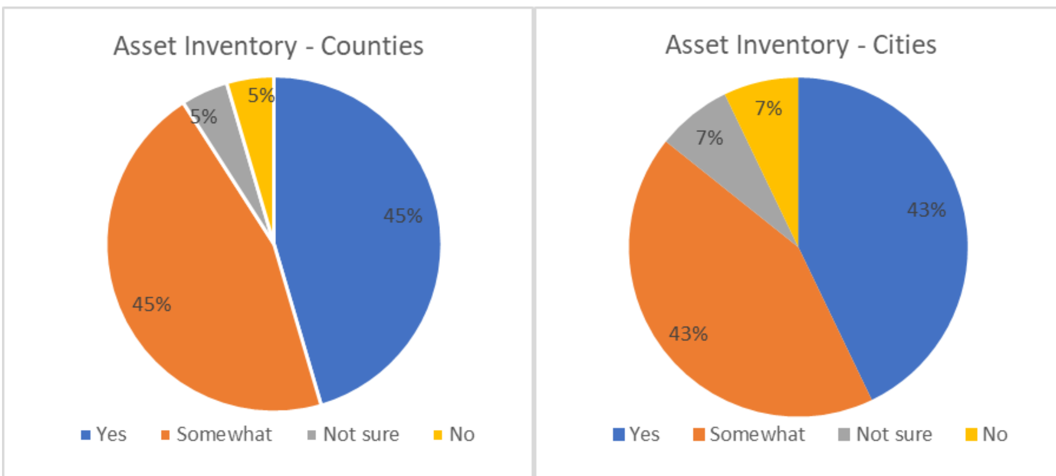


Figure I.9 Existence of Asset Inventory at Counties and Cities

For responders who haven't answered 'No' to the previous question, a question followed about the software used for asset inventory, with choices given from which multiple answers can be chosen. (Figure I.10). It shows that the paper record management system is still widely adopted by agencies with a high adoption rate of GIS Mapping tool and computerized databases, especially by counties. However, cloud computing and mobile/web applications are yet to be used in asset management at the local level.

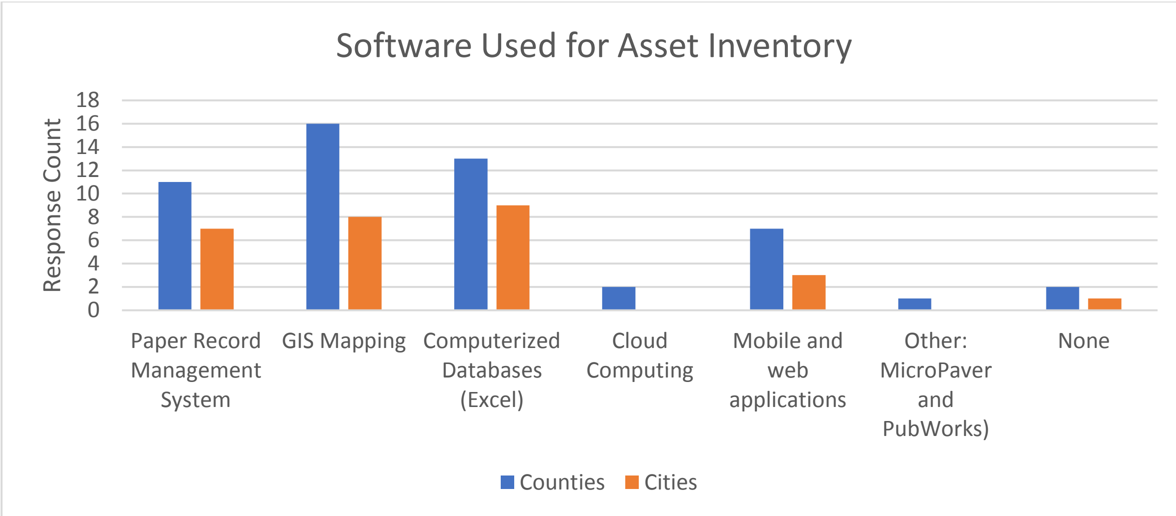


Figure I.10 Software used by transportation agencies for asset inventory

As for the condition assessment method adopted by counties and cities (Figure I.11), most of the agencies use in-house efforts for that purpose with some using a mix of in-house, contracting, and public input and other methods such as GDOT bridge assessment.

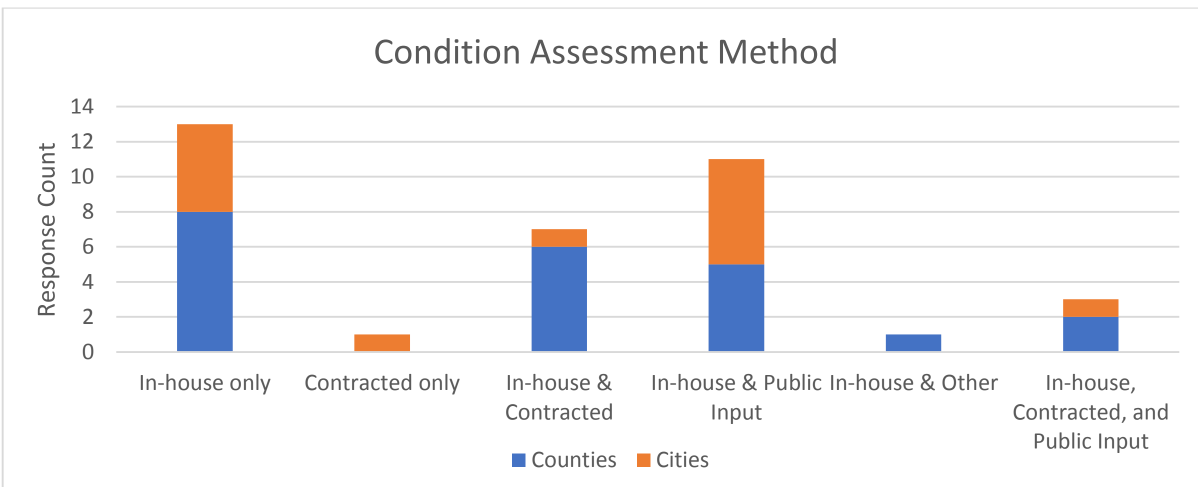


Figure I.11 Condition Assessment methods adopted by local agencies

Concerning the method used by transportation agencies for data collection (Figure I.12), the manual method is still the most used by the local agencies, with only a few using semi-automated and fully automated methods. Remote collection is not adopted by any of the surveyed local agencies, which could be explained by its high technological and financial demands.

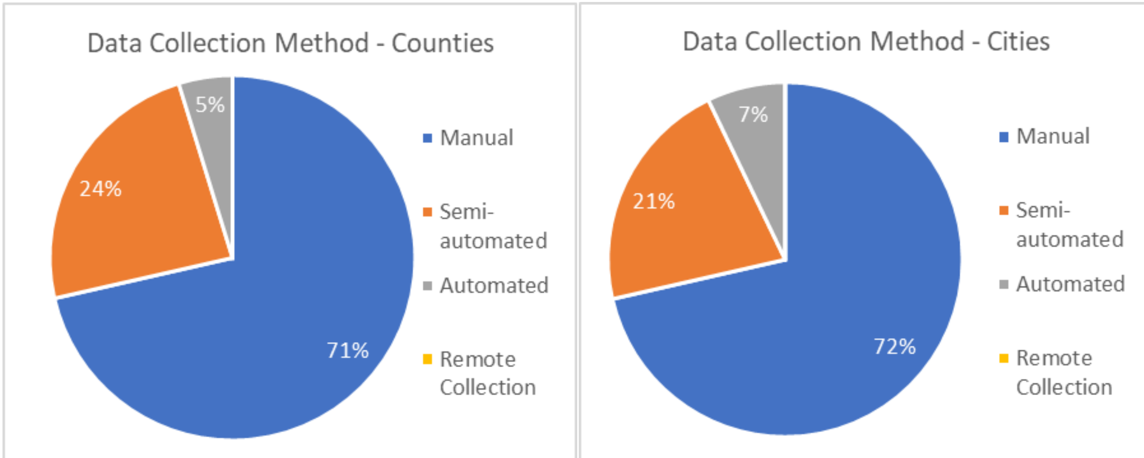


Figure I.12 Data collection methods adopted by local agencies

The final question in that part is related to the frequency of condition assessment surveys for different asset types (Figure I.13). The result of the surveyed agencies shows that the most adopted time interval between asset surveys is a 1-year interval for both county and city agencies, with some exceptions for assets of slower deterioration rates such as sidewalks.

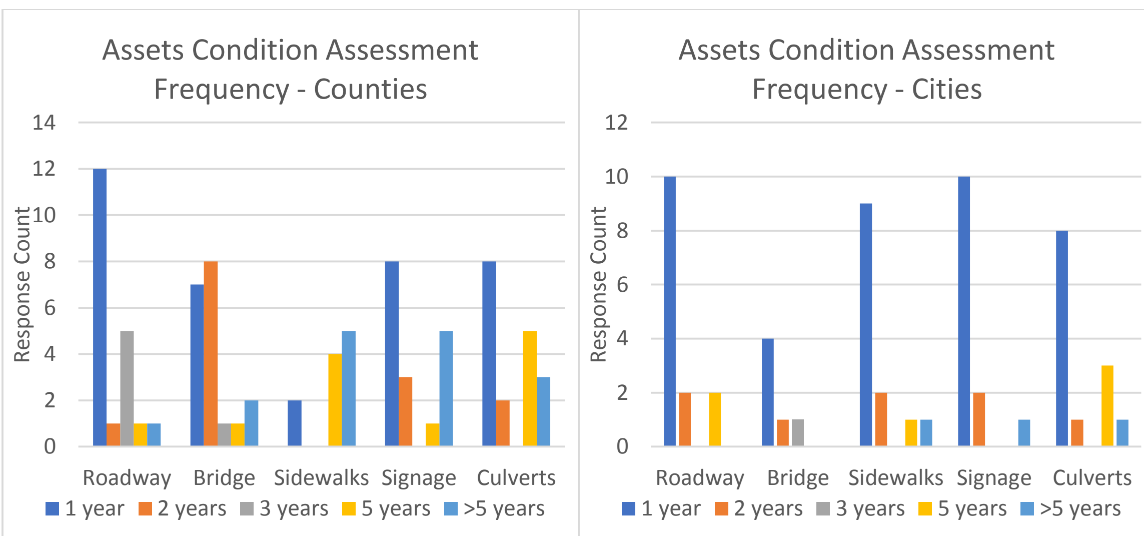


Figure I.13 Assets condition assessment frequency used by county and city agencies

Performance Measures and Decision-Making

The purpose of that section is to evaluate the performance measures and decision-making process adopted by the local agencies. The first question asks the responder to evaluate some statements related to performance measures used by them (Figure I.14 & Figure I.15).

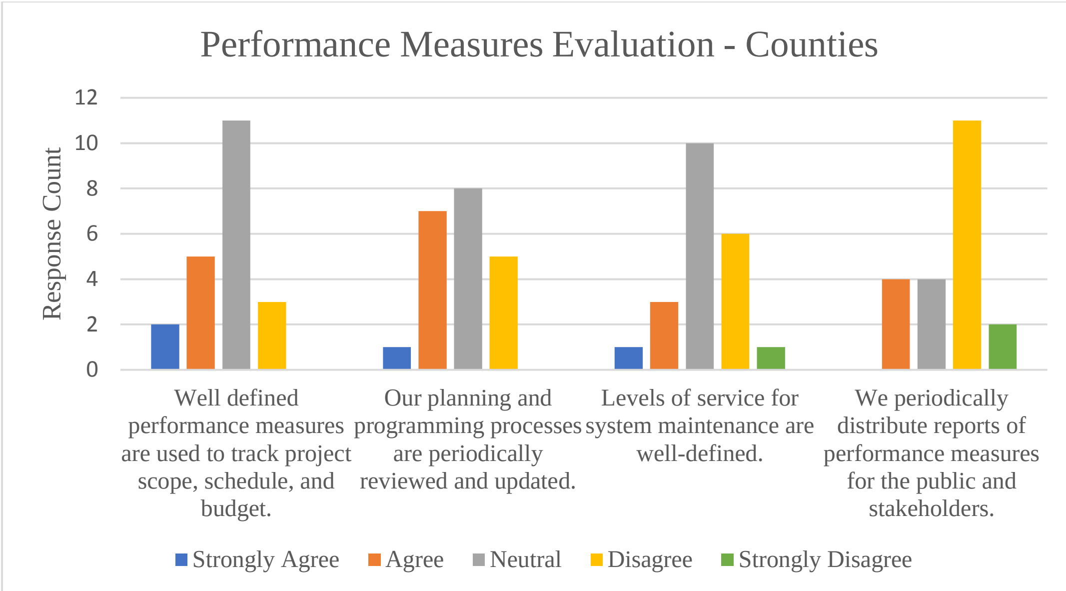


Figure I.14 Evaluation of performance measures adopted by county agencies

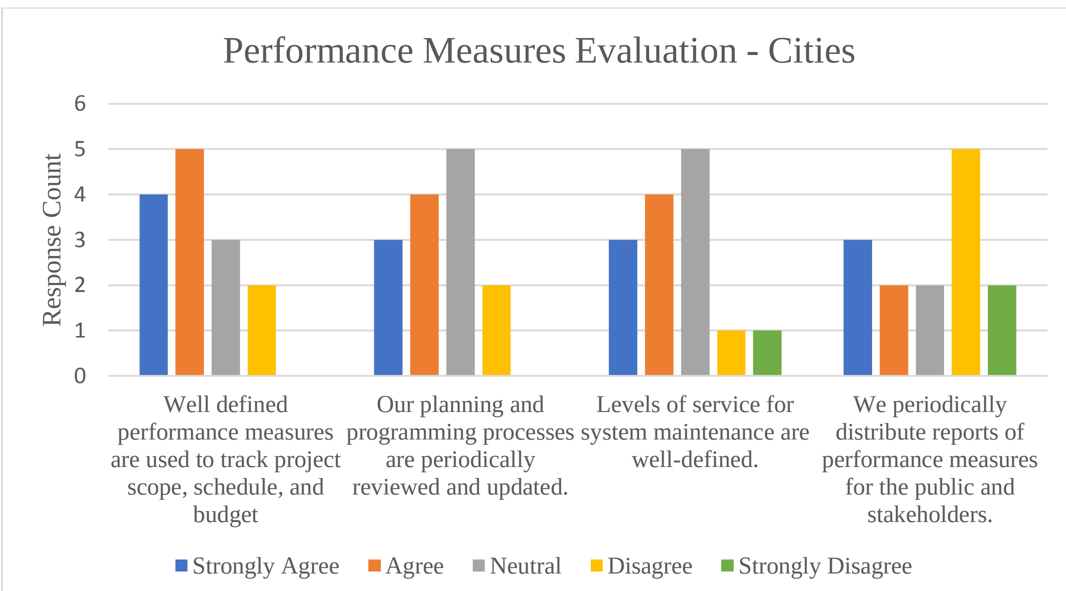


Figure I.15 Evaluation of performance measures adopted by city agencies

As shown in the below figure, most local agencies don't regularly publish reports of performance measures to the public and stakeholders (Figure I.16). A city agency who chose the 'Other' option mentioned that monthly reports are provided to the elected officials primarily but are also open to the public, and another county agency said that they are working on getting this data on their webpage soon.

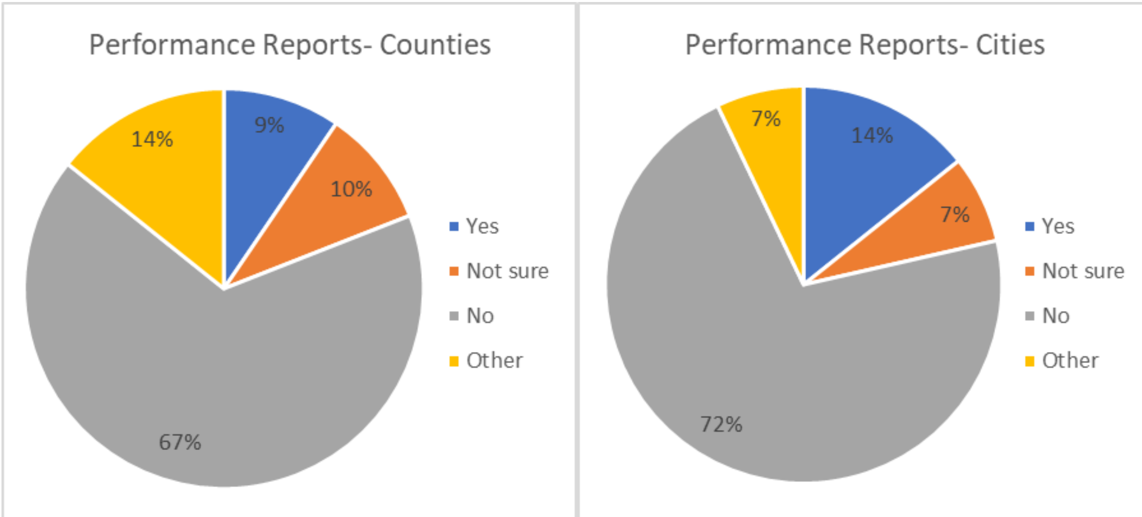


Figure I.16 Performance reports publishing by county and city agencies

The final question in that section is about the method used by agencies to prioritize projects (Figure I.17). The results prove that most local agencies adopt simple subjective ranking based on the judgment of their decision-maker, or a ranking based on simple parameters such as level of service or condition. None of the responders uses mathematical optimization or any type of advanced analysis in their decision-making process.

Funding

The Funding section follows the Performance Measures and Decision-Making section and contains six questions given to all survey respondents. The first question is a four-part Likert-type question that asks respondents to record their agreement on four statements, from strongly disagree to strongly agree. Figure I.18 and Figure I.19 below show that the majority of county and city respondents agree to all four statements. No respondent answered, 'Strongly Disagree,' and very few respondents answered, 'Disagree.'

