Capitalizing on GIS and Asset Management

NCHRP Project 08-87
Successful Practices in GIS-Based Asset Management

Implementation Guide

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1. Introduction

Purpose of This Guide

Transportation agencies are responsible for maintaining and improving physical assets to ensure safe, efficient, and reliable travel. Planning and coordinating investments within and across different classes of assets is a complex endeavor involving multiple functional areas within the agency. A geographic information system (GIS) provides a powerful set of capabilities to bring information together in a spatial context, enabling effective and coordinated decision making. While GIS is now an integral part of the information landscape in most transportation agencies, applications of GIS for managing assets are still at an early stage of maturity.

This guide identifies opportunities for agencies to manage risks and increase efficiency and effectiveness through integrating GIS into transportation asset management (TAM) practices. It provides a roadmap for agencies to use in assessing these opportunities and in undertaking initiatives to strengthen their capabilities. The guidance presented here can be tailored to organizations with varying asset management programs and GIS environments.

Guide Organization

The guide organization is illustrated in Figure 1. It is structured to lead the user through a process of:

(1) *Assessing current agency capabilities* for using GIS to enhance TAM processes;

(2) *Identifying initiatives* for advancing GIS implementation for asset management, based on agency priorities and a business case for specific GIS improvements; and

(3) *Moving forward with implementation* of initiatives, building on strategies for overcoming common barriers to progress.

Figure 1. Guide Organization

Section 2—Capabilities provides overview of key processes for transportation asset management and describes how GIS can add value within each process. It distinguishes three levels of capabilities—basic, intermediate, and advanced, and provides a framework for agencies to assess where they are and understand opportunities for advancing their practices.

This section contains several tools and templates that agencies can use to analyze and plan GIS capabilities. These are designated with the icon to the left, and include:

- Figure 6—Implementation steps for adding new spatial asset data.
- Figure 7—List of spatial data layers that are of value for risk analysis.
- Figure 8 – List of spatial data layers that are of value for tracking the state of the assets.
- Figure 9—List of spatial data layers that are of value for scoping and prioritization of asset maintenance and rehabilitation work.
- Table 7—Worksheet for recording results for assessment of current use of GIS for TAM.
- Table 8—Checklist for assessing the agency's basic GIS foundation.

Section 3—Initiatives describes how to identify actions for furthering use of GIS in support of asset management, and to evaluate the business case for investments. It provides a framework for agencies to look at specific types of improvements and determine which are worth pursuing.

Section 4—Implementation describes strategies for implementing GIS for TAM. Agencies can use this section to develop an implementation plan for a longer-term initiative, or simply to learn about techniques for avoiding common pitfalls.

Appendix A—the Applications Catalog provides specific examples of applications, cross-referenced to the capabilities in section 2. **Appendix B** provides selected examples of geospatial data collection standards and policies.

Definitions

Transportation Asset Management, or TAM, refers to an agency's processes for managing infrastructure assets throughout their life cycle to meet agency objectives. TAM is a holistic way of doing business that cuts across planning, programming, design, construction, and maintenance and operations functions. Key concepts of an asset management approach are illustrated in Figure 2.

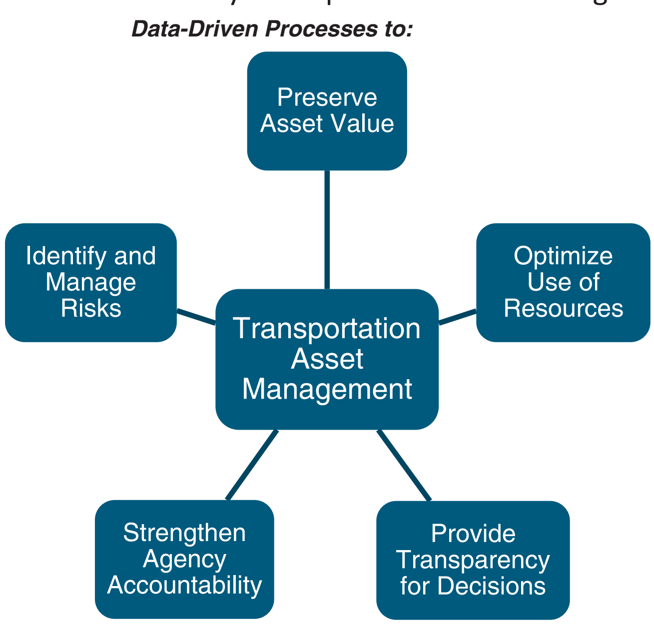


Figure 2. Transportation Asset Management: Key Concepts

Geographic Information System, or GIS, refers to capabilities for management, analysis, and presentation of spatial information. Key elements of GIS implementation include:

- Establishing geospatial data management standards and policies.
- Assembling hardware and software necessary for collecting, managing, analyzing, and displaying spatial data.
- Building a geospatial data infrastructure—including base maps and linear referencing systems.
- Collecting, maintaining, and managing spatially-referenced data
- Integrating spatially-referenced data from external sources
- Building and providing spatial analysis capabilities—both standalone and integrated with agency business applications
- Building and sustaining staff expertise for working with geospatial data and specialized tools

Key elements of GIS are illustrated in Figure 3.

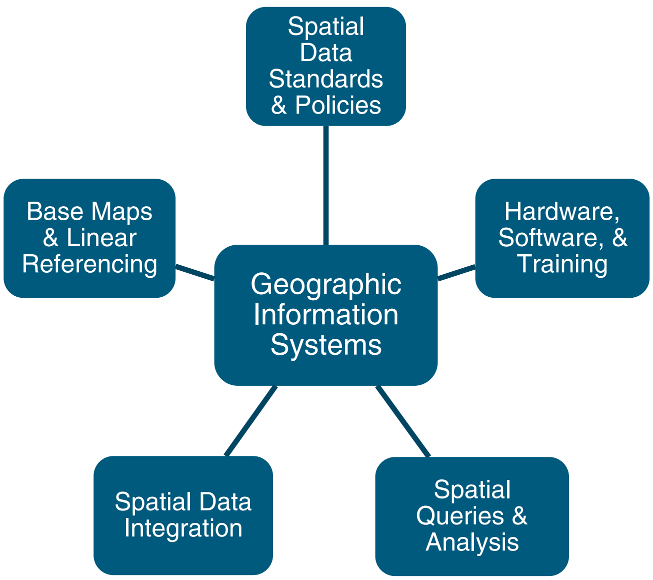


Figure 3. Key Elements of Geographic Information Systems

Setting the Context—the Practice of TAM

In order to explore how agencies can leverage GIS capabilities to support asset management, it is useful to establish the context of core business processes that are part of an asset management approach. While each agency may carry out these processes in different ways and to varying extents or use different terminology to describe them, five basic activities of TAM can be distinguished, as illustrated in Figure 4 and summarized below:

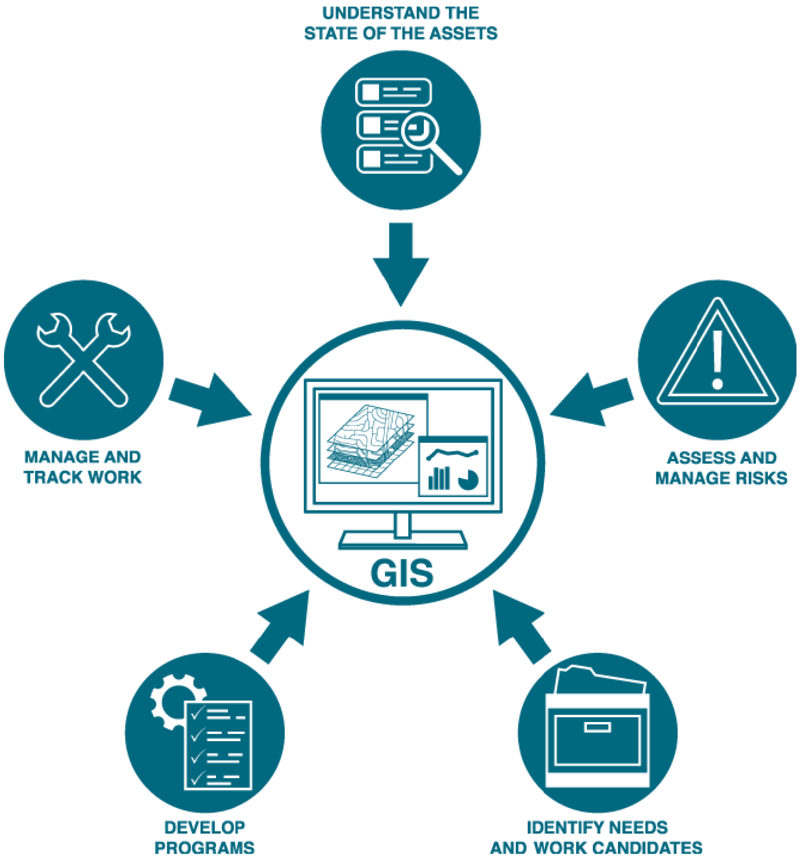


Figure 4. TAM Business Processes

- **Understand the State of the Assets:**
  - Gathering asset inventory and condition data in order to understand what assets the agency owns, their location, current condition, remaining useful life, and economic value, and
  - Assessing network-level asset performance against established targets.
- **Assess and Manage Risks:**
  - Assessing risks and asset vulnerabilities—identifying events or conditions that can lead to failure of assets to adequately provide their intended functions,
  - Assessing the likelihood and consequences of asset failures,
  - Establishing a risk tolerance level,
  - Utilizing risk as a factor in asset rehabilitation/replacement priority setting, and
  - Developing risk mitigation and recovery strategies.