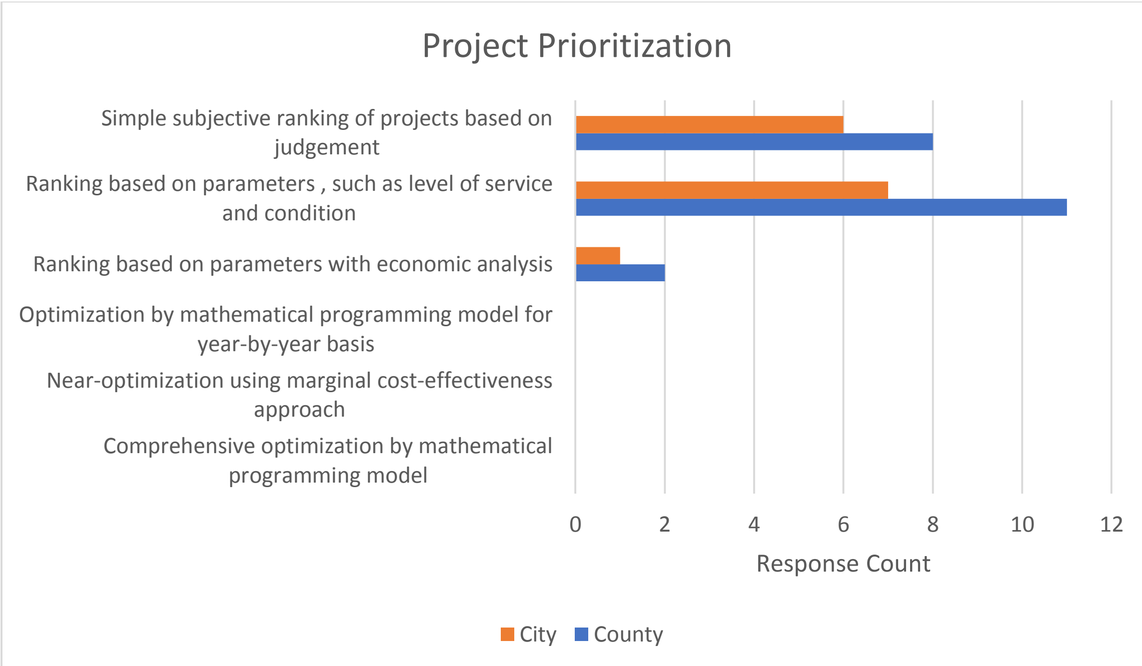


Figure I.17 Project prioritization methods adopted by county and city agencies

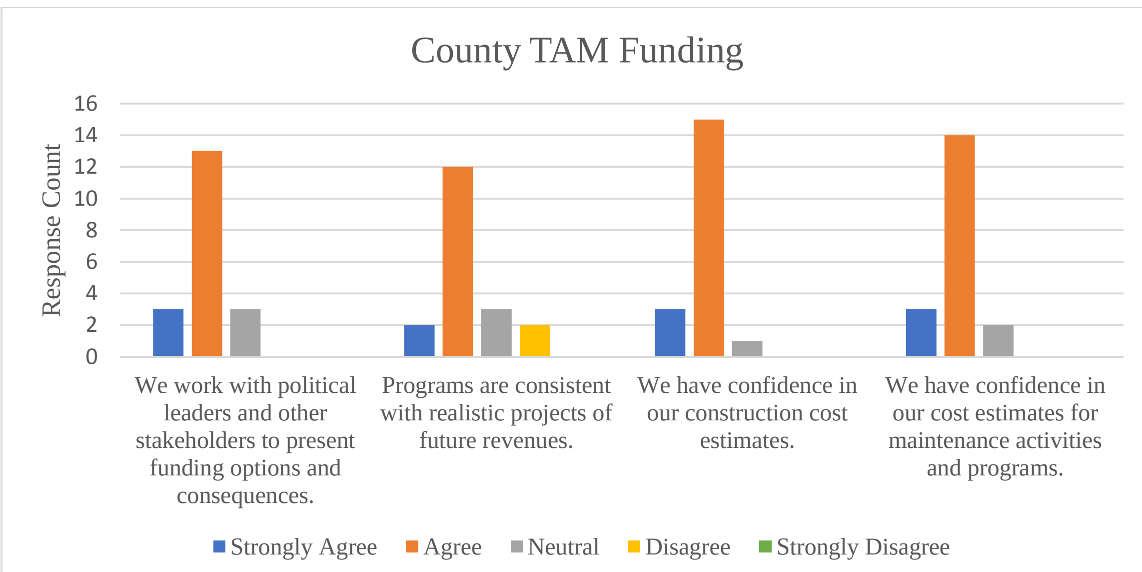


Figure I.18 County TAM Funding

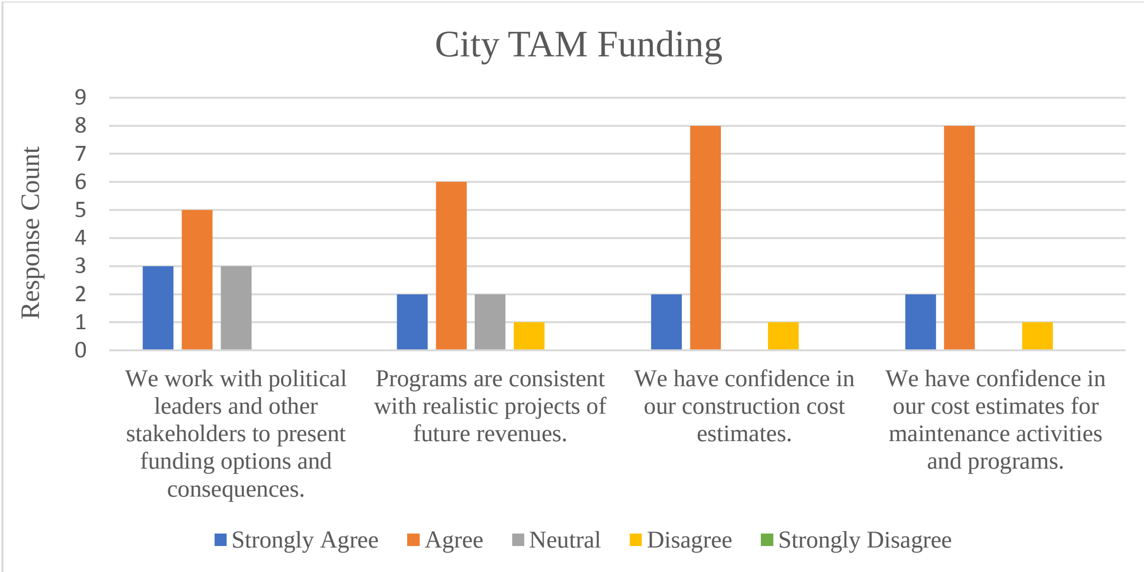


Figure I.19 City TAM Funding

The following question was only asked to respondents who previously indicated that their agency has implemented a TAM program. The question asked respondents to, 'Select the statement which best describes your agency's transportation asset management funding.' The answer choices are shown in Figure I.20. Respondents who selected 'Other' as an answer indicated that funding was determined by Special Purpose Local Option Sales Tax (SPLOST) and LMIG.

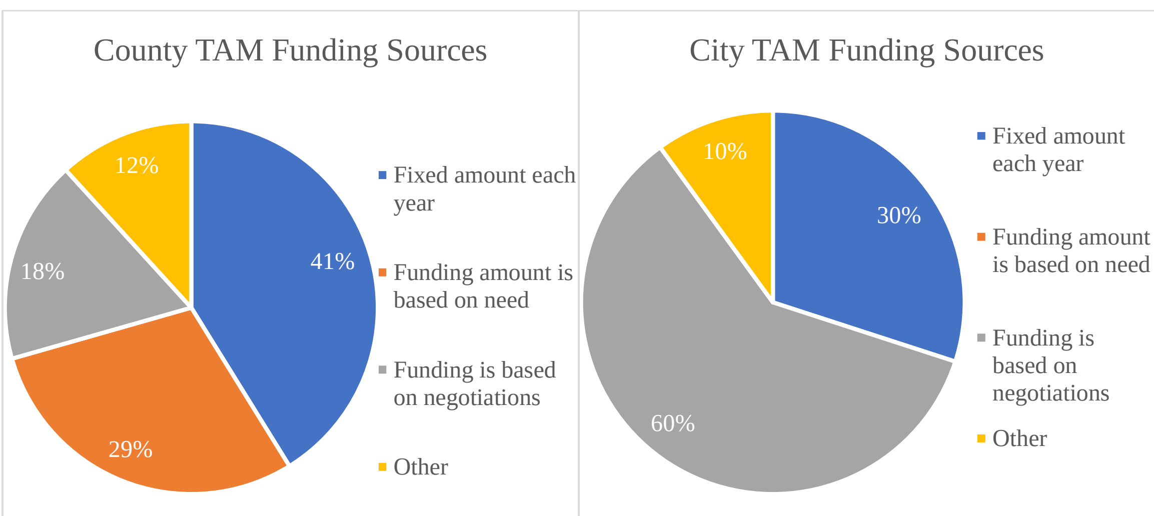


Figure I.20 County and City TAM Funding Sources

Another question asks respondents to indicate their agency's annual budget for Maintenance Rehabilitation and Reconstruction (MR&R). The results for county and city agencies are shown in Figure I.21. The majority of city agencies reporting spending less than $100,000 annually on MR&R. However, some cities reported spending more than $2,500,000 annually on MR&R, which shows the huge difference in budget allocation among Georgia city agencies. This spending is likely a result of the availability of funding and resources. The majority of county agencies spend more than $500,000 on MR&R annually.

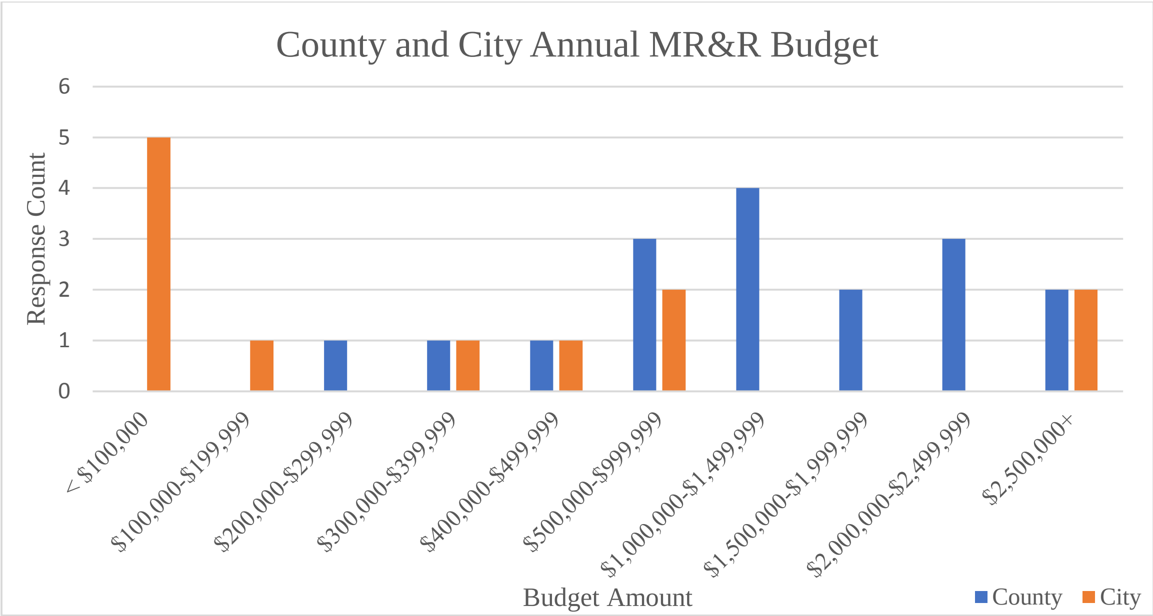


Figure I.21 County and City Annual MR&R Budget

This question gave respondents a sliding scale bar to break down their agency's percentages of spending on routine maintenance, capital investment, and an optional, 'Other,' fill-in the blank. The respondents were instructed to have totaled percentages sum to 100%. Figure I.22 and Figure I.23 below display the distributions of county and city spending. Two respondents selected other as an option choice and wrote in, "Labor," and, "Resurfacing." There is no apparent trend in spending distributions for city and county agencies. Both city and county agencies spend more on routine maintenance than capital investment, on average.

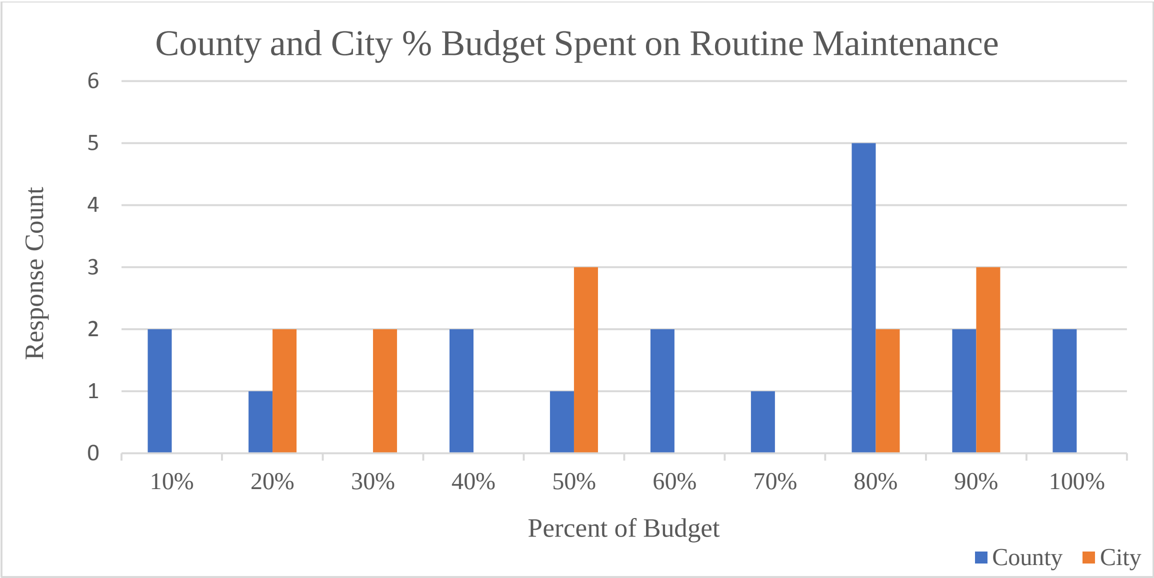


Figure I.22 County and City Percent of Budget Spent on Routine Maintenance

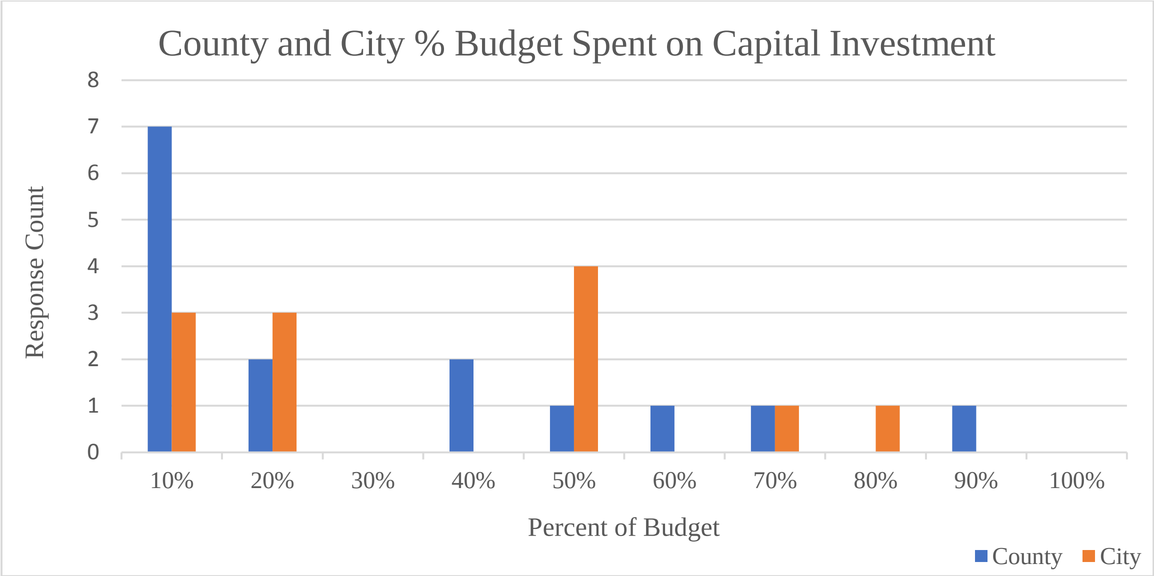
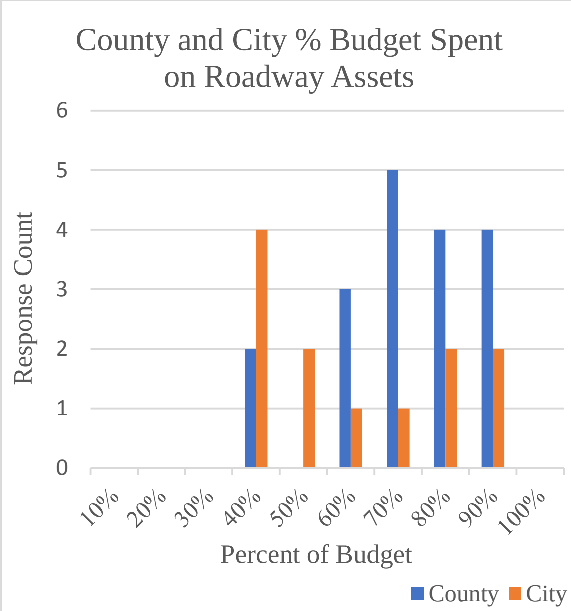
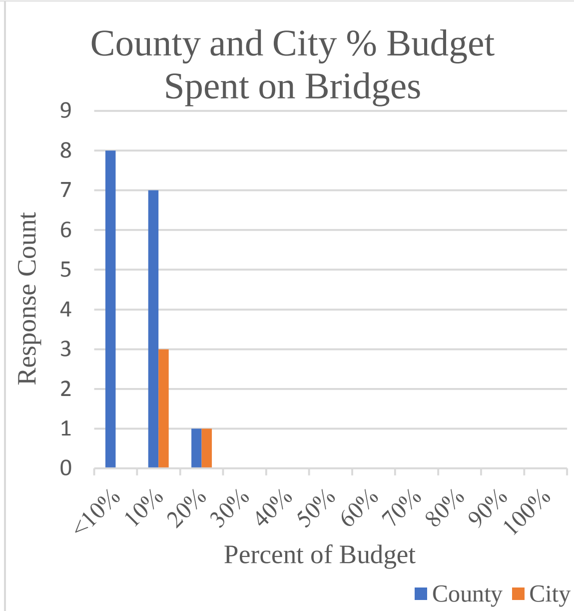
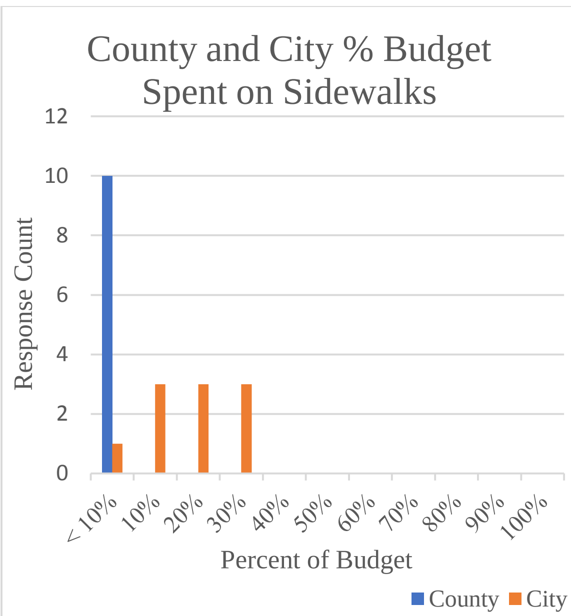


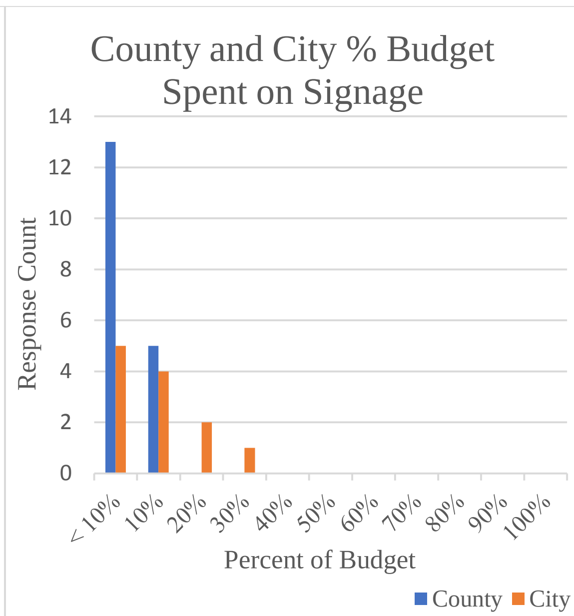
Figure I.23 County and City Percent of Budget Spent on Capital Investments

Similar to the previous question, survey respondents were given another set of assets with sliding scales. The question asks survey participants to indicate the percent of funding allocated for each managed transportation asset. As the previous question stated, the respondent is instructed to ensure that the percentage values sum to 100%. The question gives some asset options, including roadway, bridges, sidewalks, signage, and culverts (Figure I.24). The respondent can write-in additional assets as they need.


County and City % Budget Spent on Roadway Assets
Response Count
0
1
2
3
4
5
6
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Budget
County
City


County and City % Budget Spent on Bridges
Response Count
0
1
2
3
4
5
6
7
8
9
<10%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Budget
County
City


County and City % Budget Spent on Sidewalks
Response Count
0
2
4
6
8
10
12
< 10%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Budget
County
City


County and City % Budget Spent on Signage
Response Count
0
2
4
6
8
10
12
14
< 10%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Budget
County
City

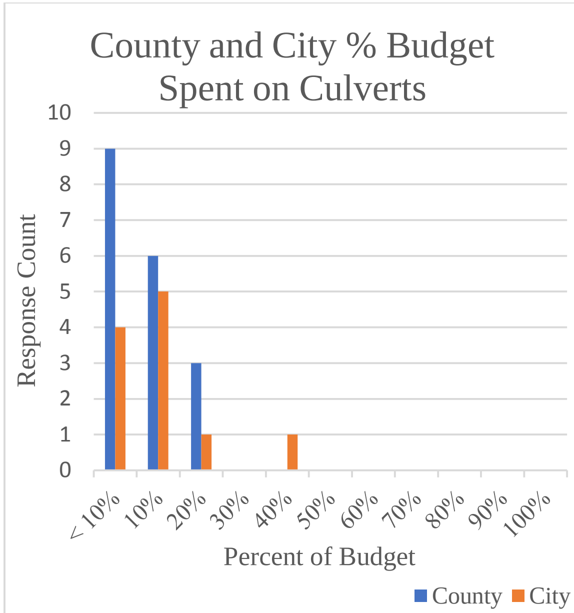


Figure I.24 County and City Percent of Budget Spent on Transportation Assets

The final question in the funding section of the survey asks participants if they have received Local Maintenance and Improvement Grant (LMIG) Funding in the past year. All respondents from county agencies that reached this question indicated that they received some amount of LMIG funding. All but one city agency respondent reported receiving LMIG funding. The question then asks the respondent to indicate the amount of funding and the local agency's cost match Most county and city agencies respondents reported a cost match of 30%, with the exception of two counties reporting 10%, one city reporting 20%, and another city reporting 70%. Figure I.25 below displays the range of LMIG funding awarded to local agencies.

Rating of Current Status

In that section, agencies were asked about their opinion regarding their current practice of the TAM program, how do they rate it, and what factors are impeding its development. Figure I.26 shows the access of agencies to data and support from regional and state agencies such as GDOT and Atlanta Regional Commission.

Figure I.27 below pinpoints the interest of local agencies in some statements regarding actions that could affect positively their TAM practice. Most agencies showed a high interest in increased support from GDOT, more collaboration with neighboring local agencies, more funding, better educational programs, and the concept of sharing the purchase of software and technologies with other local agencies.

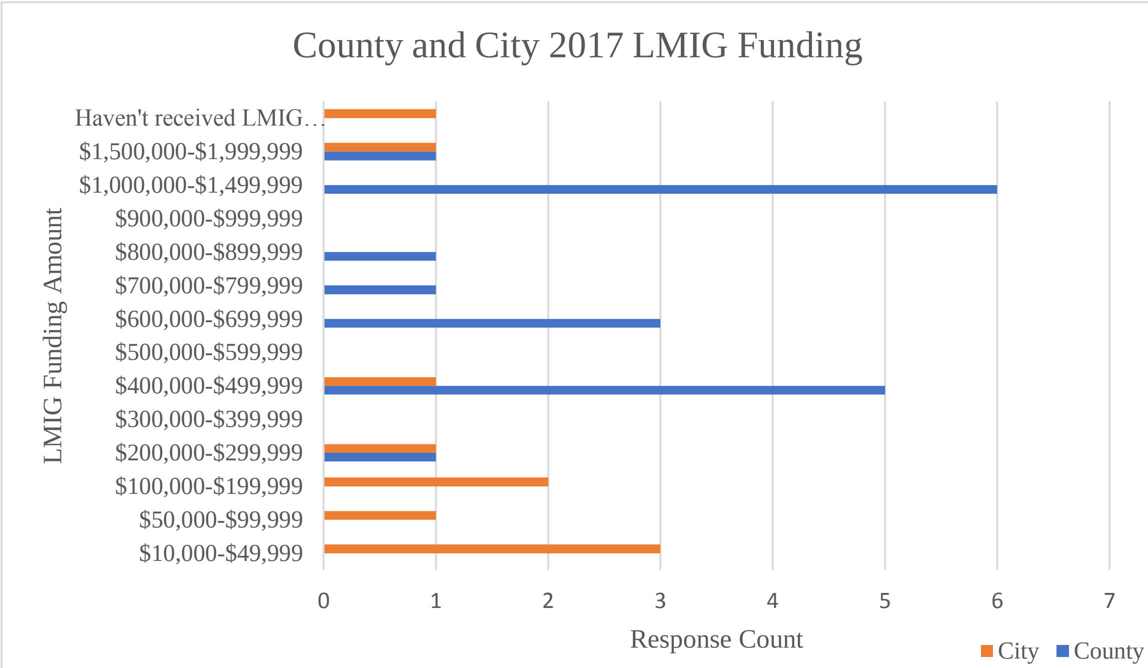


Figure I.25 County and City Access to other Agency Data

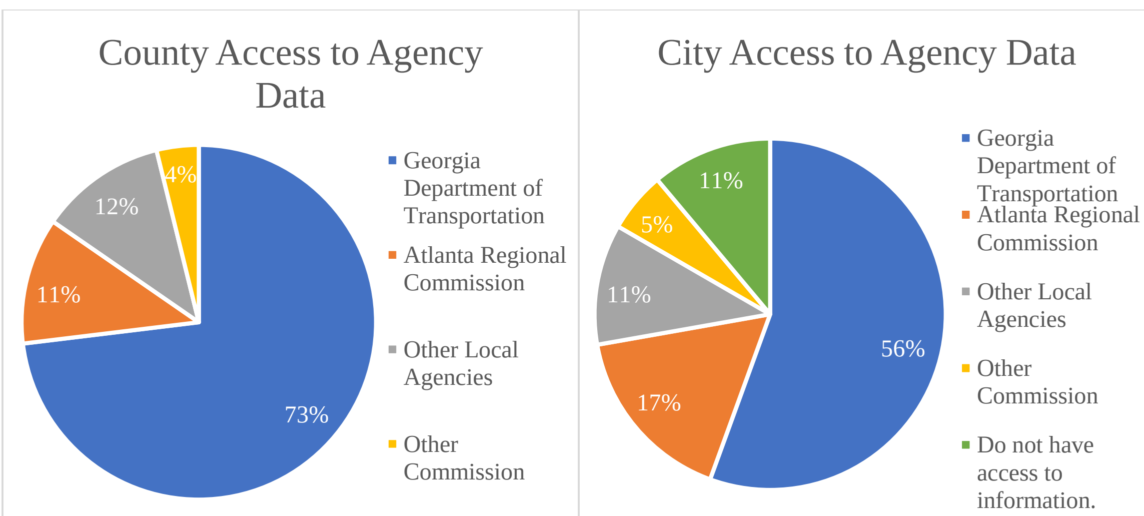
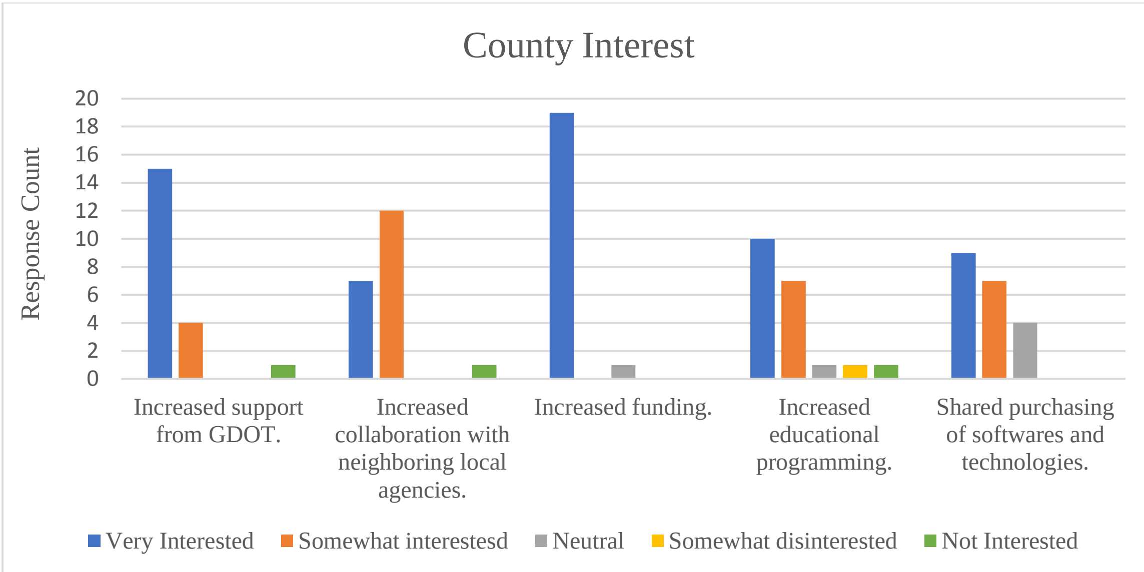


Figure I.26 County and City Access to other Agency Data

As shown in Figure I.28 and Table I.4, most agencies have received some form of aid from Local Technical Assistance Program (LTAP), either in the form of funding or through training programs on equipment, tools, and skills.



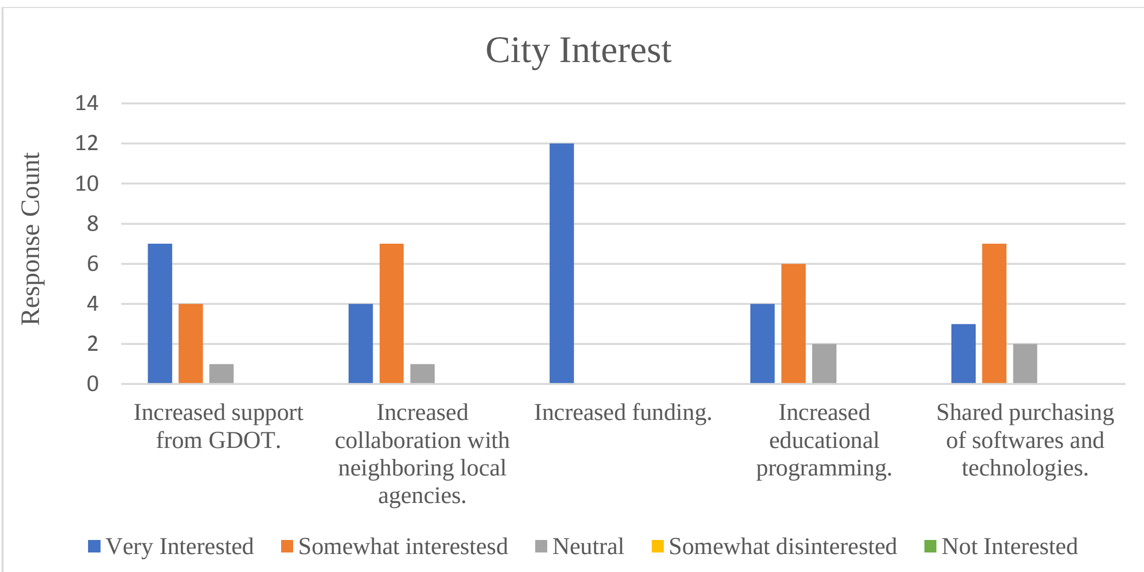


Figure I.27 County and City Interest in Actions affecting TAM

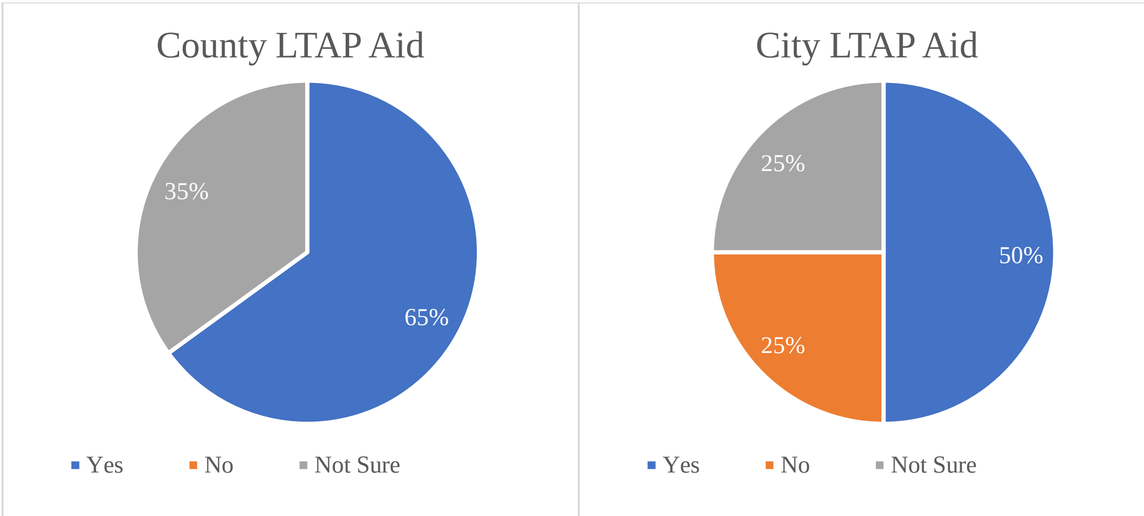


Figure I.28 County and City Aid from Local Technical Assistance Program (LTAP)

Finally, rating their TAM current status on a scale of 5 (best), county agencies gave a score of 2 mostly while cities reported a score of 4 (Figure I.29). When asked about the factors that are hindering the agencies from applying proper TAM practice, the following answers were recorded: lack of funding, lack of education, training, and experience, need of more personnel and more equipment, and no planning, with only few exceptions denying the presence of any factors impeding the TAM good practice.

Table I.4 LTAP Aid examples received by agencies

County Received LTAP Aid
Chain Saw Training and COPACES-CC
Classes
Funding
On-going training in many areas of Public Works
Staff went to classes offered.
Training on Sign Management, COPACES-CC, TMOST, Flagging School, and others
Training seminars
We have received regular training for our transportation workforce from LTAP. I have also received project management training from LTAP.
City Received LTAP Aid
Classroom and online training
classroom training and education
Flagging training; pavement maintenance training
Personnel training
training classes

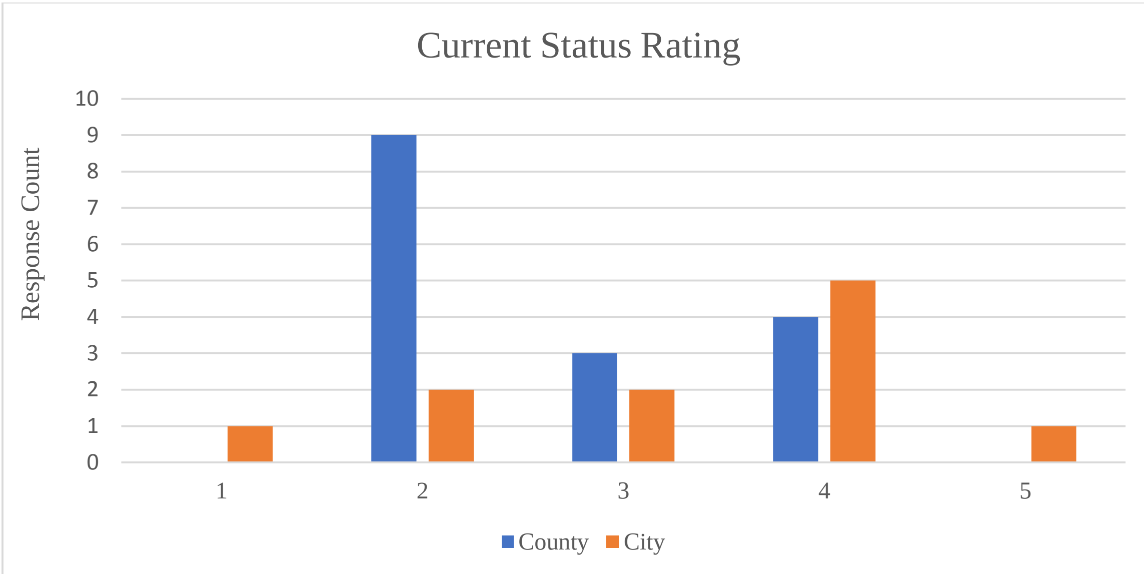


Figure I.29 Current Status Rating from 0 (worst) to 5 (best)

Appendix II: An Asset Management Guideline

A Framework of Transportation Infrastructure Asset Management

A Guided Approach to Transportation Multi-Asset Management for Local Georgia Agencies

Table of Contents

Chapter 1: Introduction

The local governments (LGs) in the United States are managing three-fourths of the total four billion miles of roadway and more than half of nearly 600,000 bridges, which are critical transportation infrastructure assets to support mobility, economy, and homeland security in local communities and the nation. To maintain the aging transportation infrastructure in the state of good repair under the shrinking budget, the state Departments of Transportation (DOTs) have adopted asset management systems (AMSs) to conduct cost-effective maintenance, rehabilitation, and reconstruction (MR&R). However, most LGs in Georgia still rely on individuals' knowledge and experience to manage and make decisions on transportation infrastructure MR&R. The lack of a systematic approach for managing transportation infrastructure assets makes it difficult for LGs to maximize the benefit of scarce transportation budgets and demonstrate accountability to legislatures, the public, and stakeholders. To address the above issues, a Georgia Tech research team (hereinafter, "research team") conducted a statewide online survey to analyze the underlying factors that hinder Georgia's counties and cities from adopting AMSs. Based on this survey, a systematic framework for transportation infrastructure asset management is proposed in this document. The proposed framework extensively considers the LGs' particularity in the organization, workforce, and funding sources. Additionally, the research team investigated similarities between the corresponding state DOTs. Thus, the state DOTs' resources can be wisely leveraged. To implement the asset inventory, condition assessment, and management, the most up-to-date technologies such as 3D sensing, computer vision, crowdsourcing, cloud computing, GIS/GPS, and mobile and web applications are evaluated and incorporated.