- **Identify Needs and Work Candidates:**
  - Identifying strategies for optimizing performance of the transportation system;
  - Identifying suitable maintenance, rehabilitation, replacement, and functional or operational improvements for assets and developing work candidates for consideration;
  - Scoping construction projects and maintenance activities to address multiple needs; and
  - Understanding the current and potential future backlog of work required to maintain assets in a state of good repair that keeps risks within established tolerance levels.
- **Develop Programs:**
  - Planning multi-year investments that minimize lifecycle agency and user costs,
  - Packaging projects and maintenance activities into programs constrained by available funding, and
  - Setting priorities for work when there aren't sufficient revenues to meet all identified needs through a process of investment versus performance tradeoffs within and across asset and program categories.
- **Manage and Track Work:**
  - Scheduling and managing delivery of asset maintenance and rehabilitation work to maximize use of available resources and minimize customer disruption, and
  - Tracking work accomplished to provide accountability for use of funds and build knowledge about asset life-cycle cost and performance.

TAM is fundamentally a set of business processes that every transportation agency is already doing to some extent. TAM is often *supported* by several information technology (IT) systems, but implementing TAM is not synonymous with building or buying an asset management system. Even if formal or automated processes are not set up for all of the five areas of TAM, agencies can still consider augmenting GIS capabilities to support whatever processes are in place for TAM. There is no need to wait to implement a fully integrated asset management system, and there is no set required order of implementation.

It is also important to note that fully integrating GIS with TAM takes more than acquiring asset or maintenance management software with GIS capabilities. If an agency does have asset management systems in place—or is considering acquiring one, they need to consider not only how to use the built-in GIS capabilities of these systems (for "in silo" analysis) but also how to make sure one can integrate the data from these systems for other purposes. The guidance that follows emphasizes a comprehensive approach to GIS/TAM integration that goes beyond any single management system implementation.

TAM+GIS: Using GIS for More Effective Transportation Asset Management

GIS provides three essential ingredients that enable agencies to effectively carry out the TAM processes outlined above: information integration, analysis, and communication. Figure 5 illustrates how these three capabilities can be applied within an asset management context. Asset management is by nature data driven; using GIS maximizes the value of data for decision making across the organization. GIS capabilities help agencies understand what they own, what their needs are, and how to best apply available resources to meet these needs in a holistic manner. The guidance that follows assists agencies to better utilize the information integration, analysis, and communication features of GIS to strengthen TAM practice.

Information Integration	• Collect, assemble, and combine data needed for asset management, leveraging location referencing standards and spatial technologies. • Maximize use of the same data for multiple purposes—"collect it once, use it multiple times."
Analysis	• Use spatial and temporal analysis capabilities to understand trends and relationships that would be difficult to discern without a spatial view. • Gain insights that lead to better decisions in support of agency goals and priorities.
Communication	• Create spatial data views that facilitate understanding of asset conditions, risks, needs, and strategies. • Actively use GIS to communicate information within the agency and with external stakeholders.

Figure 5. GIS Capabilities for Transportation Asset Management

2. Assessing Your Agency's Capabilities

Levels of GIS Implementation for TAM

There is no single "right way" to utilize GIS for asset management—each agency will want to assess the available options based on its own particular needs and constraints. However, it is useful to distinguish different levels of implementation in recognition that there are some "basic" capabilities that need to be in place before an agency can move on to more advanced applications.

Table 1 provides a generalized description of a simple model defining levels of implementing GIS for TAM. Note that this is not meant to replace the more detailed maturity models available to capture the multiple dimensions of a GIS implementation. (See references 1, 2, and 3). Rather, its intent is to provide a basic framework for agencies to assess where they are and formulate plans for advancing their capabilities.

In general, **basic capabilities** involve using GIS on an *ad-hoc* basis *within individual business units* (e.g., pavement or bridge management) to visualize information such as asset location and condition. More **advanced capabilities** involve use of spatial data integration and analysis, specialized GIS-enabled applications that support workflow, and more formalized and automated processes for creating, using, and sharing geospatial data *across* business units. As agencies progress, they will typically require more of a coordinated, agency-wide approach and will need to strengthen the underlying agency-wide foundation for GIS. Moving to more advanced levels also involves embedding use of GIS within every day tasks and work flows.

Information in Table 1 can be used to provide an initial idea of the agency's current level of GIS implementation for TAM. In the sections that follow, similar tables drill down into each of the five basic asset management business processes. Tables 2 through 6 present more detailed views that can help agencies to identify how GIS might be used to advance specific areas of asset management practice. Each of these tables describes what an initial, basic level of GIS implementation would entail for the specific asset management business process and lists sample actions that can be considered to advance.

Table 1. GIS for Transportation Asset Management: Levels of Implementation

	Basic	Intermediate	Advanced
Information Integration	**Siloed** Business units collect and manage spatially-referenced asset inventory (for major assets)—little or no integration of data across the silos	Some integration of spatially-referenced asset inventory across business units (e.g., traffic data shared with pavement group), some geo-referencing of project and financial data	**Coordinated** Agency-wide integration of spatially-referenced asset inventory and project data; capability to integrate new spatial data on an ad-hoc basis
Analysis	**Basic & Ad-Hoc** Simple thematic maps created showing information for a single asset (e.g., locations of structurally deficient bridges)	Special studies or limited initiatives undertaken involving spatial analysis—including simple visualization, spatial overlays, dynamic segmentation	**Powerful & Embedded** Routine use of spatial and temporal analysis for decision making—e.g., proximity analysis, geo-statistics
Communication	**Limited** Maps showing asset condition or work location produced and shared on an ad-hoc basis using desktop tools or built-in capabilities of asset management software tools Central GIS portal may exist with limited asset data (e.g., bridge locations)	Standard maps supporting internal asset management processes are defined and semi-automated processes are in place to produce them Central GIS portal is available with inventory data for multiple assets as well as project information from the transportation improvement program	**Automated & Extensive** Comprehensive spatially-referenced asset and work data are available to internal staff and external partners on web-based and mobile platforms Senior management uses interactive maps for external communication Agency makes data feeds or application programming interfaces (APIs) available for public use Project teams routinely use maps for collaboration and information sharing

GIS Capabilities by TAM Business Process

Understand the State of the Assets

This first business process—understanding the state of the assets—is perhaps the most common area within which GIS is currently being used. Agencies collect spatially-referenced asset inventory and condition data using various technologies [e.g., GPS mobile devices, light imaging detection and ranging (LiDAR), digital images], and use GIS capabilities for inspection planning, data quality assurance, and data display. Map 1 provides an illustration of a data display capability for understanding the state of the assets—with both map and straight line diagram views for multiple assets.

Where are our deficient assets?

Map 1. Understand the State of the Assets (NHS = National Highway System)

Many agencies are at the basic level for this business process—using GIS-enabled applications within individual business units to collect and view asset inventory and condition information. More advanced capabilities involve standardized and consolidated data collection efforts *across assets*, leveraging additional GIS capabilities for data quality assurance and inspection routing optimization, and standardizing and automating processes for communicating information about the state of the assets.

Table 2 presents a summary of the Basic implementation level and actions that can be taken to advance use of GIS to Intermediate and Advanced levels.

Table 2. Using GIS to Understand the State of the Assets

	Basic	Intermediate	Advanced
Information Integration	**Siloed** Individual business units collect spatially-referenced asset data for major assets & map it independently	✓ Collect spatially-referenced data for additional assets ✓ Develop and adopt agency-wide GPS and location referencing standards ✓ Standardize field data collection hardware and software across business units	**Coordinated** ✓ Coordinate asset inventory and condition data collection efforts across business units to maximize efficiencies—e.g., extract data for multiple assets from videos or LiDAR data ✓ Integrate spatial asset data updating processes within asset maintenance workflows ✓ Extract geo-referenced asset inventory data from CAD files
Analysis	**Basic & Ad-Hoc** Individual business units view maps of current asset location & condition (single asset view)	✓ Use GIS for quality assurance—check for data gaps, anomalies, and inconsistencies ✓ Use GIS for inspection tracking—map inspections due, scheduled, and completed	**Powerful & Embedded** ✓ Compare performance across asset classes to understand interrelationships ✓ Display assets exhibiting faster than expected deterioration rates or assets that have recently moved into "deficient" status ✓ Detect patterns in asset deterioration
Communication	**Limited** Individual business units share asset location & condition maps with agency management and field office staff on request	✓ Implement standard process to produce and publish standard maps showing asset condition to common GIS portal or website	**Automated & Extensive** ✓ Implement dynamic mapping of current conditions from source data systems ✓ Provide access to asset inventory/condition data to field staff via mobile apps

Example: State of the Culverts (Intermediate Level)

Agency A uses a tablet-based field data collection tool to inventory and inspect culverts. The tablet-based software has been configured for several different assets, and allows users to add photographs, videos, audio clips, or notes to inventory or inspection records. The tool allows the user to locate each culvert on the agency's official linear referencing system (LRS).

After the user has completed inventory and inspection work for a day, a "sync" process uploads new or modified records into a queue for approval. Once approved, the data are uploaded into the agency's enterprise database, where they are available for viewing and analysis by central office and field staff across the agency.

Maintenance personnel use the information to create maps of culverts for inspection—by querying for date of last inspection, observed condition, and flood risk. District engineers review thematic maps showing culverts by material, size, and condition to gain an at-a-glance picture of the state of the inventory. Design drawings are linked to the GIS culvert features. This allows the design group to easily access detailed information from the map, including capacity calculations for existing culverts. They use this information as they are developing new designs for nearby locations.

—Figure 6 lists steps that an agency might take to implement or enhance GIS capabilities for understanding the state of its assets. These steps provide a template that can be used to plan, collect, and manage new spatially-referenced asset information.