1.1 Definition of Asset Management

The American Public Works Association (APWA) defines asset management as,

> "a methodology to efficiently and equitably allocate resources amongst valid and competing goals and objectives."

APWA is an association of all county and city public works officials. In addition to APWA, many other transportation organizations define asset management with slight variations. AASHTO and the FHWA define asset management as,

> "a systematic process of maintaining, upgrading, and operating physical assets cost-effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decision-making. Thus, asset management provides a framework for handling both short- and long-range planning."

The Transportation Research Board (TRB) defines asset management as, "a systematic process for maintaining, upgrading, and operating the physical assets of a transportation system. Asset management employs engineering principles, economic theory, sound business practices, and information systems to determine short and long-term resource allocations" (Midwest Regional University Transportation Center).

These definitions help to establish a standard basis and consistency in the understanding of asset management. Federal, state, and local agencies translate these definitions to best fit the resources and methods in place within their agency. Asset management plans should be tailored to serve the interests, financial plans, investment strategies, and available resources of each government individually.

1.2 General Components in Asset Management

Figure 1 displays an asset management flowchart developed by the FHWA (2007) that serves as a framework and guide to asset management. As shown in Figure 30, the critical components involved in the process of asset management are connected and form a feedback loop system. The following section briefly introduces each component, which will be explored in more depth in subsequent chapters of this report.

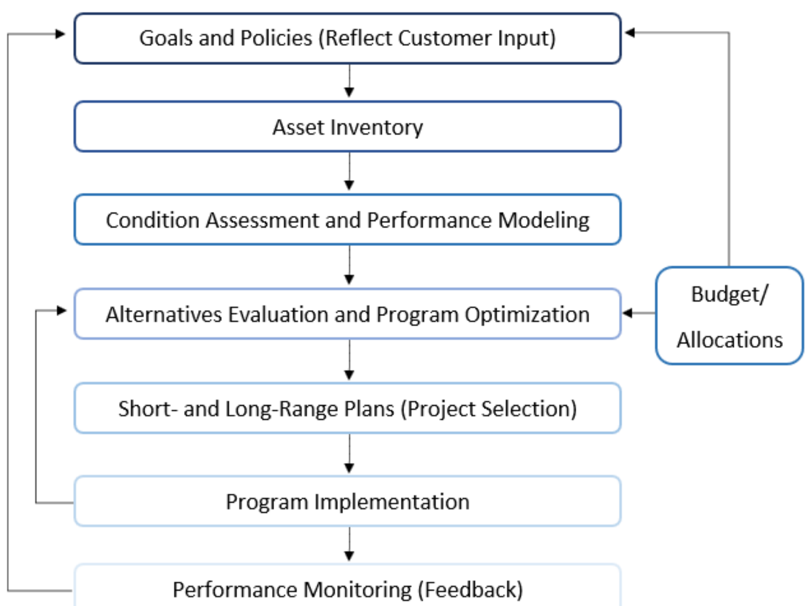


Figure 30 FHWA Transportation Asset Management Framework

The initial step of transportation asset management is to define the goals and policies of the system, which must state the agency's mission and reflect the customers' input and expectations. Agency goals and policies will guide the remaining sections of the TAMP. As the flow chart in Figure 30 depicts, both budget allocations and performance monitoring are factored into goals and policies. Performance monitoring is used as a check to ensure an agency's goals and policies are reflective of an agency's performance. An agency's goals and policies should be updated based on feedback gathered from performance monitoring and/or changes to the agency's budget.

The following step in asset management is asset inventory. APWA defines an asset as, "a physical component of a facility which has value, enables services to be provided, and has an economic life greater than twelve months" (Midwest Regional University Transportation Center, 2015). The FHWA defines transportation infrastructure assets as, "the physical elements, such as pavements, bridges, culverts, signs, pavement markings, and other roadway and roadside features that comprise the whole highway infrastructure network" (FHWA, 2012[a]). Asset type and quantity vary at the federal, state, and local levels, as well as between local governments. Georgia DOT (GDOT) maintains over 18,000 of Georgia's 123,456 miles of roadway and about 6,600 of 14,700 bridges. Local Georgia agencies are responsible for maintaining the remaining 85% of roadways and 55% of bridge assets. An effective inventory includes infrastructure assets by type, condition, location, function, and value. This critical step in the asset management process allows agencies to maintain a cohesive, accurate, and updated log of managed assets. Additionally, it allows agencies to track and monitor the conditions of managed assets.

Condition assessment and performance modeling follow asset inventory. All agencies, regardless of size, must understand the existing conditions of managed assets. The frequency of conducting condition assessments may vary, depending on agency size and budget. The conditions of managed inventory must be properly assessed to determine current performance and forecast future performance. Condition assessments can be conducted manually, semi-automatically, or automatically. There are many tools and programs that may be utilized for condition assessments. Additionally, local agencies must establish performance measures to assess current conditions. Performance measures help agencies effectively communicate their asset conditions, determine financial need, and target cost-effective solutions. Additionally, performance measures improve external communication and internal operations. Performance measures should be feasible, communicable, and measurable. Measuring systems will vary between different types of assets.

Asset inventory, conditions assessment, and performance modeling are used to evaluate different maintenance strategies and evaluate project alternatives. The next step is to plan for the changing conditions of existing assets. The main objective of the decision-making process is to understand the connection between existing conditions and project investment. Agencies strive to maintain a suitable level of service among all managed assets but face budgetary constraints that limit decision-making. Many agencies apply a 'worst first' case scenario to their decision-making process. Instead, mathematical optimization can be used to make more informed and calculated decisions. Performance modeling aids in forecasting future asset conditions, identifying proper maintenance and rehabilitation strategies, and allocating funding appropriately. While taking the available budget into consideration, projects are selected for short- and long-term plans.

Decision-making is followed by project and program implementation. The entire asset management program helps to ensure that projects are implemented and completed on time and on budget. Budgeting is a critical component of TAM and must be closely evaluated before other steps of the process can occur. Financial resources may be available at federal, state, and local levels for transportation asset management. This report will explore funding opportunities for local agencies.

The final step in the FHWA's asset management flow diagram is performance monitoring, which loops back to the first step in the process, goal and policy setting. Performance monitoring ensures a feedback loop that continually improves an agency's TAMP. Performance monitoring includes regular reporting to keep the public and stakeholders engaged in the asset management process. Additionally, performance monitoring ensures accountability and communication within agencies. Regular meetings and discussion-based workshops encourage collaboration during the performance monitoring stage.

The successes at the federal and state levels have led to an increased interest in local agencies pursuing similar methods of asset management. Early local agencies that adopted asset management plans have shown an increase in infrastructure maintenance and conditions, as well as increased funding (Bernardin and Durango-Cohen, 2006). However, many documents and guides related to TAM are targeted toward state agencies. Federal legislation requires state agencies to report spending, decision-making, and project construction for transportation assets in the form of an asset management plan. Guides and framework plans accompany these legislatures, providing state agencies with the tools and guidance necessary to conduct TAM. Local agencies often lack framework plans and guidance on TAM processes. Local agencies vary from federal and state agencies in terms of resources, budget allocations, number and types of assets managed. This framework guide is intended to guide local Georgia agencies through the process of creating, implementing, and maintaining an effective and customized TAMP.

1.3 Use of This Framework Document

This framework plan incorporates elements of the FHWA's asset management framework plan as well as information collected from a survey that was administered to Georgia's county and city agencies. The survey was administered online and was completed by over twenty cities and counties within the state of Georgia. The survey contained thirty-five questions that asked agencies about their current asset management practices. The survey contained sections on general information, condition assessment and data management, performance measures and decision-making, funding, and rating of status. The information gathered from the survey was used to develop a customized transportation infrastructure asset management framework for Georgia's agencies at the local level. Survey insights are displayed within each section of this document to highlight important findings from the study. The sections in this framework explore each of these core principles and apply them to Georgia's local agencies.

This guide includes eight chapters, including organization, policies and plans, asset inventory and condition assessment, data management, performance measures, decision-making and risk assessment, funding and budgeting, and reporting. It is intended for use by Georgia's local agencies who are interested in implementing a TAM program or maintaining and/or improving an existing TAM program at both the city and county levels. The following guidelines can be adapted to fit agencies in all regions of Georgia, regardless of geographical size, population, or experience with TAM processes. Agencies are encouraged to read through the entire document but should not feel required to implement all section objectives. Agencies should use discretion to implement what is feasible with current tools, resources, and capabilities. The guide is intended to be revisited as agencies are ready to implement more advanced TAM practices. A list of additional links, readings, and resources are listed at the end of each section for reference.

Chapter 2: Organization

Objectives Checklist:

- ☐ Identify the current organization and resources available within your agency
- ☐ Establish a steering committee or asset management champion
- ☐ Establish clear roles and responsibilities for agency departments/divisions
- ☐ Create a schedule for educational workshops, regular meetings, and information sessions

Georgia has 159 counties that vary in geographical size, population, and the number of managed assets. Therefore, there is no one size fits all approach to asset management. The organizational structure of an agency's asset management program is essential for the success and efficiency of a TAMP. Organizational structures of asset management programs vary between federal, state, and local agencies. Georgia's Department of Transportation (GDOT) has a TAM Steering Committee that leads its asset management program. The steering committee helps to build consensus and improve communication between the agency's divisions. The number of employees and divisions within local agencies is significantly less than state agencies, therefore resulting in a different organizational structure. However, it is still critical to employ a structured asset management system with clearly defined roles and tasks. Widespread understanding and agreement are critical to the success of a TAMP. If your agency is new to the idea of asset management, an internal workshop can help with visioning within the agency. GDOT has a Local Technical Assistance Program (LTAP) that can provide assistance in developing an asset management program. LTAP provides technical assistance to rural and local governments, including workshops and educational seminars. Many local agencies already take advantage of this assistance to conduct on-going training, classroom sessions, and seminars. Additionally, the National Highway Institute (NHI) has training courses that demonstrate asset management principles and techniques to agency managers to enable them to begin the process within their own agencies. Resources for training information can be found at the end of this section.

Survey Insights:
Local Technical Assistance Program (LTAP)

65% of County agencies and 50% of City agencies reported receiving aid from LTAP.

Smaller agencies may have fewer resources and therefore more integration between departments. It is common that smaller agencies share roles and responsibilities between departments. Steering committees may not be feasible for smaller agencies with already stretched job roles. Instead, it may be best to clearly redefine roles for employees that more explicitly integrate the practice of TAM. In this case, a leader should be selected who will spend the majority of his or her time implementing the TAMP and guide others. This individual should be a senior leader or manager involved in defining the agency's strategy, goals, and priorities. TAM leaders may have the title of chief executive officer, Deputy Secretary, Director of Public Works, etc. The leader should partake in training courses and be well-informed on the practice of TAM before introducing the program to his or her agency. Although the program will be led by an individual, it is critical to educate the entire agency on the major principles of TAM. TAM is not a single-division practice. Asset management practices should involve a variety of departments or divisions within an agency. As the TAMP grows and becomes more complex, the champion may opt to diversify and expand to a TAM committee. Smaller agencies may create part- or full-time positions to work on TAM.

Department Involvement in TAM: Survey results showed that many agencies were involved in local agency asset management practice. Public works was reported as the most commonly involved agency department, with other involved departments ranked by frequency below:

1. Public Works
2. Engineering
3. GIS
4. Planning
5. Finance
6. Road Department

Larger agencies are encouraged to establish TAM steering committees. Organizational culture has proven to be one of the largest obstacles in establishing an asset management program (Wittwer, et al., 2003). Larger agencies with multiple divisions may have trouble reaching consensus when creating new system processes. Steering committees can improve communication and build consensus within agencies. Steering committees should consist of mostly senior managers from each agency department or division. These individuals can serve as liaisons between their departments and the TAM steering committee. The steering committee will serve to ensure that the program is working together as a unit. Larger agencies may also benefit from selecting an asset management champion to lead and guide the steering committee. TAM requires comprehensive coordination and communication among the agency's employees working under different units, therefore it is critical to get all agencies involved and understanding the importance of the TAM. Additionally, steering committees are responsible for educating the public and stakeholders on the agency's mission, vision, goals, performance measures, strategies, and progress. Agencies should focus on creating a management position or TAM office that acts as a focal point for guiding the asset management program, where information is filtered and analyzed to be directed for decision makers (Transportation Research Board, 2008). Figure 31 depicts an example of a steering committee's organizational structure. The steering committee is composed of several division managers and a TAM champion. The division managers represent each of the agency's departments/divisions. This cross-disciplinary support helps to build consensus within the agency and can reduce duplicated efforts and inefficiencies.

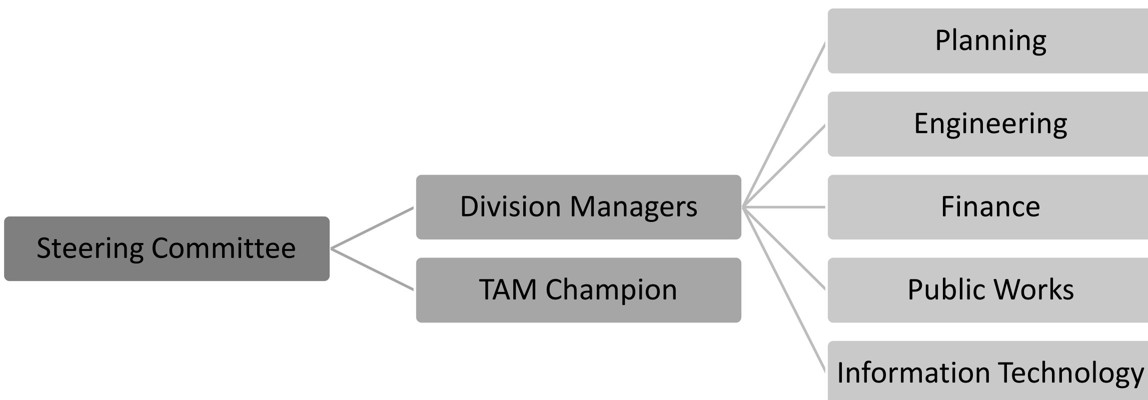
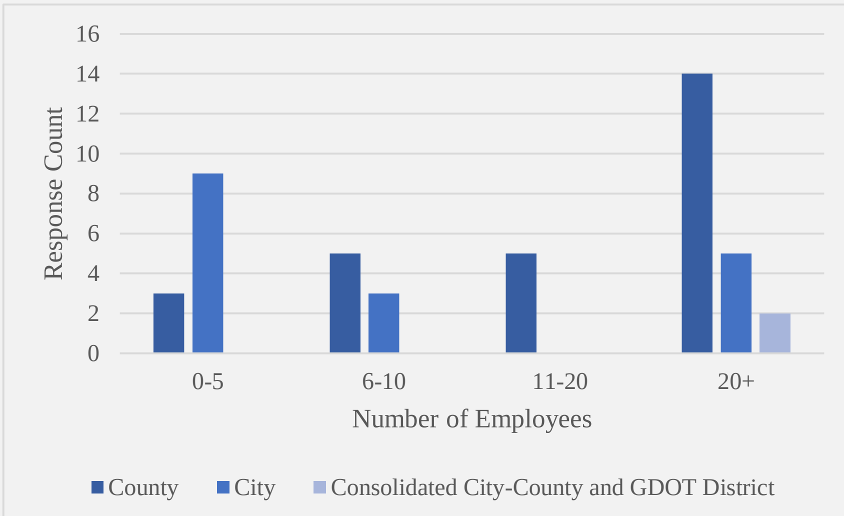


Figure 31 TAM Organization Chart

The number of part- or full-time employees working on TAM will depend on the resources available within the agency. Smaller agencies may opt to combine roles and employ one or two individuals to work on TAM part-time. Whereas larger agencies who opt to develop steering committees may also employ several part-time or full-time employees as resources allow. The agency should establish workload requirements, responsibilities, and actionable items for each TAM employee to promote accountability and reporting. Educational sessions and workshops can be helpful when establishing a TAM workforce. Additionally, regular meetings are essential in maintaining the success of a TAMP.

Part-Time and Full-Time Employment: Survey responses from city and county agencies varied greatly in size. The smallest responding city agency has a population of 500, and the largest has 73,800. The population of the smallest responding county is 6,800 and the largest is 1,020,000. The graph below shows responses to the question, "How many employees are involved in managing transportation infrastructure assets?"



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Additional Links and Resources:

- GDOT LTAP Resources
  - Register for classes, view schedule, and learn more: http://www.dot.ga.gov/PS/Local/LTAP
- FHWA Training Resources
  - https://www.fhwa.dot.gov/asset/training.cfm

Chapter 3: Policies and Plans

Objectives Checklist:

- ☐ Understand existing asset management practices within your agency
- ☐ Conduct asset management self-assessment
- ☐ Understand TAM mandates: GASB Statement 34
- ☐ Define the scope of your TAMP
- ☐ Build consensus and support within your agency

3.1 Self-Assessment

Many agencies practice elements of a TAMP, but lack formalized TAM processes. Therefore, agencies are encouraged to conduct asset management self-assessment. The self-assessment will aid in understanding an agency's current decision-making processes and identifying strengths and weaknesses in existing processes. An analysis can lead an agency to identify opportunities for improvement and can guide an action plan for setting and achieving agency goals. The results from the self-assessment can be used to clearly define the scope of a TAMP. During the assessment, the agency can determine which assets should be included in the TAMP, the types of investments (preservation, capital, operational), and common principles and approaches. Table 5 displays AASHTO's descriptions for levels of TAM Maturity. This table can begin to help guide local agencies in understanding their current level of TAM and identify the next steps in the process. The table displays five levels of maturity. This table is intended to be used in conjunction with the AASHTO Self-Assessment tool.

The recommended self-assessment was created by AASHTO and is available for download in Microsoft Excel format. There are links to access this self-assessment tool and its user guide at the end of this chapter. The self-assessment tool provides agencies with a structured set of questions that determine the agency's current level of organization, need, resources, and consensus. The tool aims to help agencies organize planning processes and build a consensus within the agency about strengths, weaknesses, and opportunities. The information can then be used to structure a plan for change and improvement within the agency. The agency's responses to the self-assessment tool will guide the next steps in the TAM process. The tool will help agencies identify useful processes, tools, and approaches to pursue.

Table 5 AASHTO Description of TAM Maturity Levels (AASHTO, 2013)

TAM Maturity	Generalized Description
Initial	No effective support from strategy, processes, or tools. There can be a lack of motivation to improve.
Awakening	Recognition of a need and basic data collection. There is often a reliance on the heroic effort of individuals.
Structured	Shared understanding, motivation, and coordination. Development of processes and tools.
Proficient	Expectations and accountability drawn from asset management strategy, processes, and tools.
Best Practice	Asset management strategies, processes, and tools are routinely evaluated and improved.

Following the self-assessment tool, an agency must define an appropriate TAM practice. The agency must consider its current practice, strategic goals, legislative requirements, public and stakeholder expectations, managed assets, available resources, and budget. Organizational goals, policies, and budgets should be used to evaluate the asset management framework. Policies are broad, non-engineering, non-economic factors that reflect the transportation agency's values, perceptions, and tendencies. Goals can be established based on users' priorities, values, and standards in measurable terms, such as ride smoothness, level of service, travel time, mobility, and accessibility. Performance targets are a way to convey to the public how assets are being managed in a logical and fact-based approach, since asset management is a customer-focused and goal-driven management and decision-making process (FHWA, 2007).

After studying the different elements in TAM, action plans should be formed to identify objectives and formulate tasks. Identified tasks should have a defined time frame that takes factors into consideration, such as the overall priority of each task and the logical sequence of the tasks. AASHTO defines several key components to consider when initiating change within an agency:

1. Communicate the need for and benefit of change
2. Establish a guiding team – TAM Champion or TAM Steering Committee
3. Develop a vision of change and strategies to achieve that vision

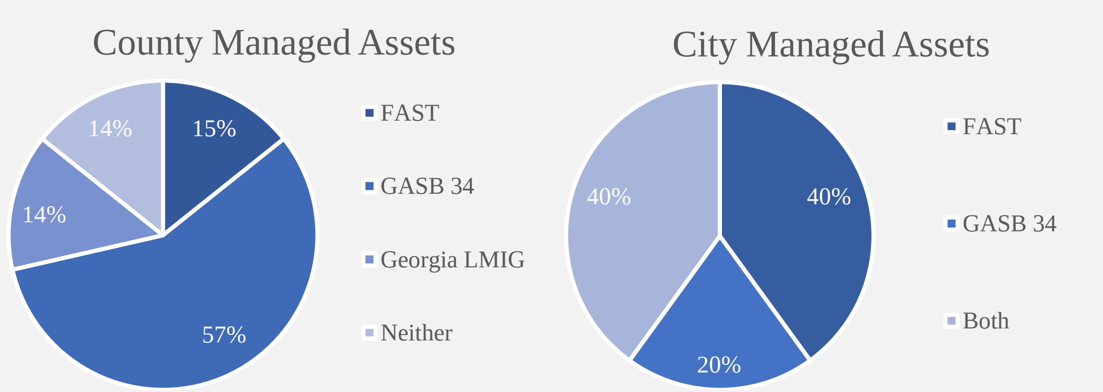
4. Involve employees in the process, assign roles, and delegate tasks
5. Maintain progress and hold regular meetings to update staff on successes
6. Implement a feedback loop to improve the system

3.2 TAM Legislation

In addition to establishing a self-determined TAMP, there are many policies and standards established by the FHWA. State agencies are legally bound to abide by legislature set by federal agencies. For example, GDOT is responsible for reporting to the federal government on the existing conditions of federally owned roads, bridges, and other transportation infrastructure. Additionally, federal- and state-owned transportation infrastructure must be documented and tracked for reporting purposes. However, standards established by the National Highway System (NHS) and guidelines recommended by the FAST Act address only 25% of the nation's roadways. GDOT manages and maintains over 18,000 of Georgia's 123,456 miles of roadway and 6,600 of 14,700 bridges. The remaining 85% of roadways and 55% of bridges are maintained by local governments (Georgia Department of Transportation, 2014).

The Governmental Accounting Standards Board (GASB) Statement 34 establishes financial reporting requirements for state and local governments, including states, cities, towns, villages, and special-purpose governments such as school districts and public utilities (GASB Statement 34 Summary, 1999). GASB Statement 34 requires agencies to report the value and condition of transportation capital assets in accordance with stated standards. GASB Statement 34 has been in effect as early as June 1999. Smaller agencies, such as towns and school districts, are required to complete basic financial statements as listed in GASB Statement 34 Appendix C.

Federal TAM Legislation: The charts below show county and city responses to the survey question, "What state or federal laws or initiatives impact your agency's transportation asset management practices?"



Agencies should develop a complete and comprehensive TAMP that includes a summary of the agency's policy goals, objectives, financial targets, and performance targets. The FHWA states that agencies must, "examine exactly where they are, what information they have available, and where they want to go before determining an approach to implementing asset management" (FHWA 2017). The guide should include detailed instructions for financial, accounting, and administrative tasks to adhere to in future decision-making processes. Local agencies in Georgia can modify GDOT's strategic goals and adapt them to best fit local goals and performance targets. Additionally, local agencies are encouraged to partner with neighboring or other similar local agencies to discuss transportation needs and priorities and identify where interests overlap. After identifying policies and goals for the TAMP, it is important to establish quantifiable performance measures that support agency goals. Agency goals and initiatives should be updated regularly to reflect changes in policy, technology, and emerging issues. AASHTO developed a TAMP outline that is useful to help guide the development of a new local agency TAMP. Agencies may choose to modify AASHTO's suggest outline below:

I. Executive Summary & Introduction
    a. Overview of the agency's mission, goals, and purpose of creating a TAMP
    b. Description of assets (value, quantity, conditions, age, life-span)
II. Levels of Service
    a. Description of agency's mission and priorities
    b. Identify relevant stakeholders and key user groups
    c. Identify laws and regulations that impose mandates and regulatory constraints on the agency (GASB Statement 34)
    d. Description of the agency's current and desired capabilities
III. Life-Cycle Management
    a. Information about the agency's assets (conditions, performance, life cycles, remaining life, etc.)
    b. Life-cycle strategies and management methods for asset-based activities
        i. Operations, maintenance, renewals, condition and performance monitoring, risk management, procurement, project delivery
    c. Overview of current and desired capabilities in asset management
IV. Growth and Demand
    a. Assess current and future growth and demand for transportation services
V. Financial Summary
    a. Summarize program needs and assign to short, medium, and long-term plans

   b. Projected asset valuation and depreciation
   c. Overview of funding sources, funding constraints, and other aspects of budgeting and funding processes

VI. TAM Practices
   a. Summary of self-evaluation and current organizational processes
   b. Description of tools and systems used to support TAM
   c. Description of data needs and quality expectations

VII. Improvement Plan
   a. Report of performance measures and feedback loop
   b. Description of risk factors and anticipated obstacles

Asset management can be implemented and accomplished in stages. Agencies must determine what is feasible given existing budgets and resources. Establishing short, medium, and long-term goals can help keep attainable objectives. Common goals from county and city survey responses include maintaining 50%, 80%, 90%, or 100% of our road system at a fair or better condition. Other agencies have less quantifiable goals, such as, "Build out infrastructure that was previously ignored by the county. This includes paving streets, installing streetscapes and sidewalks, bike paths, and lighting."

Additional Links and Resources:

- AASHTO Gap Analysis Microsoft Excel Tool and User Guide
  - https://www.tam-portal.com/resource/aashto-transportation-asset-management-gap-analysis-tool-users-guide/
- GASB Statement 34
  - http://www.gasb.org/st/summary/gstsm34.html
- FAST Act
  - https://www.fhwa.dot.gov/fastact/summary.cfm
- GDOT 2018-2021 Strategic Plan
  - http://www.dot.ga.gov/PartnerSmart/Public/Documents/publications/StrategicPlan/StrategicPlan-FY2018-2021.pdf
- GDOT 2014-2018 Transportation Asset Management Plan
  - http://www.dot.ga.gov/BuildSmart/Programs/Documents/AssetMgmt/TAMPlan.pdf

Chapter 4: Asset Inventory and Condition Assessment

Objectives Checklist:

- ☐ Define a solid transportation assets' inventory record
- ☐ Highlight the importance of a data collection plan
- ☐ Define proper condition assessment practice
- ☐ Show condition assessment rating systems, methods, and tools
- ☐ Highlight assets' rating protocol selection strategy and the best practice for condition assessment

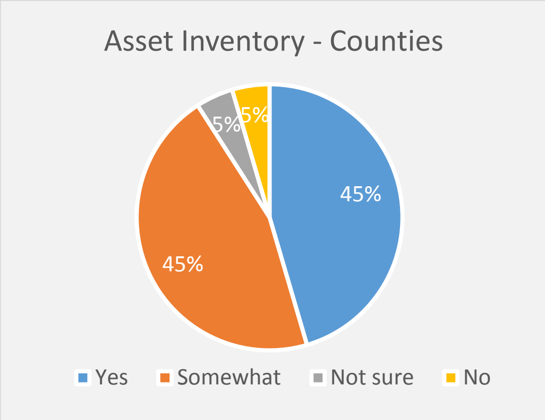
4.1 Overview

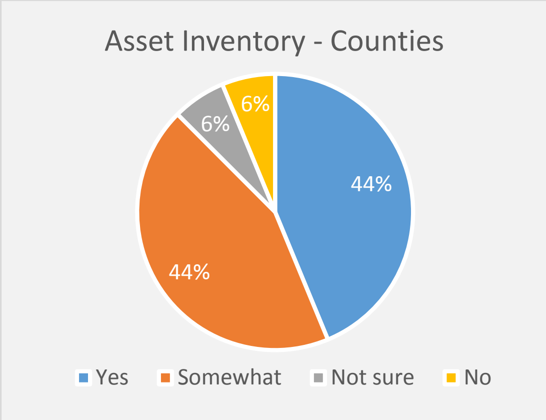
A solid asset inventory acts as the cornerstone for a successful transportation asset management program as it compiles all the infrastructure assets under the jurisdiction of a certain agency in a well-established, up-to-date, accurate, and accessible record (FHWA, 2007). These assets are tied to relevant spatial and physical characteristics such as the location, quantity, type, size, function, AADT, age, replacement cost, maintenance history, etc. The effort put to collect attributes for the surveyed assets, its accuracy especially for the critical assets, and completeness characterizes the inventory as either basic, intermediate, or advanced (Smith, 2013). The more attribute data is collected for the assets surveyed, the more supported the agency's decisions will be. However, agencies should plan ahead their data collection to take into consideration their available resources and should avoid collecting data that is not used in the decision-making at later stages. Therefore, a routinely-revised data collection plan is crucial for a complete and accurate asset inventory record. In addition to assets' basic identification characteristics, condition assessment data should also be added to the agency's records and updated continuously according to a certain rating system. This condition assessment should be performed consistently to characterize the current status of the managed assets in order to predict their future conditions and to find the most cost-effective and beneficial MR&R decisions based on the data collected (FHWA, 2013[b]).

Therefore, the plan should clearly define what data needs to be collected, what methods will be used, and how often will the information be updated. As data requires time, effort, and money to collect, store, retrieve and use, a decision should be made to indicate what data is actually required to enable the agency to manage its assets. This is a key point since it leads to a long-term commitment by the agency, knowing that this data needs to remain current and valid by performing continuous updating. Therefore, agencies should try to minimize their planned data collection by setting realistic and sustainable goals, without affecting the quality of their decision-making process. Pilot studies are very useful for that purpose as a way to test the data collection scope, effort, and cost in order to evaluate and modify the plan accordingly. (World Bank, 2007)

The frequency of conducting a condition assessment varies between agencies based on the available funding and resources (Cambridge Systematics, Inc., 2006). The survey is usually done either using in-house resources, subcontractors, public input, or a combination of more than one methodology. Several tools and methods are currently being used among state and local agencies for data collection while noting a remarkable technological evolution whose goal is to collect large volumes of asset condition data quickly and efficiently. The following sections discuss the condition assessment rating systems and tools and methods used for the survey of different types of assets.

Asset Inventory: Most counties and cities confirmed having a well-established asset inventory, or at least some form of it. However, 50% of both counties and cities were not confident ('Somewhat', 'Not Sure') of the inventory data collection practices at their agencies.





4.2 Condition Assessment Rating System

Choosing an asset rating system or protocol is a critical step in the condition assessment process as it defines the asset's deterioration characteristics and distresses according to a certain scale of extent and severity levels. It is a scoring system that calculates the rating of the overall condition of an asset according to well-defined criteria, thus leading to information-based decision making at later stages of the asset management program. Many rating systems exist for different types of assets, some of which are adopted by different state and local agencies on the national level, and others that were set by certain states to fit their own resources, strategies, and assets' requirements.

As for the pavement, the most popular rating systems on the national level include ‘Pavement Condition Index (PCI), ‘Pavement Surface Evaluation and Rating (PASER)’ and the Present Serviceability Rating (PSR). PCI, which was developed by U.S. Army Corps of Engineers and recently standardized by in ASTM (D5340, Standard Test Method for Airport Pavement Condition Index Surveys), involves a specific computation process that rates the pavement with PCI values ranging from 0 to 100, representing failed and excellent pavement condition, based on observations in the severity and extent of 19 types of pavement distresses (ASTM, 2018). Although this system helps determine maintenance activities needed by the pavement surveyed; however, it is complex and requires extensive data collection. PASER, on the other hand, allows transportation agencies to understand and rate the pavement surface conditions in their jurisdiction, from one to ten, with one being the worst and ten being the best, through a visual inspection of the road. PASER Manual, which was developed by University of Wisconsin-Madison Transportation Information Center, highlights key distresses in pavements when conducting visual inspections; these include: block cracking, drainage issues, edge cracking, fatigue cracking, longitudinal cracking, roughness, rutting, transverse cracking, and utility cuts/potholes. This rating proved to be beneficial for local agencies due to their cost-effectiveness, ease of use, and minimal workforce requirements for data collection. The manual has also developed a score computation sheet with recommended maintenance strategies based on the rating score, whereas PCI is based on both the overall rating and specific distresses, which makes it more accurate (Fitzpatrick, 2016). PSR originated from the AASHTO Road Test in which raters in a moving vehicle determined pavement condition values based on the ride quality. Statistical relationships and correlations were then developed between the panel ratings and pavement distresses such as cracking, rutting, and roughness to determine Present Serviceability Index (PSI). Ranging from 0 to 5, for very poor to excellent condition respectively, it is calculated based on slope variance, mean rut depth, cracking, and patching (Fitzpatrick, 2016). Georgia Department of Transportation issued the Pavement Condition Evaluation System (PACES) in 1970 thus becoming a common ‘language’ among its pavement engineers. GDOT has accumulated about 30 years of well-documented data for its pavement network based on 10 types of distresses, some of which are used along with the rating score to select the proper treatment strategy (GDOT,2005). Software applications adopting the above rating systems have been developed to facilitate the management of the assets such as ‘Micro Paver’(PCI), ‘Street Saver’ (PCI),’ RoadSoft GIS’ (PASER), and ‘COPACES’ (PACES).

Concerning the bridges, the most adopted rating system for bridges is AASHTO National Bridge Inventory (NBI) General Conditions rating, where the bridge condition is determined as the lowest of the condition ratings of its elements (Deck, Superstructure, Substructure, Culvert). If the lowest rating is greater than or equal to 7, the bridge is classified as good; if it is less than or equal to 4, the classification is poor. (FHWA, 1995)

Other transportation assets also have specific rating protocols while some agencies adopt the remaining service life (RSL) system for assessing the condition of these assets by representing the expected number of years of operation based on the asset's life (the period between construction/installation to first maintenance) before maintenance or rehabilitation is required. Road signs, traffic signals, pavement markings, and other similar traffic control assets are usually managed according to Manual on Uniform Traffic Control Devices (MUTCD).

When it comes to choosing a rating system that the agency should follow when assessing their assets, several considerations should be taken into account. First of all, if the agency has adopted a certain protocol for a long period of time during which it has accumulated sufficient history of condition data, then it is logical to continue using that system as the data available is valuable when building the asset's deterioration models. The agency should also evaluate its resource capabilities as some rating systems require a certain level of accuracy that can only be obtained through the use of specific tools and equipment, whose costs should be assessed. Some rating systems may also require expert staff that may not be available at the agency. In that context also, agencies should try to aim to adopt systems that are used by their state's and nearby local agencies, as this will allow the possibility for staff transfer, especially those who retire from state agencies with high accumulated expertise. In addition to the benefit accrued from the assistance programs provided by state agencies which may help the local agencies in both training and resources, adopting systems similar to the neighboring agencies might pay-off sometime in the future if a merger takes place at the county/city level or even at the state level.

For instance, in the case of Georgia State county and city agencies, it would be wise to adopt for their pavement management the Computerized Pavement Condition Evaluation System (COPACES) as this rating system is adopted by GDOT and incorporates the most up-to-date cloud computing and mobile technologies that may be accessible by local agencies through the help of GDOT. And for that purpose, a study has been developed by Georgia Institute of Technology under the title "COPACES for Georgia's Cities and Counties (COPACES-CC)" to ease the transfer of GDOT experience and knowledge to the local government. Therefore, due to GDOT's success and experience using that system, the availability of trained staff that may be hired by the local agencies, the ease of communication when using the same rating system, and the assistance programs provided by the state agency such as Local Technical Assistance Program (LTAP) and Local Maintenance and Improvement Grant (LMIG) Program, local agencies within Georgia State should tend to adopt the COPACES rating protocol for assessing the condition of their pavement.