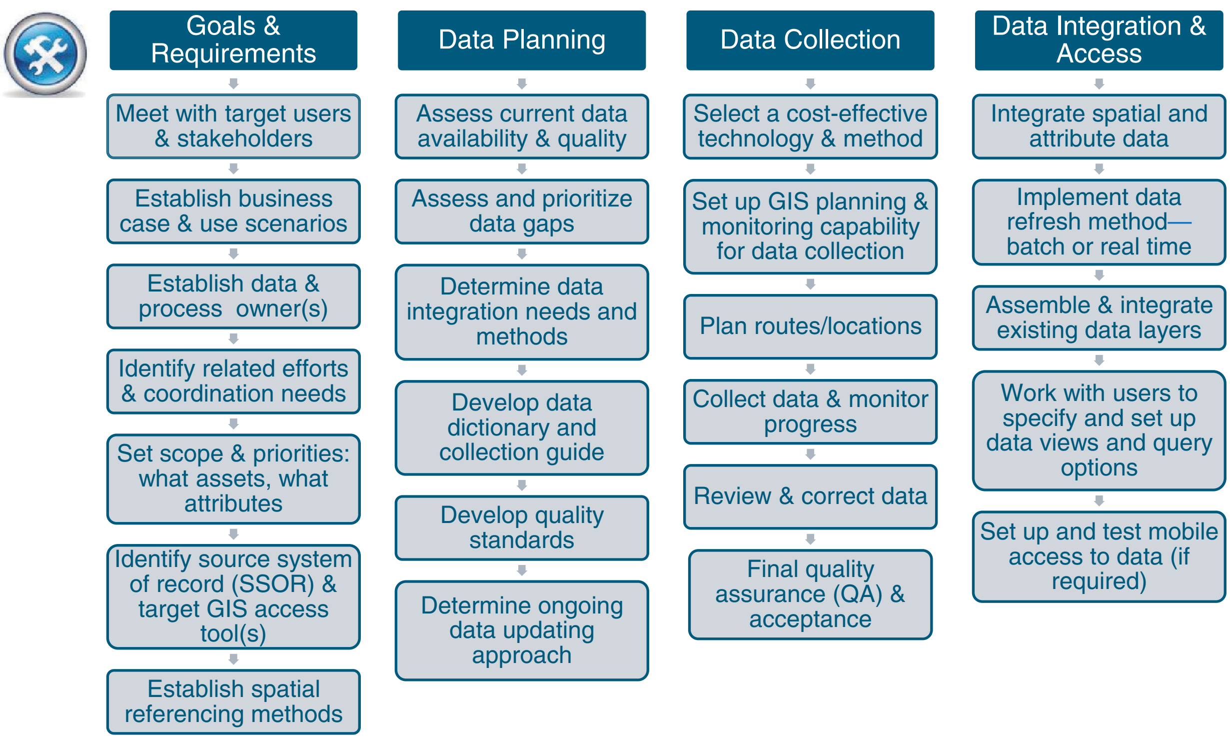


Figure 6. Understanding State of the Assets—Implementation Steps

Assess and Manage Risks

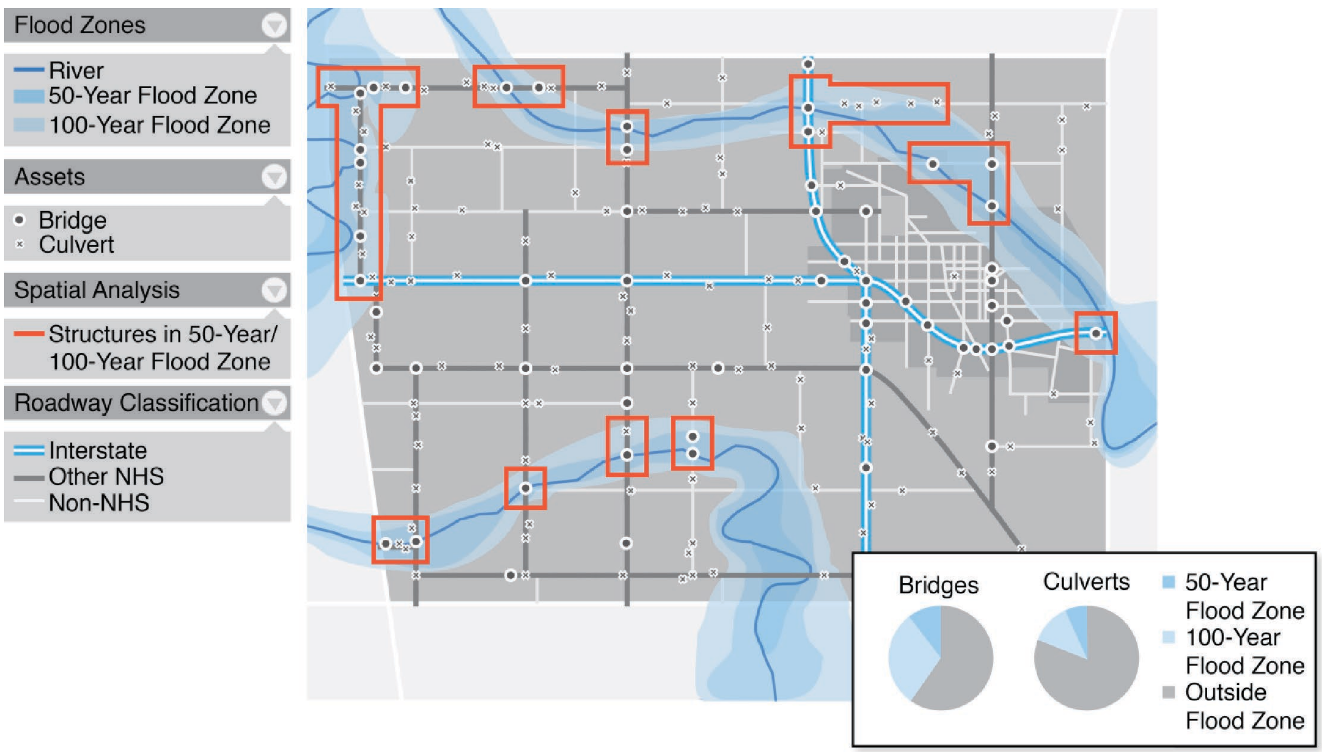
The second asset management business process involves understanding various asset failure mechanisms, assessing their likelihood and consequences, and developing mitigation strategies. As used here, "failure" does not necessarily imply structural failure (such as a bridge collapse); it means failure of assets to provide their intended level of service. For example, a sign that does not meet retro-reflectivity standards, or a pavement section that has extensive rutting are safety risks that could be considered. Several different asset failure modes can be distinguished: gradual deterioration due to loadings and natural degradation of materials, premature failure due to poor quality construction or materials, failure associated with major climatic events such as floods or earthquakes, or failure associated with other chance events such as vehicle hits.

GIS can provide useful risk analysis capabilities by integrating multiple data sources that affect:

- The *probability* of asset failure—for example, traffic loadings, weather, flood zones, seismic zones, and soils; and
- *Consequences* of asset failure, including traffic exposure, detour lengths, and population density.

Map 2 illustrates a GIS risk assessment capability for identifying bridge and culvert vulnerabilities related to flood events.

Where are our vulnerabilities?



Map 2. Assess and Manage Risk

Basic uses of GIS in this area involve examination of assets that do not meet established target service levels together with readily available data such as traffic and road classification. More advanced uses of GIS integrate additional data, utilize spatial analysis capabilities for calculating risk scores based on multiple data sets, and standardize communication of risks across multiple asset classes. Increasingly, agencies are using tools such as risk registers or risk matrices as an input to asset rehabilitation and replacement priorities.

Table 3 presents a summary of the Basic implementation level and actions that can be taken to advance use of GIS to Intermediate and Advanced levels.

Table 3. Using GIS to Assess and Manage Risks

	Basic	Intermediate	Advanced
Information Integration	**Siloed** Individual business units assemble available basic geospatial data pertinent to likelihood and consequences of asset failure to perform as designed—e.g., locations of deficient assets, detour lengths for structures	✓ Assemble spatially-referenced information on assets likely to be impacted by flooding ✓ Undertake pilot efforts to integrate geospatial data layers of value for risk analysis—e.g., traffic volumes, growth rates, freight corridors, socio-economic characteristics, sea level rise, seismic zones	**Coordinated** ✓ Assemble and maintain a common pool of geospatial data for risk analysis ✓ Maintain spatially and temporally referenced data on asset failures
Analysis	**Basic & Ad-Hoc** Individual business units use maps showing deficient asset locations to assist with risk assessment	✓ Develop spatial analysis capabilities to display assets in different risk categories reflecting failure likelihood and consequences ✓ Calculate and display risk scores based on spatial data related to likelihood and consequences of asset failure	**Powerful & Embedded** ✓ Calculate replacement quantities and costs for at-risk assets based on spatial overlays ✓ Integrate historical information and model asset failure risk ✓ Identify atypical performance clusters through historical analysis ✓ Assess benefits of mitigation strategies
Communication	**Limited** Individual business units develop ad-hoc maps illustrating key areas of concern	✓ Use maps to share information about risks across different asset classes	**Automated & Extensive** ✓ Develop interactive maps to communicate consequences of different funding levels and allocation strategies

Example: Risk Assessment (Intermediate—Advanced Level)

Agency B sought to identify roadway assets that may be affected during flood events. They contacted the state department of natural resources (DNR) and obtained a GIS data layer with flood zone information. GIS staff imported this data layer into a geodatabase that also contained data for pavement, roadside assets, and structures. They created an overlay map that showed road sections that fell into the areas of concern, and highlighted structures that have a marginal or below structural adequacy rating.

The agency provided copies of the maps to district engineers to utilize for development of risk mitigation strategies.