4.3 Condition Assessment Tools and Methods

Pavements

The methods for pavements condition assessment are listed in the order from the most basic to the most advanced (technologically):

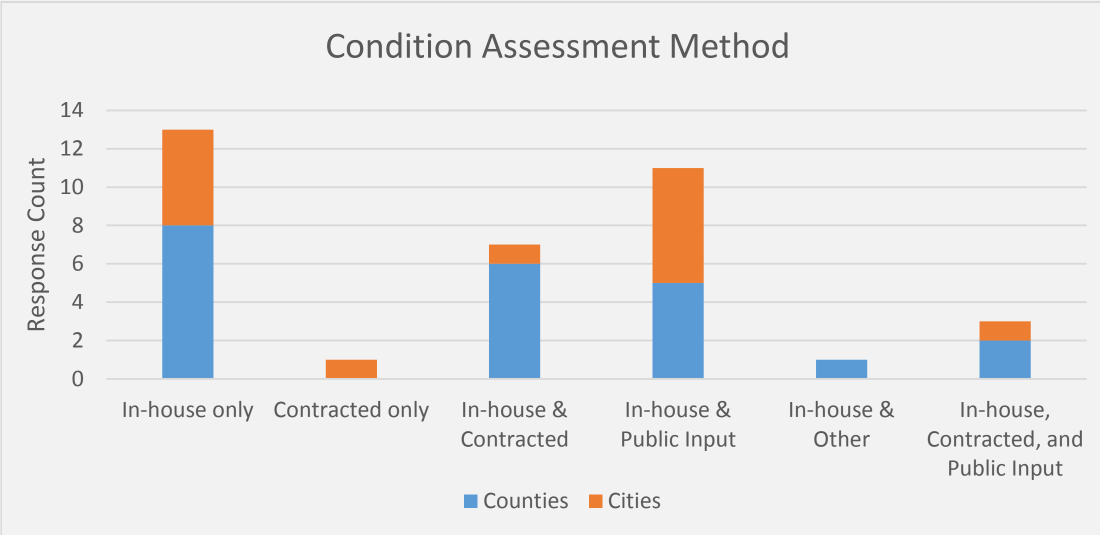
- Manual surveys which employ two or more trained staff collecting data and documenting it with a pen and a paper, or in most recent cases with handheld computers equipped with GPS. Distresses are either noted by the staff walking on foot and examining the assets carefully, or through their vehicle's windshield while driving. Although this method allows for detailed yet biased data collection, it is labor demanding and requires more time than other advanced methods (FHWA, 2013[b]). COPACES protocol entails adopting a manual inspection of the pavement assets where a tablet-based mobile application is used by a field engineer to collect pavement conditions in the field and store it within a cloud database along with data history, which can be retrieved using a developed web application.
  Pic manual
- Automated collection involves the use of a multipurpose vehicle equipped with advanced camera, laser, and computer equipment that captures at highway speeds digital images for the transverse and longitudinal road surface profiles. The automated method can be categorized into 2 branches based on the method employed for data processing:
  - Semi-automated process involves trained personnel evaluating the images captured by the vehicles and identifying visible distresses (ex: cracks). In that case, software is only used to display the images, record the distresses, and to process the sensor data used for determining rut depth, IRI, and faulting.
  - Fully-automated process uses the pattern recognition technology adopted in specially designed software to automatically detect distresses without any human interference. Some systems can process the data in real time at highway speeds while others adopt post-processing to detect the distresses as a separate stage. Note that this method also processes sensor data in a similar fashion as the semi-automated method. (FHWA, 2013[b])

Many companies and institutions are developing these multipurpose vehicles for the automatic pavement data collection for commercial purposes such as 'FUGRO' and 'Pathway Services', and for research purposes such as Georgia Institute of Technology (Figure 32).

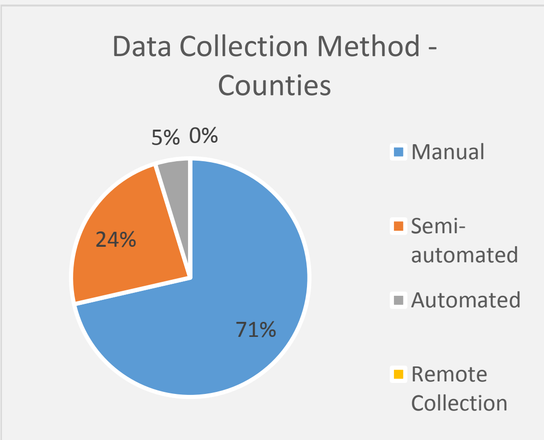
Figure 32 Georgia Tech Sensing Vehicle (GTSV)

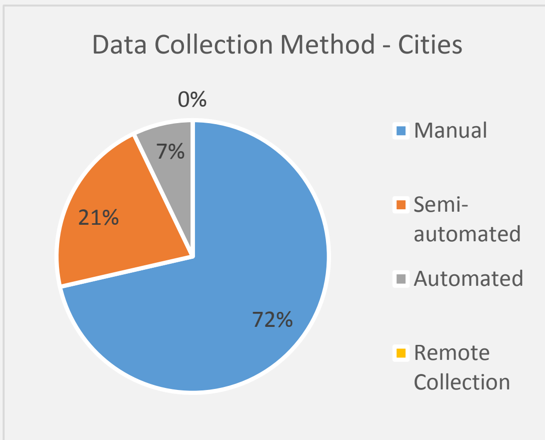
- Remote collection is the most advanced method as it uses satellite imagery and remote sensing applications to acquire high-resolution images. These images are then used in conjunction with ground information for the transportation assets' location referencing and condition assessment by capturing many of their attributes and characteristics. (Pantelias, 2005)

Data Collection Methods: Most of the agencies use in-house efforts for that purpose with some using a mix of in-house, contracting, and public input and other methods (ex: GDOT bridges assessment).



Concerning the method used by transportation agencies for data collection, manual method is still the most used by the local agencies, with only few using semi-automated and full automated methods. Remote collection is not adopted by any of the surveyed local agencies, which could be explained by its high technological and financial demands.





Bridges

Concerning the methods used for bridge inspection, it can only rely on the visual evaluation of professional and experienced staff, or it can use several tools and technologies which provide a more accurate assessment. Below are some of the most adopted methods by state and local agencies: (Omar, T. & Nehdi, M., 2016)

- Visual inspection (Figure 33) is conducted according to certain guidelines and standards, mainly using the 'National Bridge Inspection Standards (NBIS)'. Bridge inspection software has been developed with an interactive interface that retrieves guidelines, saves a history backup of previously collected data, and records new bridge inspection data on the component-level. Although visual inspection entails a subjective and qualitative evaluation, it is still used as a major aid for bridge condition assessment by many agencies. New technologies are incorporating special drones in the inspection of bridges as an easier and safer way to assess the condition of the bridges (Figure 34), especially those whose location and physical characteristics act as obstacles for a proper condition assessment.

Figure 33 Bridge Manual Inspection through Crane (*Source: Agile Assets*)

Figure 34 Bridge Manual Inspection Using Drone (*Source: www.roadsbridges.com*)

- Load testing response method involves loading the bridge with static or dynamic loads and recording the bridge's critical components' responses using strain transducers. As a result, bridge load ratings are determined using one of several models that should account for external conditions such as ambient temperature, wind speed/direction, and wave heights.

- Non-Destructive evaluation (NDE) methods provide objective and accurate surveys that detect bridges' deterioration behavior at an early stage and tracks its development, if performed periodically. These methods are usually employed after detecting irregularities through visual inspection. The NDE tools can either test one physical aspect of the bridge and are referred to as single-application NDE, or can use a single system utilizing multiple NDE technologies (also known as hybrid NDE), thus allowing it to determine various deterioration incidents with a single assessment. (Figure 35)

Figure 35 Bridge Non-Destructive Evaluation (NDE) (*Source: Smart Sensys*)

- Structural Health Monitoring (SHM) technique incorporates sensor and instrumentation installations embedded on a bridge's structural components for either a short-term or a long-term assessment, in order to evaluate its structural performance and to detect signs of deterioration.

Road Signs

The main concern for road signs' condition is maintaining a minimum retro-reflectivity or illumination. The Manual on Uniform Traffic Control Devices (MUTCD) issued by the FHWA in 2009 presents 2 common assessment methods to evaluate the performance of road signs along with other management strategies to make the right decisions: (FHWA, 2009)

- Visual nighttime inspection involves a 60-year or older trained inspector conducting the assessment through the windshield of a moving vehicle in dark conditions, and identifying visually the signs that don't meet the minimum retro-reflectivity requirement. This method although being practical is considered also subjective due to the difficulty of setting a benchmark value for the retro-reflectivity measure.

- Measured sign retro-reflectivity method uses a hand-held retro-reflectometer and then compares the recordings to the minimum retro-reflectivity levels. This measurement method usually accompanies other methods to add accuracy to the overall program and thus to optimize the maintenance budgets and to protect the agency from potential tort claims. (Figure 36)

Figure 36 Road sign contact retro-reflectometer (*Source: Roadvista*)

- Management methods may include comparing the existing sign's age to its expected life which in turn is location-dependent as it is based on the experienced retro-reflectivity degradation at each geographical area. Blanket replacement method replaces all signs in a certain area at a fixed interval of time that is based on the signs' life expectancies, and thus eliminating the need for periodic assessment. Another method involves placing sample control signs representing some field signs, and monitoring their condition over time to determine the end of the retro-reflective life of the associated signs.

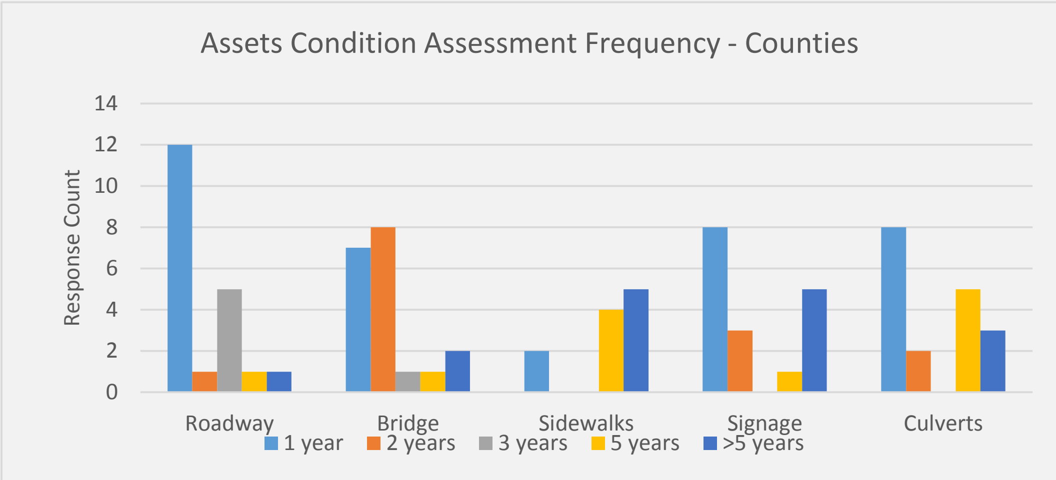
Note that MUTCD discusses similar techniques like the ones listed above to assess the conditions of road markings, as both assets share the same goal of maintaining a certain level of retro-reflectivity which provides the required level of safety precaution.

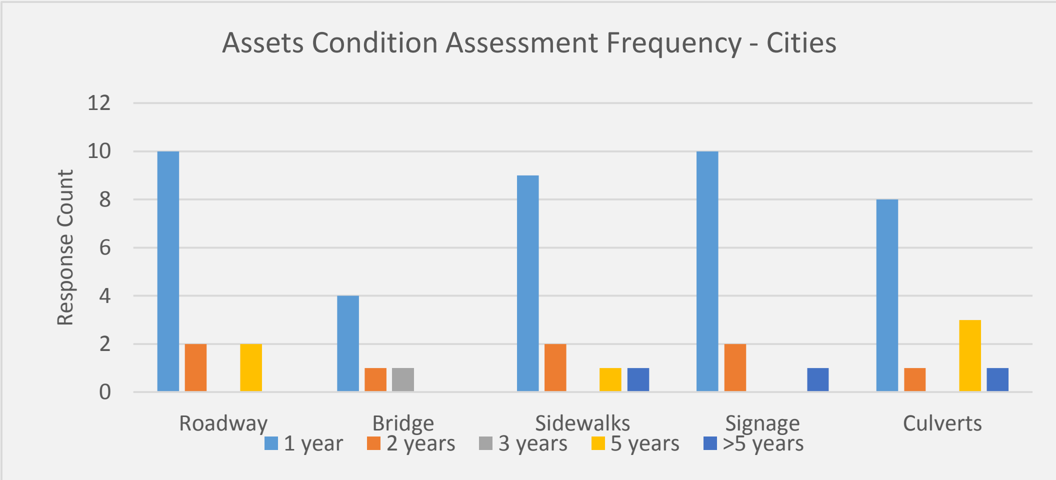
Other Road Furnishings

Road furnishings include many assets that contribute in a way to a safe, fast, and comfortable transportation system. These include but are not limited to pavement markings (Figure 37), road signals, culverts, curbs and gutters, sidewalks, etc. Agencies should review the successful management strategies and guidelines for each type of asset and choose the most suitable one according to their own resource capabilities.

Figure 37 Pavement marking retro-reflectometer (*Source: Kemakmuran Group*)

Condition Assessment Frequency: Concerning the frequency of condition assessment surveys for different asset types, the result of the surveyed agencies shows that the most adopted time interval between asset surveys is a 1-year interval, with some exceptions for assets of slower deterioration rates such as sidewalks.





Additional Links and Resources:

- *FHWA (2013[b]). Practical Guide for Quality Management of Pavement Condition Data Collection.* https://www.fhwa.dot.gov/pavement/management/qm/data_qm_guide.pdf
- World Bank (2007). Data Collection Technologies for Road Management. http://siteresources.worldbank.org/INTTRANSPORT/Resources/07-02-12DataCollectionTechnologiesReport-v20.pdf

- ASTM (2018). *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*. ASTM D6433 – 16, 2016.
- Walker, D. (2002). "Pavement Surface Evaluation and Rating Asphalt PASER Manual", Wisconsin Transportation Information Center
- FHWA (2009). *Manual on Uniform Traffic Control Devices (MUTCD)* https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf
- GDOT (2005). Pavement Design Manual. http://www.dot.ga.gov/PartnerSmart/DesignManuals/Pavement/Pavement%20Design%20Manual.pdf
- Omar, T. & Nehdi, M. (2016). "Condition Assessment and Deterioration Prediction Tools for Concrete Bridges: A New Look", CSCE Conference London 2016, MAT-714.

Chapter 5: Data Management

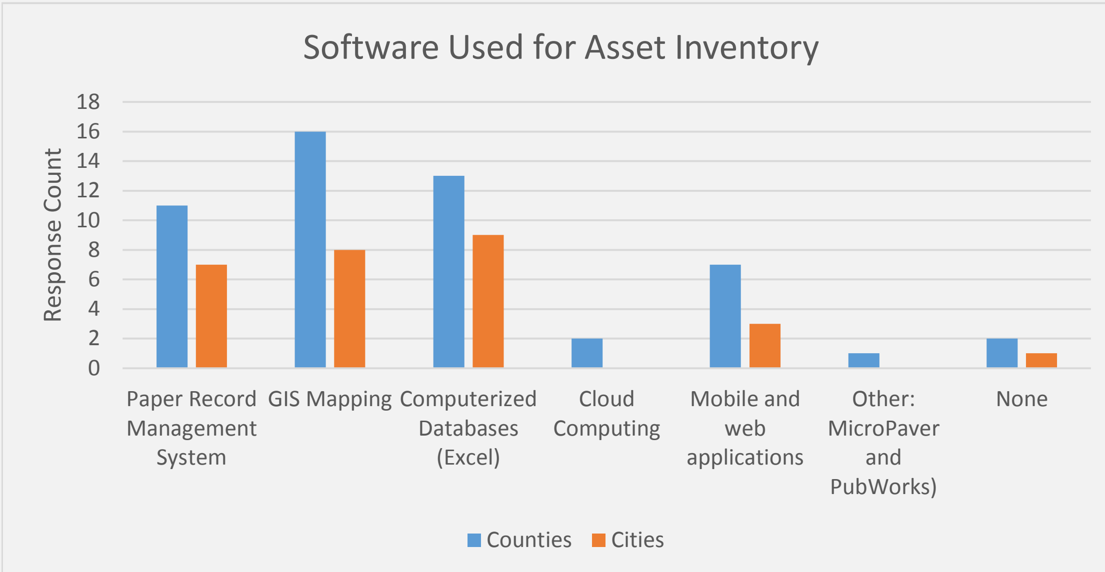
<u>Objectives Checklist:</u>

- ☐ Highlight the importance of data management systems
- ☐ Define the required attributes of the collected data
- ☐ State various methods used for data management
- ☐ Highlight the importance of Geographic Information System (GIS) department

As the asset inventory data is highly critical and valuable, data management systems should be set up to efficiently organize and analyze the information. That information should have certain attributes when being incorporated within a database in order to fulfill the purpose of its collection and act as a solid foundation for the asset management program. The data collected must be complete and with minimal assumptions, as an incomplete database will result in fabricated decision-making strategies as an output. Data must also be current and valid by performing continuous updating to the agency's information for its assets. The frequency of the inspections must be clearly defined in the policies and plans and may vary between the various types of assets due to the difference in their deterioration rates and safety priority considerations. Data accuracy, precision, and consistency are also important factors for a well-established database. Quality control and assurance programs should also be considered within the agency's plans as a means to evaluate the collection methods and the inspectors' performance. Finally, data should easily accessible by the agency's departments dealing with asset management as data that is not at hand cannot be helpful. However, good security measures should also be implemented to protect the agency from any breach.

Agencies usually adopt one or a combination of management systems such as simple paper record systems, data spreadsheets with basic or complex functions, geographic information systems (GIS) mapping, mobile and web applications, cloud computing, and other commercial software. Computerized tools streamline asset management processes for local agencies and have the capability to improve data collection, resource allocation, and decision-making. As agencies often have multiple assets to manage, data integration is an important component of the data management process. Data integration can help connect different components of an agency's transportation assets and prevent data redundancy, which is common in large agencies. Agencies are becoming increasingly attracted to the idea of data integration as a means of reducing data collection and storage costs, improving data quality and accuracy, improving data security, and improving accessibility to data. On the other hand, data interoperability improves coordination with multiple agencies at the local, regional and federal level, and also promotes data sharing and shared learning. (Bernardin and Durango-Cohen, 2006)

Data Management Tools: The responses show that paper record management system is still widely adopted by agencies with a high adoption rate of GIS Mapping tool and computerized databases, especially by counties. However, cloud computing and mobile/web application are yet to be used in the asset management at the local level



A Geographical Information System (GIS) department is recommended for TAMPs. GIS departments are responsible for creating and managing a standardized, accurate, and consistent information database of agency assets. Sixty-seven percent of county agencies and 41% of city agencies have established GIS departments. GIS departments can be expensive and require licensing and education. Survey respondents reported having contracts with their regional commission to assist with GIS work. This can be an affordable approach for smaller local agencies with fewer resources. Other survey respondents reported collaborating with neighboring cities or counties. Cities may rely on partner county agencies to maintain complete and consistent GIS databases. This helps to ensure consistent and compatible databases. Furthermore, neighboring agencies can share software to reduce overall costs. Additionally, some respondents indicated hiring privately for GIS assistance. This is a more expensive approach and it is recommended to explore other options before contracting out for GIS work. The Atlanta Regional Commission (ARC) has an open source GIS database that can be accessed online. Seventy-eight percent of county agencies report utilizing access to agency data from GDOT, 11% from ARC, 6% from other commissions, and 5% from other local agencies. Fifty-six percent of city agencies report utilizing agency data from GDOT, 17% from ARC, 11% from other local agencies, and 5% from other commissions.

Additional Links and Resources:

- FHWA (2013[a]). "Practical Guide for Quality Management of Pavement Condition Data Collection", Applied Pavement Technology, Inc.
- World Bank (2007). Data Collection Technologies for Road Management. http://siteresources.worldbank.org/INTTRANSPORT/Resources/07-02-12DataCollectionTechnologiesReport-v20.pdf

Chapter 6: Performance Measures

Objectives Checklist:

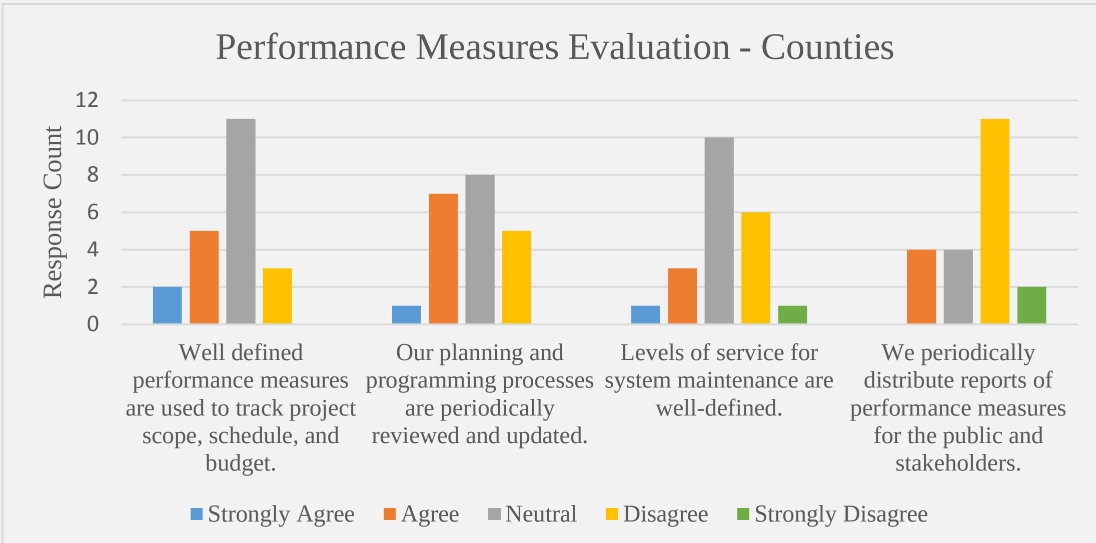
- ☐ Define performance-based asset management
- ☐ State the benefits of an asset management program incorporating that approach

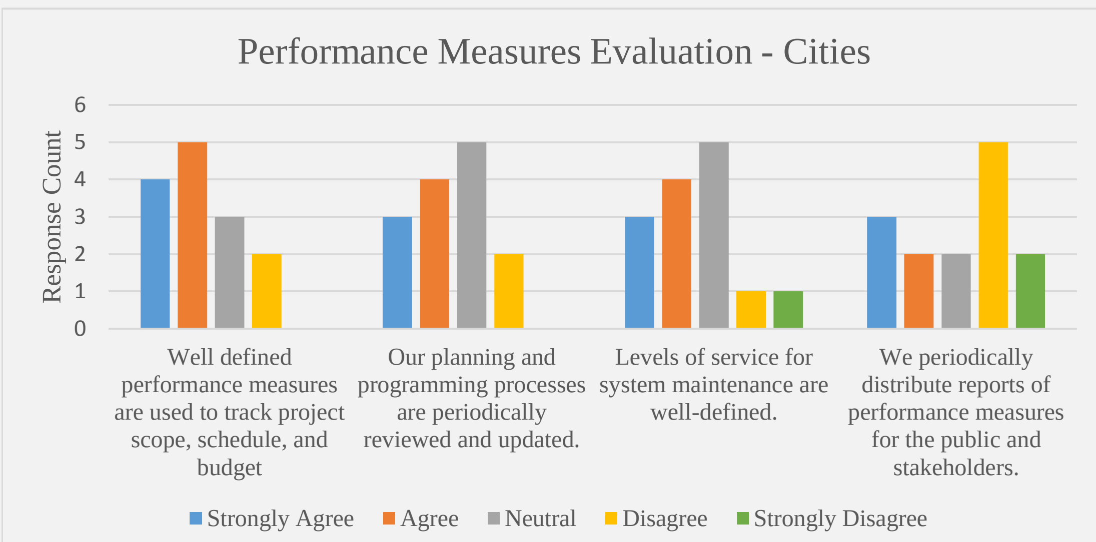
Performance-based asset management program, supported by both MAP-21 and FAST Act, aims to preserve transportation assets by translating policy objectives into system performance measures with realistically set targets. Performance measurement is a way to monitor the efficiency of the asset management program using the performance measures' target compliance as a benchmark. This approach allows the agency to track and forecast the impact of the system investments and resource allocations on the system's performance. In addition, it achieves greater accountability to the policy-makers and better communication of information among the stakeholders, increases the organizational efficiency by setting targets for the staff to focus on and the effectiveness through achieving measurable objectives, allows for better understanding of the impacts of different investment strategies, and encourages an on-going improvement of the business processes. (NCHRP, 2006)

As an example on the application of the above approach, consider the preservation of assets as the goal set in the agency's policies. The measures for that goal may include pavement condition index, bridge health index, remaining life of another asset, etc. The next step involves setting a proper and realistic target for those defined measures. For example, the agency may decide to aim for an X percentage of the pavement to be above a certain condition Y for a certain fiscal year Z.

These performance goals and targets should be updated periodically by the agency to reflect changes in policy or priorities or the emergence of new information that was not previously available.

Performance Management Evaluation: The chart below displays county and city responses from the survey question asking to evaluate some statements related to performance measures which they adopt.





Additional Links and Resources:

- National Cooperative Highway Research Program (NCHRP) (2006). "Performance Measures and Targets for Transportation Asset Management", Report 551, Transportation Research Board.
- FHWA (2013[b]). "Generic Work Plan for Developing TAMP."

Chapter 7: Decision-Making and Risk Assessment

<u>Objectives Checklist:</u>

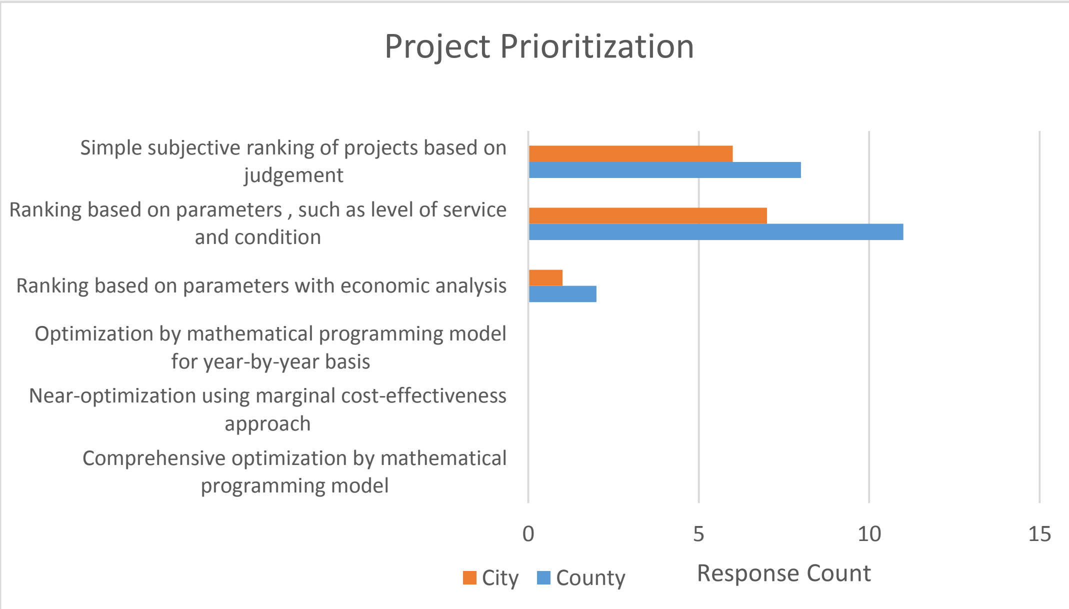
- ☐ Identify current decision-making practice
- ☐ Organize a formal project proposal process
- ☐ Establish a project review committee
- ☐ Transition from “worst-first” project selection to project prioritization

Initial project scoping, option evaluation, and selection can be the greatest opportunities for reducing project costs within a local agency (AASHTO, 2013). Selecting the right projects and completing the right work at the right time helps to improve agency spending. Agencies must instill a proactive approach to asset management by choosing the best time in a facility life cycle to intervene.

Many agencies apply a ‘worst first’ case scenario to their decision-making process. Instead, project prioritization processes can be used to make more informed and calculated decisions. Project performance modeling plays a critical role in forecasting future asset conditions by identifying proper maintenance and rehabilitation strategies and allocating funding appropriately.

By using asset inventory, conditions assessment, and performance measures, an agency has the tools needed to evaluate risks and prioritize transportation projects. An effective way to conduct project prioritization is to establish a formalized process for project proposals. Agencies should develop a standardized form that includes a nominated project’s description, a justification for nomination, anticipated cost, anticipated construction duration, projected funding source(s), impact upon completion, and user benefits. Agencies should then organize a candidate project review committee that consists of division managers and county engineers that will evaluate the project proposals. The committee will review project nominations based on accuracy in predictions, eligibility for funding, and alignment with agency goals and objectives, then make revisions as necessary. After reviewing projects, the committee can develop a ranked list of prioritized projects. The projected costs of maintenance projects are based on labor, equipment, and materials. In addition to economic benefits, rankings should consider environmental protection, network connectivity, equity, accessibility, and cultural preservation. As an agency’s budget, scope, or priorities change, the ranked list of projects should change to reflect new information (AASHTO, 2013).

Project Prioritization: The chart below displays county and city responses from the survey question, "Which best describes your agency's method of maintenance or new construction project prioritization?"



This process is outlined below:

I. Formalize the process of proposing projects
II. Develop a standardized project proposal form document
    a. Include: project name, description, justification, cost, timeline, funding source, impacts, user benefits
III. Require project proposals to utilize this standardized procedure
IV. Establish a project review committee, consisting of division managers or TAM committee members
    a. Review committee will evaluate project proposals on a regular basis – monthly, quarterly, biannually
V. Review projects
    a. Evaluate based on eligibility for funding, overall need, importance, urgency, and impact
VI. Revise selected project proposals
VII. Create a ranked list of projects

a. Consider economic benefit, as well as environmental protection, network connectivity, equity, accessibility, cultural preservation

VIII. Revise ranked project list as necessary

There are several spreadsheet workbooks and database applications that assist with tradeoff and decision-making analyses. The FHWA has developed the Highway Economic Requirements System State Version (HERS/ST) that assists state agencies in tradeoff analyses. HERS/ST determines the most economically desirable combination of projects given specified funding levels. The program determines minimum spending that satisfies specified performance targets.

Another component of decision-making includes hiring in-house or outsourced contracting. Agencies should weigh the cost-effectiveness of out-sourcing for specific maintenance and capital projects. If out-sourcing, it is necessary to develop methods of conducting quality assurance and compare the costs of service providers.

7.1 Risk Assessment

Local governments can utilize risk assessments and risk management as tools for identifying and evaluating sources of risk. Risk management aims to incorporate mitigation strategies into daily agency operations. The process of risk management should be viewed as a core business driver that influences all activities in an agency (AASHTO, 2013).

Any risk associated with an agency's asset is a risk associated with a local agency. There are several sources and types of risk that might affect local agencies, including natural events and hazards, external impacts, physical asset failures, and operational risk events (AASHTO, 2013). Figure 38 displays AASHTO's flowchart for risk management processes. The flowchart emphasizes the importance of monitoring and reviewing during each stage of the process.

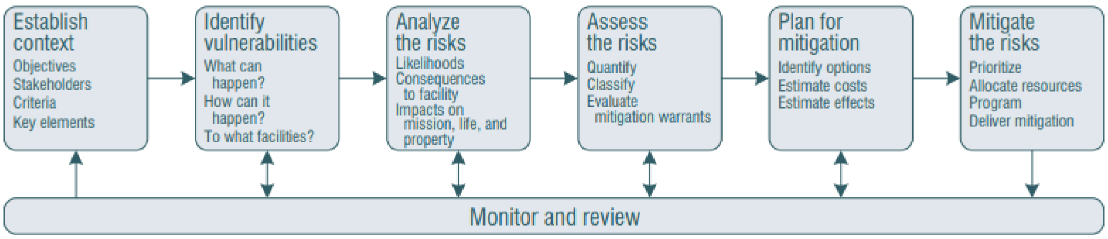


Figure 38 Risk Management Framework (AASHTO, 2013)

Similar to the process of asset management, the risk assessment component is highly effective when operating as a continuous feedback loop. Risk assessment and risk management can be implemented through internal workshops, stakeholder intervention, or guidance from agency management. Agencies must first establish a context and define the objectives of the risk management program. This step involves deciding what hazards and assets are within the scope.

Following the first step, agencies should identify vulnerabilities within their system. This can be based on historical trends or modified from state or other local agencies' risk management plans. Agencies should understand what assets are most at risk, and which assets have the largest impact on the jurisdiction. Risk assessments typically score assets based on likelihood of risk, consequence, and impact. Scores can be expressed in a range 0-100 or by categories, low, moderate, high, and extreme. Scores can be used to compare risks, prioritize mitigation strategies, and express forecasted outcomes (AASHTO, 2013). Risk assessment should be stored in an agency's asset inventory, along with asset conditions.

Additional Links and Resources:

- FHWA Highway Economic Requirements System State Version (HERS-ST)
    - http://bca.transportationeconomics.org/models/hers-st
- GDOT Interstate Risk Assessment
    - http://www.dot.ga.gov/BS/Studies/InterstateRiskAssessment
- FHWA Risk-Based Transportation Asset Management
    - https://www.fhwa.dot.gov/asset/pubs/hif13018.pdf

Chapter 8: Funding and Budgeting

Objectives Checklist:

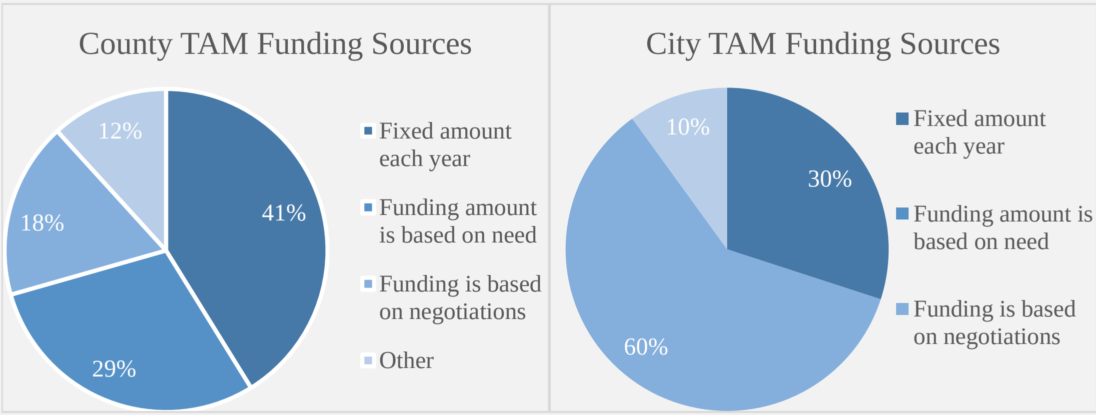
- ☐ Obtain a clear understanding of current agency funding and budgeting
- ☐ Identify areas of improvement in current budget and financial plan
- ☐ Understand local and state funding options
- ☐ Secure short, medium, and long-range budget plans
- ☐ Create a financial summary

Local agencies must have a clear understanding of available sources of funding to establish realistic condition targets and implementable projects. Some recommendations for local governments include assuming consistent levels of funding, identifying potential variations in funding, and evaluating and targeting new funding (Cambridge Systematics, Inc., 2006). Funding varies at the federal, state, and local levels. State DOTs receive federal funding for developing, implementing, and maintaining a TAMP. As long as national highways are included in the state's asset management program, federal funds can be used to maintain the state's entire asset management system. The federal government allocates funding from the National Highway Performance Program (NHPP) and the Surface Transportation Program (STP) (FHWA, 2012[b]). However, state DOTs are the recipients of these funds, not LGs. This section will explore potential funding sources specifically for LGs.