Figure 7 lists sample spatial data layers that can be used for asset risk management.

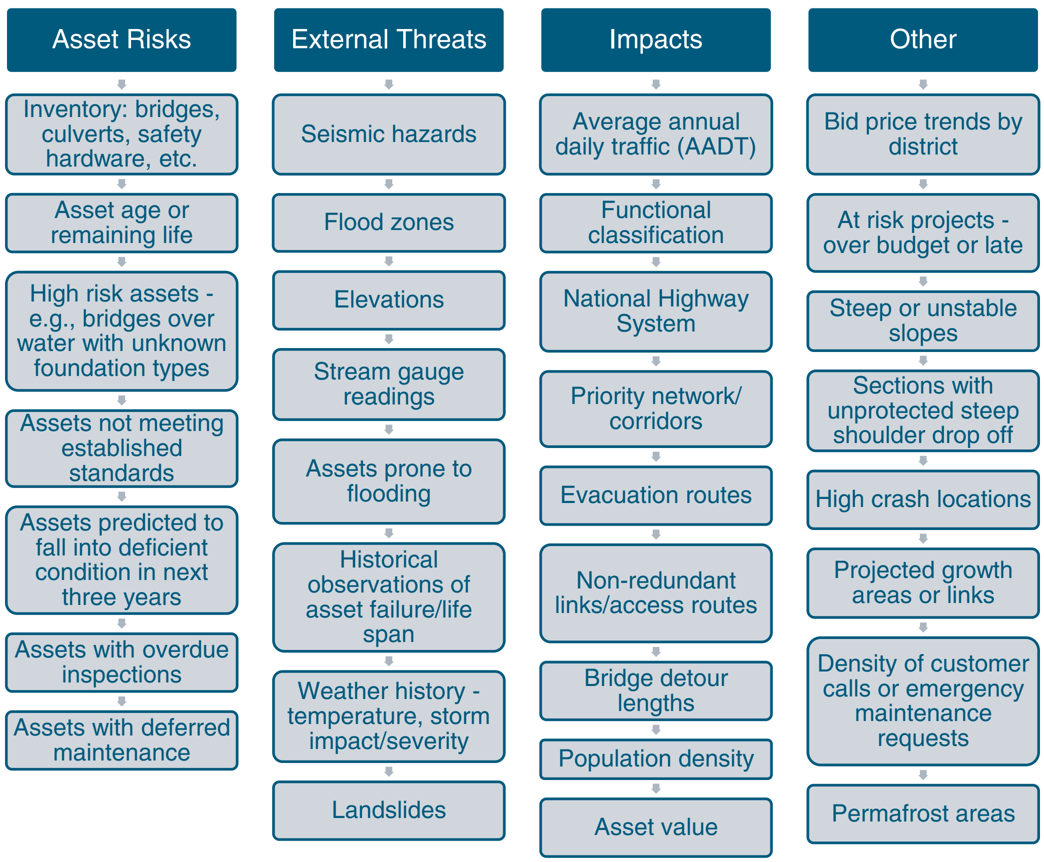


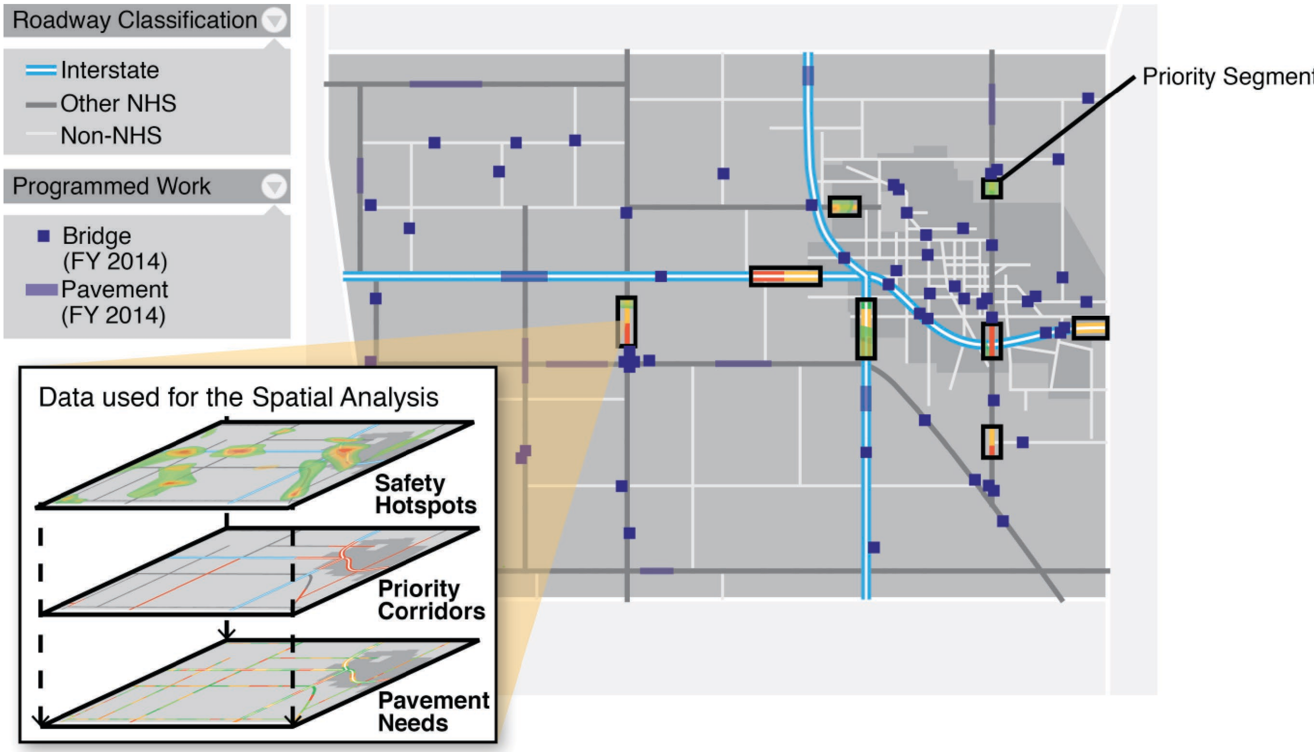
Figure 7. Using GIS to Assess and Manage Risks—Sample Data Layers

Identify Needs and Work Candidates

The third asset management business process involves developing asset maintenance, rehabilitation, replacement, and improvement strategies that address risks and optimize life-cycle costs.

Identification of needs and work candidates is often accomplished within individual asset or maintenance management systems, at varying levels of complexity based on the asset. For example, pavement needs may be assigned based on decision trees that take into account factors such as pavement type, date of last treatment, traffic level, and functional class. Traffic barrier needs identification, on the other hand, may be event-driven (e.g., a vehicle hit) or established based on adherence to established standards and level of risk based on safety analysis. More advanced asset management programs cut across different asset and program areas and provide corridor and system-wide perspectives on safety, preservation, and restoration needs. GIS is particularly helpful for providing this more holistic perspective. Map 3 illustrates a GIS capability for reviewing opportunities to address multiple needs across asset classes.

How can we scope work activities to incorporate multiple needs?



Map 3. Identify Needs and Work Candidates

GIS can be used to display assigned needs and work candidates, to maintain a history of locations where emergency or responsive maintenance has been requested, and to integrate and display information required to assign appropriate treatments. It can also be used to evaluate different decision rules for treatment assignment – e.g., produce maps showing treatments recommended by different rule sets. More advanced GIS applications use spatial analysis features to create uniform sections for treatment application, and integrate information from multiple sources to enable scoping of projects accounting for multiple needs. Table 4 presents a summary of the Basic implementation level and actions that can be taken to advance use of GIS to Intermediate and Advanced levels.

Table 4. Using GIS to Identify Needs and Work Candidates

	Basic	Intermediate	Advanced
Information Integration	**Siloed** Individual business units assemble basic information on asset characteristics, deficiencies, and current programmed projects	✓ Integrate information beyond condition data within individual asset management systems (traffic, crashes, road inventory, maintenance history, soils, etc.) using common spatial referencing	**Coordinated** ✓ Integrate information from multiple asset management and work planning/ programming systems within a single common platform
Analysis	**Basic & Ad-Hoc** Individual business units review maps showing asset deficiencies to identify new work candidates	✓ Develop spatial queries to prioritize deficient assets based on traffic, functional classification, crash history, and other factors ✓ Use GIS to create uniform sections for application of a single treatment	**Powerful & Embedded** ✓ Develop spatial queries to identify opportunities to address needs of multiple assets ✓ Review and assign appropriate treatment/fix based on overlaying multiple data sets
Communication	**Limited** Individual business units create maps to show need categories and locations of work candidates for each individual asset—using built in mapping capabilities within asset management systems or through exports to stand-alone mapping tools	✓ Produce and share maps showing locations with multiple needs—e.g., pavement, bridge, and safety	**Automated & Extensive** ✓ Create interactive communication tools that display condition of multiple assets and other factors that were considered for identifying work candidates

Example: Pavement Needs Analysis (Intermediate—Advanced Level)

Agency C has an established pavement management system (PMS) and uses a video log/pavement assessment vendor to collect pavement inventory and condition data every other year on state-maintained routes. A variety of other data sets are integrated from other business units that utilize the agency's common LRS for spatial referencing: deflection test results, core samples, and soil characteristics. Geospatial analysis is used to overlay the different data sets, develop uniform sections for treatment application and apply results of decision rules. Periodically, the PMS owners in the central office conduct a review of the decision rules with district pavement engineers, using maps to display recommended treatments and to drill down to the characteristics that triggered them.

Work candidates from the PMS are published through an automated process to the agency's central GIS portal, where they can be viewed together with information on deficient bridges and candidate safety improvements. District staff use this portal to scope projects that address multiple types of needs.

Figure 8 shows a list of potential spatial data layers representing a range of DOT asset types. Figure 9 includes a list of other common data layers that agencies might make available to assist with scoping and prioritization of needs and work candidates.

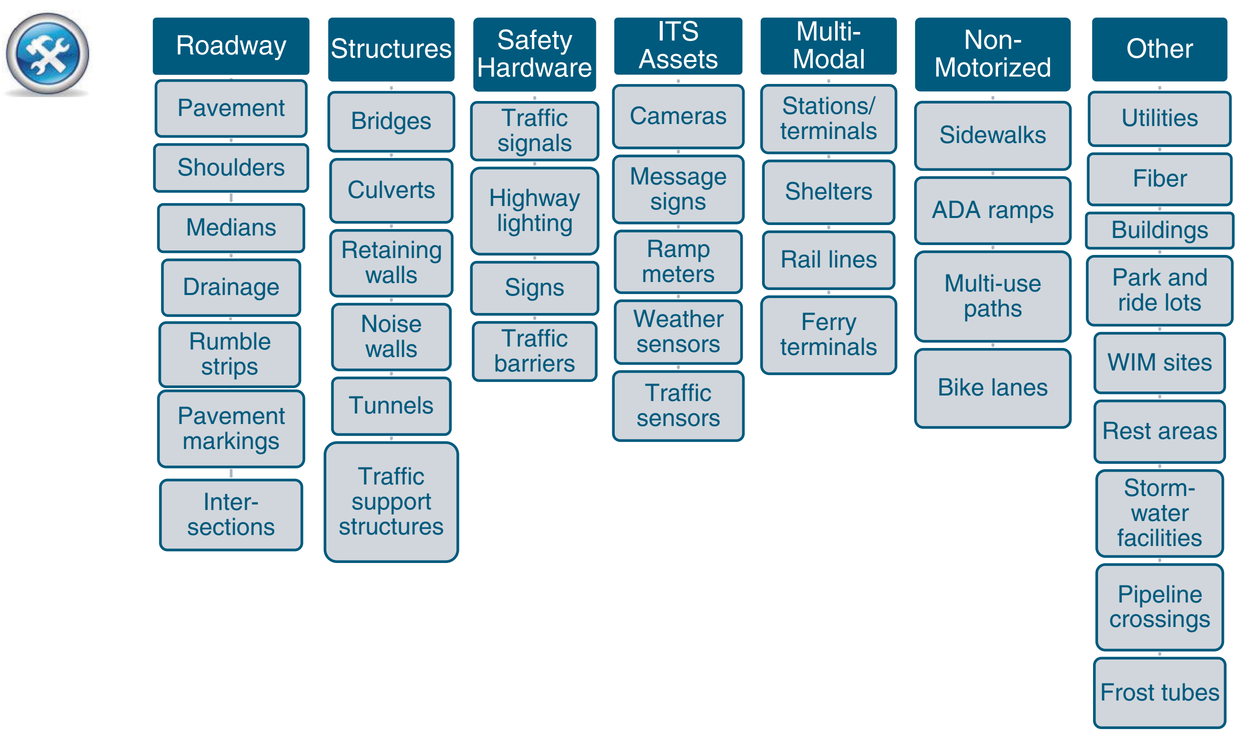


Figure 8. Data Layers for Physical Assets (Location and Condition) (WIM = weigh in motion)

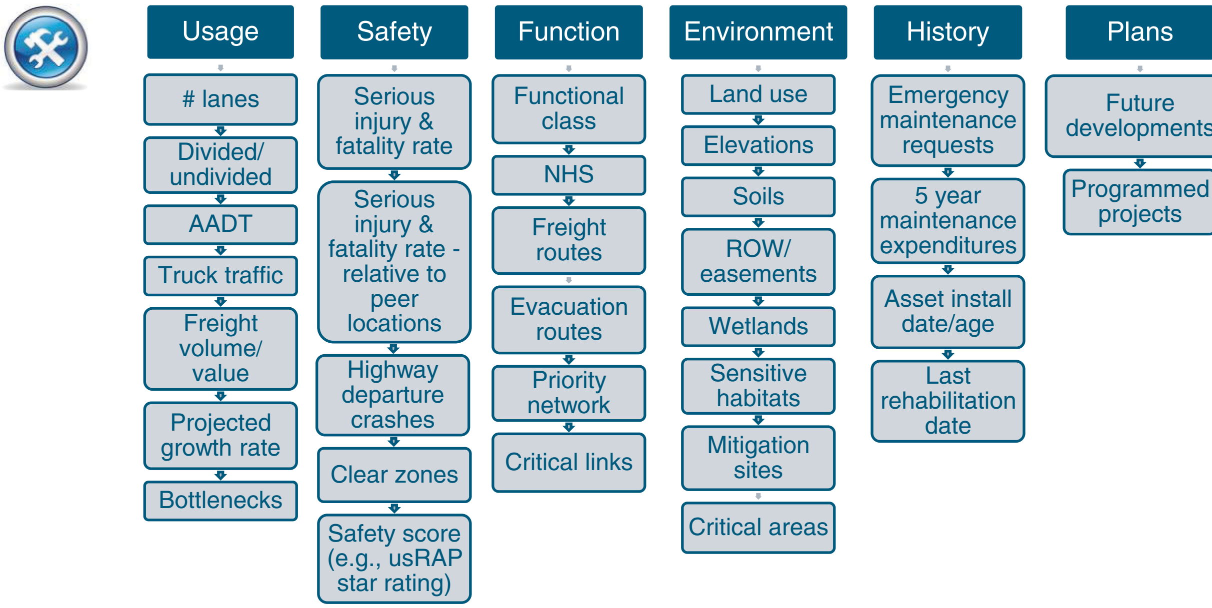


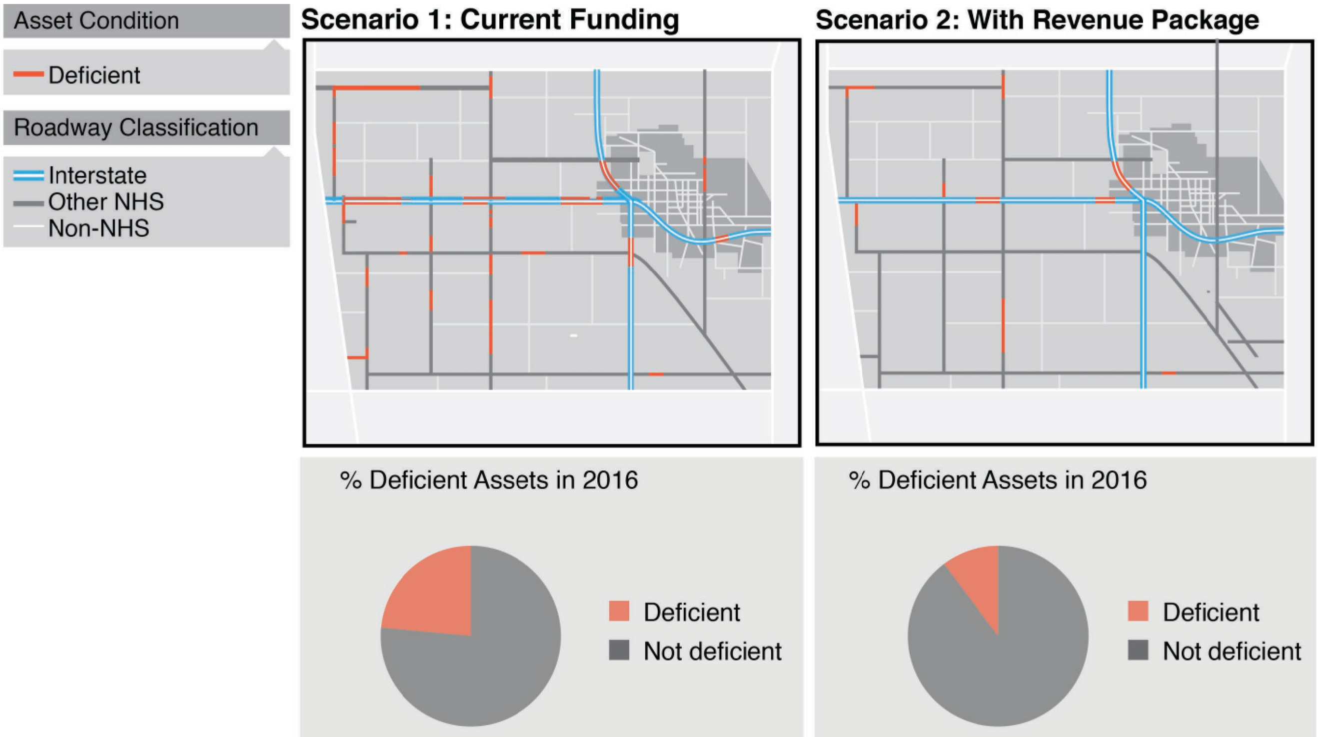
Figure 9. Common Data Layers for Scoping and Prioritization (ROW = right of way, usRAP = United States Road Assessment Program)

Develop Programs

The fourth asset management business process involves developing optimized, funding-constrained programs of construction projects or maintenance activities. It builds on the process of identifying needs and work candidates but focuses on setting priorities and making tradeoffs in order to maximize use of available funds. It also involves coordinating timing of work to take advantage of economies of scale and minimize impacts on road users.

GIS can be useful within this process for integrating information that is used to set priorities. For example, different tiers of the road network could be established based on functional class, traffic, and proximity to major generators. Spatial views of candidate projects can also be valuable for developing corridor approaches that address multiple assets—using a “get in, get out, stay out” approach. Spatial overlays of jurisdiction and legislative district boundaries can be used to assess geographic balance of a program. Map 4 illustrates a GIS capability for displaying asset deficiencies associated with different investment scenarios.