8.1 Funding Sources

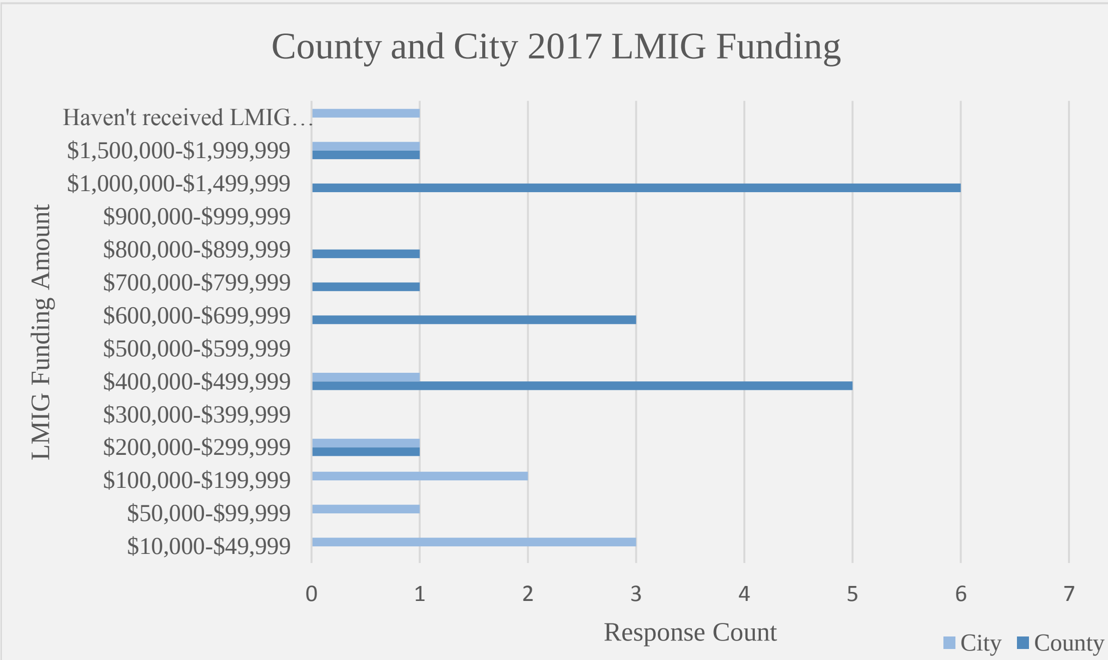
Funding is often the number one limitation to transportation agencies at federal, state, and local levels. Limited budgeting and resources increase the importance of effective TAM systems. Georgia Congressional Funding is enforced by Georgia law to require GDOT to distribute 80% of its state and federal transportation improvement funds equally among Georgia's fourteen congressional districts over a five-year period (GDOT, 2011). Additionally, the Transportation Investment Act (TIA) allocates a 1% regional sales tax to fund transportation improvements. LG's can also choose to apply for Georgia's Local Maintenance Improvement Grant (LMIG), which was created to streamline the process of granting Georgia cities and counties funding for transportation projects. Local agencies apply for LMIG through an application program, with grants ranging from $1,000 to $4,000,000.

Local Government Funding Sources: The chart below displays county and city responses from the survey question, “Select the statement which best describes your agency’s transportation asset management funding.”



LMIGs are dependent on an agency's population and the number of roadway miles. Figure 39 displays LMIG projects awarded in 2017. The awarded amount for each region of Georgia ranges from $1,511,000 to $1,681,800 (Georgia Department of Transportation, 2017). Project types awarded in 2017 include striping, signing, shoulder paving, sidewalk installations, crosswalks, ADA ramps, guardrails, vegetation removal, rumble strips, and drainage.

Local Maintenance Improvement Grant (LMIG): The chart below displays the distribution of county and city funding received from LMIG. One-hundred percent of county survey respondents and 99% of city respondents reported receiving some LMIG funding in the previous fiscal year.



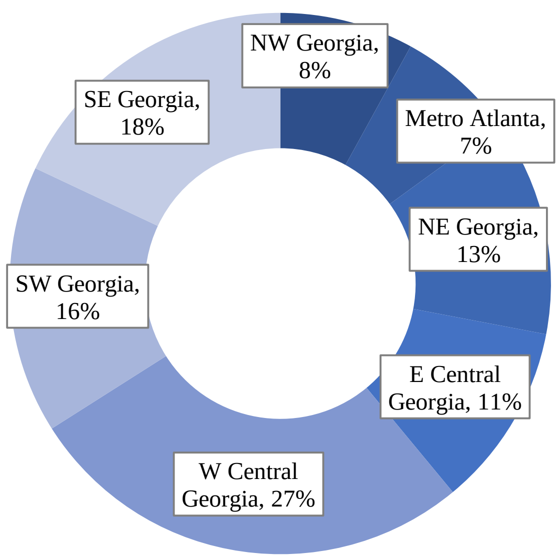


Figure 39 Local Maintenance and Improvement Grant Projects Awarded 2017

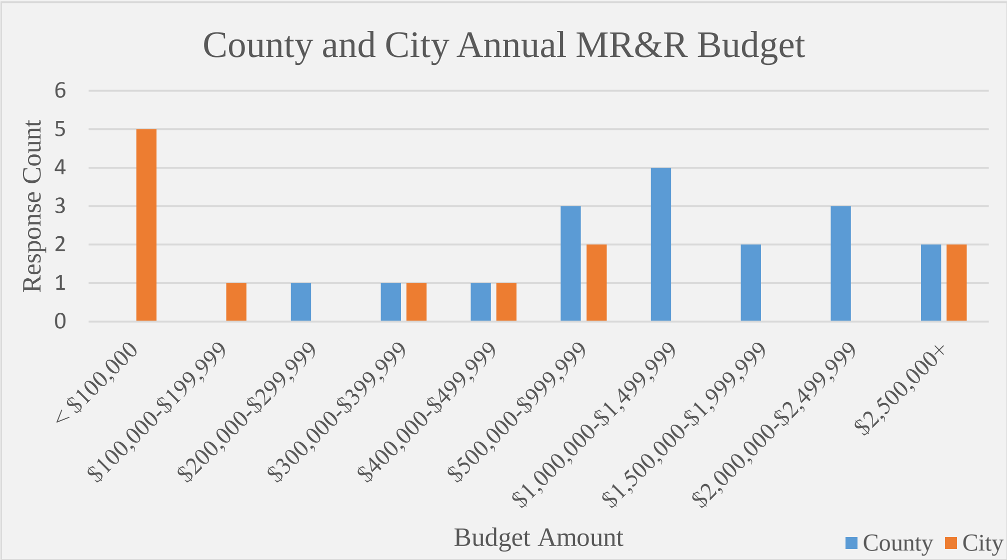
In addition to identifying potential funding sources, agencies should strive to reduce costs. Intergovernmental agreements can significantly reduce TAM costs. Collaborations with neighboring agencies or regional commissions can improve the efficiency and cost-effectiveness of maintenance and capital investments. Intergovernmental agreements may consist of shared purchasing of tools, software, equipment, or technology. Bundling projects can also be an effective measure for reducing expenditures.

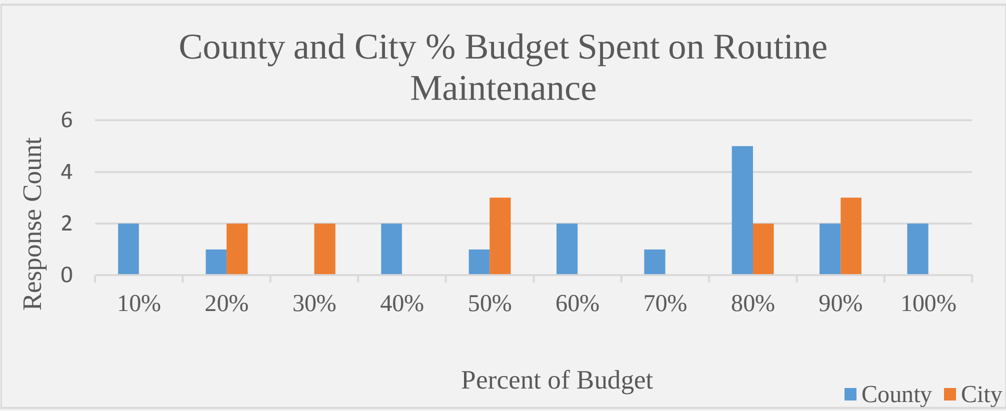
8.2 Budgeting

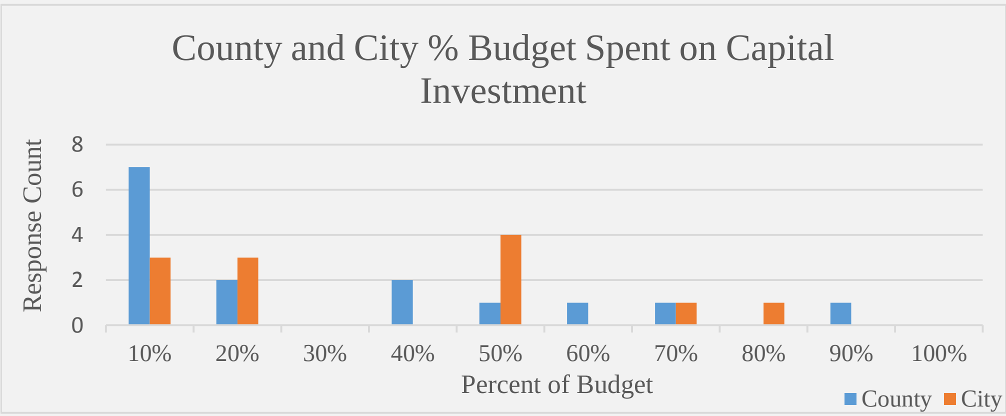
An additional component of an effective TAMP is to maintain a log of historical expenses and expenditures. Budgets should be planned and updated annually at minimum. Budgets should be specific and allocate funding for both capital investment projects and maintenance rehabilitation and reconstruction (MR&R).

Maintaining accurate cost tracking records will improve budgetary planning and forecasts. Activity-based costing (ABC) is a strategy used to set annual budgets. First, an agency must define a set of activities that cover the entire scope of project work anticipated in the upcoming fiscal year. Then, labor costs, material costs, equipment costs, operating costs, depreciation costs, and salvage values are calculated for each individual activity. Overhead costs are then calculated for each activity, including operations, finance, administrative costs, and oversight costs. All calculated costs are combined into a full activity cost by dividing by the number of output units to calculate the unit cost for each activity. Additionally, budgets should be detailed to allocate among asset types. Allocating budget among assets will depend on an agency's size and the number of federal and state-owned assets (FHWA, 2015[a]).

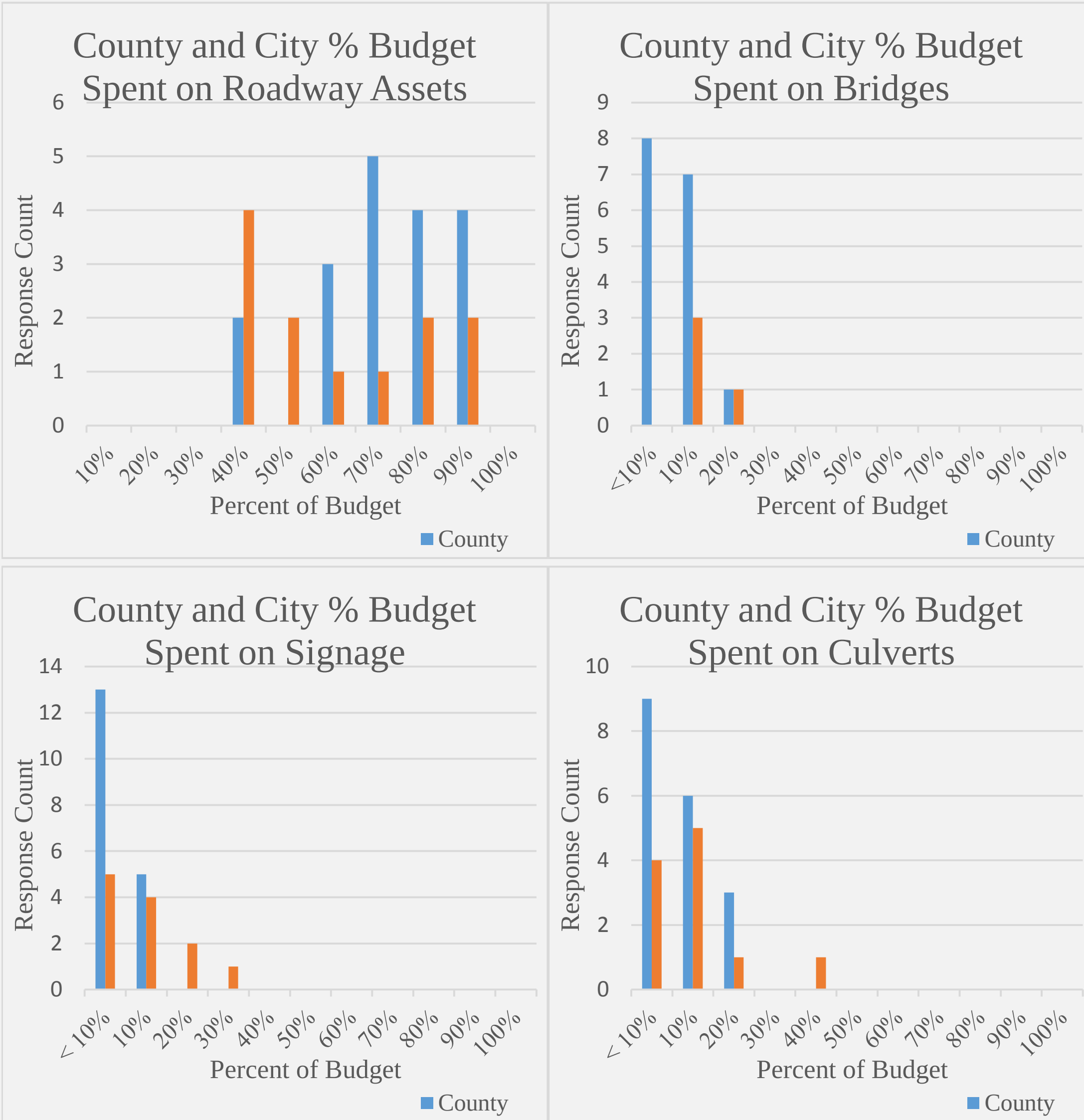
Local Government Funding Allocation: The charts below display city and county responses to TAM funding allocations.







Local Government Asset Budgeting: The charts below display city and county spending by asset type.



8.3 Creating a Financial Plan

A critical component of TAM is to develop a financial plan. An agency's financial plan validates the ability to deliver the agency's established goals and initiatives (FHWA, 2015[b]). A financial plan will clearly establish the revenue needed to sustain the desired conditions and enable more accurate projections for future project work. Additionally, a financial plan will inform the public and stakeholders about anticipated levels of service and future projects and maintenance plans.

Short-term financial planning may accommodate 1-5 years into the future, whereas long-term planning typically covers ten to twenty years. Financial plans can be edited and amended as necessary. Financial plans should include the following projections:

- Current and projected revenue sources
- Expenditure needs (operations, maintenance, and capital expenditures)
- Expenditures categorized by asset type
- Asset conditions and rate of deterioration
- Inflation
- Population and growth projections
- Anticipated gaps or surpluses
- Risks

An effective TAM financial plan will anticipate the amount of investment required annually for planned maintenance, rehabilitation, repair, and capital investment projects. The financial plan should identify areas where additional funding is needed as well as projects to consider if excess funding is secured. The FHWA does not recommend creating a financial plan for a period shorter than 10 years (FHWA, 2015[b]). Agencies should begin by drafting a financial plan outline that highlights the agency's goals, strategies, and current status.

Additional Links and Resources:

- GDOT Local Maintenance & Improvement Grant (LMIG) Resources:
    - http://www.dot.ga.gov/PS/Local/LMIG

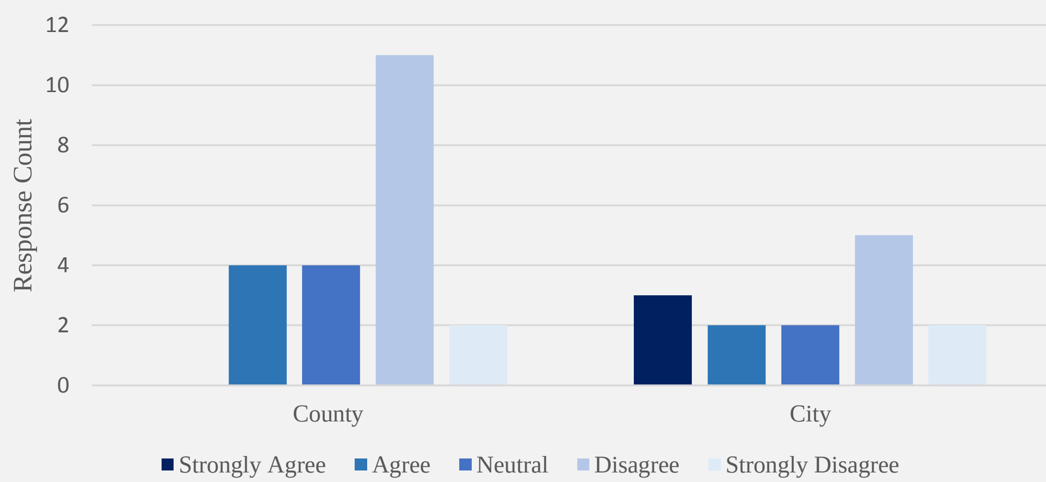
Chapter 9: Reporting

Objectives Checklist:

- ☐ Identify opportunistic reporting measures
- ☐ Understand GASB Statement 34
- ☐ Improve inner-agency accountability
- ☐ Communicate with the public and stakeholders

Asset management systems include accurate and frequent reporting processes. Agencies with TAMPs conduct system monitoring and performance tracking to monitor and report project schedules, costs, and quality of work. Reporting helps agencies identify potential improvement areas and ensure more accurate future project timeliness, quality, and delivery. However, reporting is often only required for State DOTs asset management programs. The federal legislature requires state agencies strict reporting measures. As a result, reporting is more common within state agencies than LGs.

Local Government TAM Reporting: The chart below displays county and city responses from the survey question asking respondents to agree or disagree with the following statement, "We periodically distribute reports of performance measures for the public and stakeholders." As shown from the survey responses, the majority of city and county agencies don't regularly distribute performance reports.



GASB Statement 34 requires agencies to submit financial reports regularly. Additionally, agencies can set their own reporting measures to maintain accountability and progress. Reports allow the public and stakeholders to remain educated and informed on the past, present, and future projects. Reporting can also be implemented within departments or divisions of local agencies. Internal reporting helps to build consensus within an agency. Agencies can hold regular meetings with involved staff to discuss project performance and execution. Reports can be scheduled as frequently as an agency prefers and should be used to the advantage of the agency.

Reporting allows for a standardized record of asset management that includes cost tracking, maintenance and operations, budget, and summaries of work performed. A standardized reporting document can be created to help agencies streamline the process of reporting practices. Reports should include the following items:

- Predicted conditions of assets
- Final conditions of assets
- Predicted budget
- Actual budget
- Funding allocations
- Project overbudget/underbudget
- Project timeline
- Unanticipated costs
- Updated project prioritization list

Additionally, agencies can opt to include anticipated future projects and expenditures, multi-year progress and projects, as well as reevaluations of project goals and targets. This feedback cycle is critical to the continual improvement to an agency's TAMP.

Additional Links and Resources:

- GASB Statement 34

  http://www.gasb.org/st/summary/gstsm34.html

Chapter 10: References

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