What can we achieve with a funding increase?



Map 4. Develop Programs

At the basic level, GIS is used as a tool to develop programs for individual assets and to display locations of programmed projects for both internal and external communication purposes. At more advanced levels, GIS can be used to integrate and analyze a wide variety of information used for prioritization, display results of tradeoff analysis (e.g., projects selected for programming under different cross-asset resource allocation alternatives), and identify opportunities to coordinate work across asset classes. Table 5 presents a summary of the Basic implementation level and actions that can be taken to advance use of GIS.

Table 5. Using GIS to Develop Programs

	Basic	Intermediate	Advanced
Information Integration	**Siloed** Individual business units assemble information on current programmed projects, candidate work for an individual asset type, basic traffic and road classification information (used to set priorities within individual asset or program areas)	✓ Assemble common pool of geospatial information useful for prioritization and program development: functional class/NHS, AADT, freight corridors, major generators, adjacent land use, historical maintenance costs, crash rates, etc.	**Coordinated** ✓ Embed GIS tools within financial and program management applications—e.g., project locator tool ✓ Integrate information useful for prioritization of work candidates across multiple assets and program areas—e.g., benefit/cost ratio or impact measure
Analysis	**Basic & Ad-Hoc** Individual business units review locations of existing programmed and potential candidate projects and plan rational multi-year work programs that have geographic balance	✓ Develop tiered network classifications for priority setting ✓ Review maintenance history data to prioritize locations with high recurring maintenance costs ✓ Analyze equity of program funding allocation	**Powerful & Embedded** ✓ Derive location-specific data for prioritization and calculate priority scores for projects based on a variety of factors ✓ Review locations of candidate projects for different assets and identify opportunities for project coordination ✓ Display projects and resulting system/asset performance based on budget allocations
Communication	**Limited** Agency produces maps of programmed projects and makes them available for internal and external users	✓ Share maps of proposed projects/ M&O activities for multiple program categories—using standard protocols for data integration ✓ Display completed and planned projects and performance results on mobile GIS apps—for executive stakeholder visits	**Automated & Extensive** ✓ Create system performance maps for alternative resource allocation scenarios ✓ Create retrospective view of performance and investment trends ✓ Provide public-facing web applications showing asset conditions and planned projects

Example: Program Development (Advanced Level)

Agency D has three separate management systems for pavement, bridge, and safety. Interfaces between these systems and the agency's enterprise LRS have been established and nightly routines keep the location components of the data in these systems in sync.

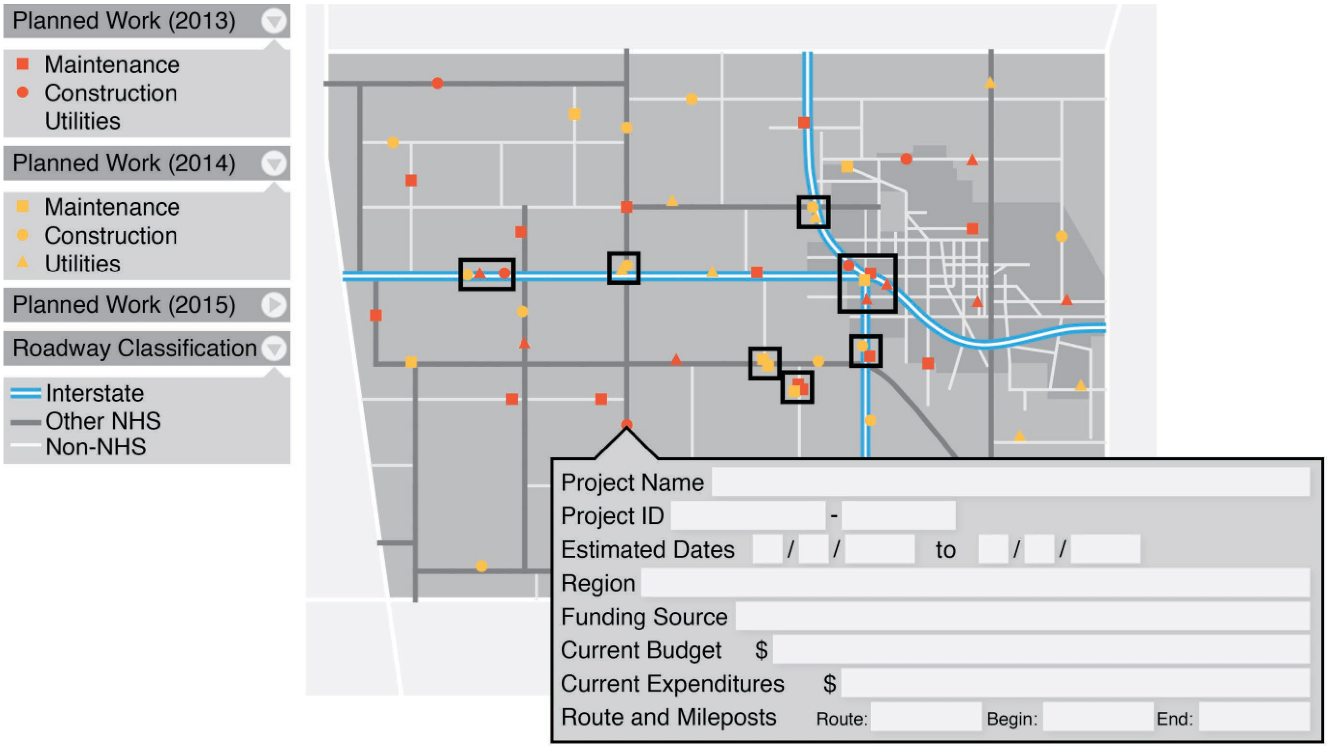
Candidate pavement, bridge, and safety projects are developed within the individual management systems. Results are then exported to a State Transportation Improvement Plan (STIP) application for further analysis. The agency has developed a formula for prioritizing the candidate projects and the STIP application provides the ability to conduct trade-off analyses across the asset classes. Through an iterative process, an agency-wide improvement program is established containing the projects to be completed over the following five years.

The programmed projects can be viewed and analyzed on a map, with options for color coding by project type, year programmed, funding type, and other variables. For each project, budgets, statuses, and multimedia such as design files, 3D models, diagrams, or work plans can be viewed. Information is available to field personnel on tablets with location-aware query capabilities.

Manage and Track Work

The final asset management business process involves scheduling, delivering, and tracking maintenance and construction work. This includes receiving and responding to work requests from customers, managing maintenance crews, coordinating contractor work schedules, and recording information about completed work. The work tracking element of this process provides important information that feeds into the prior four processes—it can be used to update asset inventory and condition information, build knowledge about asset life cycles, identify locations with recurring reactive maintenance needs that may be candidates for rehabilitation, and update "as built" location information for completed projects (which may vary from the "as planned" information). Work tracking information also supports agency accountability, allowing for detailed reporting of how funds were used. Map 5 illustrates a GIS capability for coordinating maintenance, construction, and utility work.

Where do we need to coordinate work?



Map 5. Manage and Track Work

At the basic level, GIS can be used within individual business units to plan routine and preventive maintenance work in an efficient manner and to keep track of the locations of scheduled work. It can also be used to support routing of work requests to the proper field office based on maps showing maintenance responsibilities by route section. More advanced applications of GIS involve real-time applications for asset monitoring and resource deployment (e.g., automated vehicle location, road and bridge sensors), automated processes for analyzing work history information, updating asset inventory based on work completed, and preparing reports required for disaster recovery operations. Table 6 presents a summary of the Basic implementation level and actions that can be taken to advance use of GIS.

Table 6. Using GIS to Manage and Track Work

	Basic	Intermediate	Advanced
Information Integration	**Siloed** Units responsible for work management have access to spatial information on assets, programmed projects, and maintenance responsibilities (district/region boundaries, state-maintained facilities)	✓ Create standard process for locating requested, scheduled, and completed maintenance work ✓ Integrate information on scheduled and completed work across program areas and districts/regions ✓ Integrate geo-tagged before/after photos for completed work	**Coordinated** ✓ Auto-update master asset inventory based on work completed ✓ Integrate enterprise resource planning (ERP) data ✓ Monitor real-time location of maintenance vehicles/plows ✓ Monitor real-time road surface condition and material application ✓ Geo-reference "crowd-sourced" work requests
Analysis	**Basic & Ad-Hoc** The agency determines routing of work to the appropriate work unit request based on location information Asset managers develop preventive maintenance schedules based on location	✓ Identify problem areas based on clusters of responsive/emergency maintenance needs ✓ Review planned work by location to consolidate contracts	**Powerful & Embedded** ✓ Optimize assignment of work crews based on real-time information ✓ Integrate work history information and analyze historical maintenance costs by asset and location ✓ Utilize geo-referenced asset inventory data to facilitate post-disaster reimbursement and recovery planning
Communication	**Limited** The agency creates static maps that can be used for work planning—e.g., asset location maps, district boundary maps	✓ Produce consolidated map of planned maintenance, construction, and utility work to avoid conflicts with external activities and avoid adverse customer impacts (e.g., from closing lanes on two parallel routes) ✓ Provide access to work history maps linked to before-after photos	**Automated & Extensive** ✓ Provide public access to real-time maps of road conditions during snow or other extreme weather events ✓ Provide access to asset characteristics and work history on mobile devices ✓ Automate required state and federal disaster recovery reporting

Example: Maintenance Management (Advanced Level)

Agency E uses a computerized maintenance management system (CMMS) that has work locations automatically populated from the agency's pavement, bridge, safety, congestion, sign management, and traffic signal management systems. Work orders for tasks to be completed by agency personnel are generated and queued to the appropriate division or district managers. Managers have the capability to assign tasks with priorities to individuals or crews. The field personnel are then notified through queues of assigned work and can prepare work schedules and use automated routines that optimize routes to task locations based on priorities.

Field personnel use a tablet-based module of the CMMS to indicate active assignments and to track equipment use and time spent on tasks. The tablet-based module includes the ability to include before-and-after photographs of the site to document work accomplished as a part of work records. At the end of each shift or when network connection is available, data from the tablet is transferred to a web-based tracking system. From this system, managers can monitor work through interactive maps, create reports on productivity, or assign and change task responsibilities.

Information on completed work is communicated back to each management system. This information is then used in analyses to more accurately schedule and budget future projects.

Taking Stock

Once an agency has considered how it is using GIS within each of the five core asset management processes, the next step is to take stock of where the agency is and where it might want to pursue advancements. Table 7 provides a template for an at-a-glance picture of current capabilities. For each cell, the appropriate information in Tables 2 through 6 can be used to identify what the agency is doing now and assign the associated implementation level. Agencies can expand this template to include additional notes on actions that can be considered to further leverage GIS capabilities within asset management business processes and to lead business units for each action.

To obtain a balanced perspective on current capabilities, the agency may want to consult with several different individuals responsible for different asset classes, as well as with representatives of program development, financial planning, maintenance management, and GIS functions. A group can be convened to walk through the matrix, or responsibility for different cells can be parceled out to different individuals and then consolidated.

Once the results are compiled, they can be reviewed to identify patterns. For example, an agency may be Advanced with respect to integrating information with GIS, but not yet at a Basic level when it comes to analyzing and communicating the information. This may indicate that the agency can squeeze more value out of its spatially-enabled data. Alternatively, the agency may have made good progress in the first TAM business area, but not in others. This means that it hasn't yet tapped into some of the most promising areas for using GIS within TAM that can impact investment decisions.

Table 7. GIS for TAM at an Agency: At-a-Glance Assessment

Asset Management Business Process	Information Integration	Analysis	Communication
Understand the State of the Assets	Current Level:______	Current Level:______	Current Level:______
Assess and Manage Risks	Current Level:______	Current Level:______	Current Level:______
Identify Needs and Work Candidates	Current Level:______	Current Level:______	Current Level:______
Develop Programs	Current Level:______	Current Level:______	Current Level:______
Manage and Track Work	Current Level:______	Current Level:______	Current Level:______

Assessing the Agency's GIS Foundation

While the focus of this guide is on applications of GIS *within TAM*, it is important to recognize that lack of a basic infrastructure for GIS can be a significant barrier to making progress in the asset management arena. Conversely, a strong GIS foundation can greatly facilitate implementation of GIS applications in support of TAM. Therefore, if the agency is not at the *Advanced* level for most categories in the summary assessment, it is worth considering whether the overall GIS program in the agency needs some attention. The checklist in Table 8 can be used to assess the strength of an agency's GIS foundation—independent of how GIS is being used within TAM.

Table 8. Checklist: GIS Foundation

This checklist for assessing an agency's GIS foundation considers four major areas: (1) the overall **organizational infrastructure** for GIS, (2) the presence and use of **foundation geospatial data and standards**, (3) the established **technology infrastructure**, and (4) GIS **skills and training** functions.

Agency-Level GIS Function

Management support, policy development, strategic implementation framework, and standard protocols for decision making and communication regarding geospatial data:

- ☐ Executive-level and division manager understanding of GIS value and support for its use in the agency
- ☐ Designated business unit(s) with agency GIS planning and support responsibilities
- ☐ Coordination and communication mechanisms across agency units responsible for managing spatial data—for example, regular meetings, website, standard protocol for adding new data layers
- ☐ Coordination and communication mechanism between agency GIS lead and external organizations (e.g., statewide geospatial agency, external spatial data providers)
- ☐ GIS Strategic Plan used to guide investments—regularly updated to reflect technology advances (e.g., mobile GIS, cloud solutions)

Geospatial Data and Standards

Foundation geospatial data and an architectural framework for building on this foundation:

- ☐ Comprehensive road centerlines, covering all agency-maintained roads, including ramps, with dual centerlines for divided roads
- ☐ A standardized, common agency LRS—identifying route names and street names, including overlapping routes and specifying official lengths/measures
- ☐ Support for multiple location referencing methods (LRMs) to accommodate data collected using GPS devices as well as using linear references such as mile markers or offsets from county boundaries
- ☐ Central library of GIS data resources with a regular, well-defined updating process and schedule—including jurisdictional boundaries, parcel boundaries, address points, elevations, hydrography, ortho-imagery, land use, socioeconomic and environmental data, etc.
- ☐ A standard integration architecture for linking agency GIS and LRS data to business data systems
- ☐ A standard approach to identifying and representing assets and their attributes from a geospatial data modeling perspective
- ☐ Formalized procedures and toolsets for updating road centerline and LRS data to reflect network changes
- ☐ Standards and processes for managing, viewing, and analyzing spatially-referenced business data sets as changes to location referencing information occur (temporal location data management)

Tools and Technologies

Established approach to providing the hardware and software required for agency staff to make use of GIS capabilities:

- ☐ Centralized licensing for GIS database and application software—including desktop, web, and cloud-based tools as appropriate
- ☐ Geospatial data viewer application providing agency-wide (and external) access to shared data sets
- ☐ GIS data clearinghouse—with downloadable data files
- ☐ Formalized procedures and toolsets for LRS maintenance to reflect road network changes
- ☐ Techniques for overlaying spatial data associated with different versions of the LRS as it has changed over time (e.g., due to road realignments)
- ☐ GPS data collection standards (see Appendix A for examples)
- ☐ Standard tools for viewing and exporting data related to a user-specified location (e.g., county, district, route, or route section)
- ☐ Standard tools for geocoding
- ☐ Standard tools to translate across different LRMs
- ☐ Standard tools for field data collection and quality assurance
- ☐ Mobile apps for accessing agency's geospatial data
- ☐ Mobile apps for issue reporting

GIS Expertise, Training, and User Support

Established training and support services to help staff make full use of GIS capabilities.

- ☐ Active GIS user group with regular meetings/communications
- ☐ Skills and expertise for geospatial data management and application development
- ☐ Standard process for GIS tool deployment and customization
- ☐ GIS user training courses made available to staff
- ☐ GIS expertise included in position descriptions where data management/analysis is required

Using the Assessment Results: Developing an Overall Strategy

A high-level strategy for moving forward can be developed based on (1) the agency's current level of GIS/TAM Implementation (summarized in Table 7) and (2) the strength of the agency's current GIS foundation (determined based on the checklist in Table 8). General guidelines for developing a strategy are illustrated in Figure 10 and discussed below.

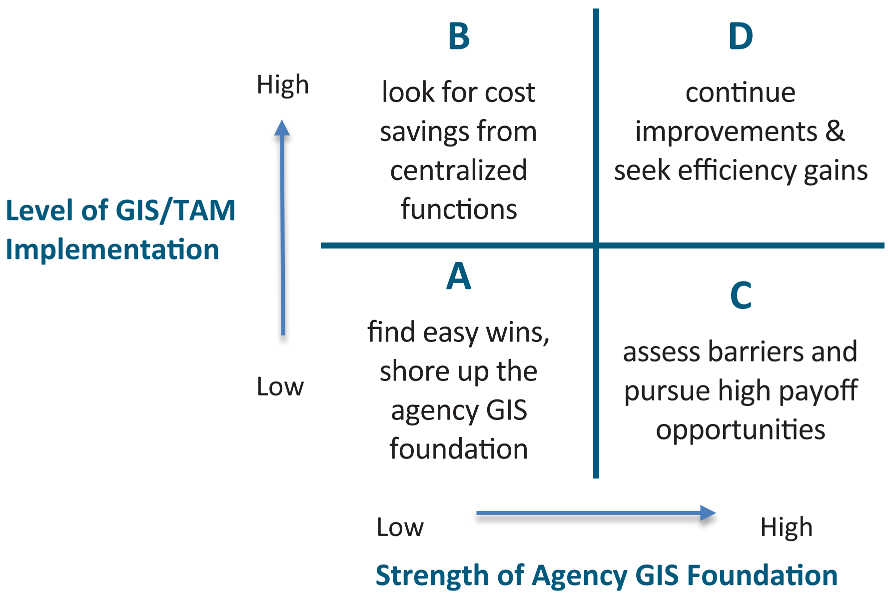


Figure 10. Quadrant View of GIS/TAM Capabilities

Figure 10 presents a "quadrant" view that can be used to identify a high-level strategy for moving forward with GIS/TAM capabilities. It has two dimensions: strength of the agency's overall GIS foundation on the horizontal axis, and level of GIS/TAM implementation on the vertical axis. Agencies in the lower left quadrant (labeled "A") are at the initial stages of both agency GIS and applications of GIS for TAM. Agencies in the upper right quadrant have advanced GIS capabilities in place for TAM, resting on a solid general agency GIS foundation. Agencies can assess where they are on the horizontal axis based on the discussion above (Assessing the Agency's GIS Foundation). Agencies can assess were they are on the vertical axis based on the results recorded in Table 7.

For Agencies with a Relatively Weak GIS Foundation

It is always possible to make progress in specific areas of asset management without a strong enterprise GIS function in place. However, lack of a basic GIS infrastructure (hardware, software, standards, architecture, compiled geospatial data sets, expertise) means that there will be more of a burden on each individual initiative—to create and manage data, and to develop tools. Sometimes it makes sense to accept these burdens in order to move forward, but it is important to recognize that at some point lack of agency-wide infrastructure and standards is likely to become a barrier to progress. In addition, lack of agency-wide coordination results in inefficiencies, with individual work units "reinventing the wheel" or moving in different directions. This makes it difficult to integrate data across units.

Given that foundational activities (e.g., establishing a shared centerline data set for state and local roads) can take multiple years, agencies can pursue a parallel track to undertake some specific asset management initiatives while working to strengthen overall agency capabilities.

Quadrant A: Basic (or Below) Level of GIS/TAM Implementation. If an agency has not yet reached the *Basic* level of GIS/TAM implementation, it is starting with a blank slate. The agency can begin by identifying an area in which it can demonstrate success with a relatively modest effort. It can select one of the "basic" capabilities for which spatially-referenced data are available and the potential exists to add value through analysis or communication. For example, an agency can begin producing and sharing maps showing pavement or bridge conditions. This early success can then be used to build broader support within the agency for a more comprehensive approach to using GIS within asset management. If an agency checked *Basic* in most areas, this means that it has achieved some success in using GIS for TAM within individual business units, but have not yet transitioned to a more holistic, agency-wide approach. The fact that the GIS foundation is relatively weak signals the need to identify where lack of standards, software, applications, or expertise may be inhibiting further progress.

Quadrant B: Intermediate or Advanced Level of GIS/TAM Implementation. If an agency checked a mix of *Intermediate* and *Advanced* in most areas of TAM, this means that they have taken advantage of GIS capabilities within and across business units, and have automated geospatial analysis and data integration functions. However, given the weaker GIS foundation, there are likely to be cost-saving opportunities through centralizing certain functions (e.g., road network and geospatial data maintenance or geospatial applications development and support). It may be possible to use successes within individual business units as a springboard for strengthening overall agency GIS functions.

For Agencies with a Relatively Strong GIS Foundation

A strong agency GIS foundation makes it easier to advance GIS capabilities for TAM since available tools, technologies, data sets, and expertise can all be leveraged. Agencies in this position can step back and develop a broad vision for how they wants to use GIS across different TAM functions. This can be integrated with development or updates to a Transportation Asset Management Plan (TAMP). GIS elements can be incorporated within this plan to describe ways in which spatial data integration, analysis, and communication will be used to strengthen TAM business processes.

Quadrant C: Basic (or Below) Level of GIS/TAM Implementation. If an agency is not yet at the *Basic* level, it should recognize the potential for making rapid progress given the availability strong existing GIS resources. The agency is in a position to look broadly at opportunities for enhancing its asset management practices using GIS and to identify some first initiatives that can leverage existing GIS tools and data. If an agency is at the *Basic* level of GIS/TAM implementation, it has made progress in some areas and it may be time to assess existing impediments to a more comprehensive approach. Identifying specific opportunities for moving forward and preparing a strong business case can help to gain the necessary level of management engagement and leadership for success.

Quadrant D: Intermediate or Advanced Level of GIS/TAM Implementation. The agency is in a strong position, and should continue to seek opportunities for continued advancement of capabilities while improving efficiencies.

3. Evaluating Initiatives for Advancing Capabilities

Options for Moving Forward

After assessing the agency's current capabilities and determining a high-level strategy for how to proceed, the next task is to develop and secure support for a plan of action that:

- Supports the agency's asset management business processes—making them more efficient and effective;
- Is realistic given the agency's budget and existing technology, data, and staff resources; and
- Includes initiatives that can be expected to have benefits exceeding their costs.

Depending on the agency's situation, there may be different ways to approach this task:

- **Comprehensive:** develop a comprehensive GIS/TAM plan—perhaps as an element of the agency's TAMP—that looks across all assets and all of the TAM business processes, identifies a vision for how GIS will be used, establishes foundational standards and policies, and identifies a phased set of initiatives to advance capabilities.
- **Pilot:** develop a pilot project that addresses a current agency pain point or focus area for the agency's executive leadership.
- **Incremental:** Focus on low-cost, incremental actions to better leverage the agency's current data and GIS technologies—for example, creating a series of decision maps using available data.
- **Targeted—Internal:** Target effort on actions that will achieve a noticeable impact within a single TAM business area—for example, implementing a spatially-enabled work management and tracking function.
- **Targeted—External:** Focus on the external communication element of GIS to strengthen the agency's relationship with stakeholders and customers—for example, publish a set of maps showing the agency's projects, or provide a mobile app showing plans for road resurfacing.

Table 9 lists initiatives that can be carried out as part of one of the approaches listed above. These initiatives are organized by the five TAM business processes. For each initiative, the type(s) of GIS use (Information Integration, Analysis, and/or Communication) are identified. In addition, the implementation level (B = Basic, I = Intermediate, A = Advanced) that the initiative represents is indicated—though some initiatives are broadly defined and can fit with multiple levels. Finally, some of the key support elements required for implementation are noted. Once candidate initiatives are identified, agencies can use the guidelines that follow to develop a business case that articulates objectives and considers benefits, costs, and risks.

Table 9. GIS/TAM Initiatives

GIS Use	Level	Initiative	Support Elements
Understand the State of the Assets			
Info Integration	B	New asset inventory and inspection program (single asset)	Field data collection hardware and software (or by contract)
Info Integration	I	New asset inventory and inspection program (multiple assets)	Common LRS GPS standards
Info Integration	A	CAD to GIS asset extraction post construction	CAD standards Software tools
Info Integration, Communication	A	Mobile application for retrieval and/or update of asset information	Data access and updating protocol Mobile device integration
Analysis, Communication	B	Mapping of asset inventory, inspection, and condition—ad hoc	Desktop or web-based GIS tool
Analysis, Communication	I-A	Mapping of asset inventory, inspection, and condition—interactive (with query and analysis functions)	Desktop or web-based GIS tool Data updating protocols
Analysis	A	GIS-based inspection planning and routing tool	Inspection planning/routing tool
➢ See Figure 8 for a list of assets that agencies may consider tracking in GIS.			
Assess and Manage Risks			
Info Integration, Analysis, Communication	B	Basic risk mapping—asset condition versus acceptable level, consequences represented by road classification, traffic data	Asset management system mapping capability
Info Integration, Analysis, Communication	I-A	Advanced risk mapping and analysis—integrating other agency and external data sets: detour lengths, population, land use, flood zones, elevations, seismic activity, etc.	Desktop or web-based GIS tool Analysis software
➢ See Figure 7 for a list of GIS data layers that may be helpful for risk assessment.			

GIS Use	Level	Initiative	Support Elements
Identify Needs and Work Candidates			
Info Integration, Analysis, Communication	B	Basic mapping of need categories and candidate projects—single asset/business area	Desktop or web-based GIS tool or integrated GIS function within asset management system
Info Integration, Analysis, Communication	I-A	Decision maps—integrating maintenance history, traffic, weather, soils, and other pertinent information from authoritative data sources	Desktop or web-based GIS tool with query and analysis capabilities Common LRS GIS data repository/stewardship program Data sharing and QA protocols
Info Integration, Analysis, Communication	I-A	Automated interactive decision maps for developing work candidates/project scopes that account for multiple needs—pavement, bridge, safety, drainage, etc. (can range from basic mapping of needs to automated project location identification based on overlays)	Desktop or web-based GIS tool with query and analysis capabilities Common LRS GIS data repository/ stewardship program Data sharing and QA protocols

- ➢ See Figure 9 for a list of GIS data layers that may be useful for prioritizing work candidates.

GIS Use	Level	Initiative	Support Elements
Develop Programs			
Info Integration, Analysis, Communication	B	Ad-hoc mapping of candidate and existing programmed work for a given asset category overlaid on road classification and AADT range—distribution to business units (headquarters and/or field) to assist with prioritization	Desktop or web-based GIS viewer or integrated GIS function within asset management system
Info Integration, Analysis, Communication	B	Maintain updated map of current asset rehabilitation/replacement/ improvement program—make available for internal and external use	Desktop or web-based GIS tool with query and analysis capabilities Common LRS Business process to attach standard spatial referencing to programmed projects Data sharing and QA protocols
Info Integration, Analysis, Communication	I-A	Automated interactive decision maps showing work candidates from multiple asset categories—options to view a variety of data layers useful for prioritization and identification of work coordination opportunities; calculate priority scores based on spatial data	Desktop or web-based GIS tool with query and analysis capabilities Common LRS GIS data repository/ stewardship program Data sharing and QA protocols
Analysis, Communication	A	GIS-based scenario analysis tool—display which projects would be done under varying budget allocations; show resulting asset condition	Custom application integrating asset management system(s) and GIS tools Common LRS Data sharing and QA protocols
Communication	I-A	Web and mobile GIS apps for communicating the data driven process behind project selection	Web and mobile GIS tools with simple query and display capabilities

GIS Use	Level	Initiative	Support Elements
Manage and Track Work			
Info Integration, Analysis, Communication	B	Develop, maintain and share map of maintenance responsibilities by route section—use to route work requests to the appropriate DOT unit or contractor	Data updating protocols Desktop or web-based GIS tool
Info Integration, Analysis, Communication	B	GIS-based maintenance scheduling and tracking for a single asset (e.g., bridge washing or sign replacement)	Asset/maintenance management system with integrated GIS Mobile GIS application and hardware
Info Integration, Analysis, Communication	I-A	GIS-based maintenance scheduling and tracking for multiple assets—with advanced GIS capabilities for scheduling, preventive maintenance planning, activity coordination, automated inventory updating	Asset/maintenance management system with integrated GIS—single system handling multiple assets or integration across multiple systems Mobile GIS application and hardware
Info Integration, Analysis, Communication	A	Automated vehicle location (AVL) capability for asset maintenance vehicles/crews with real-time tracking and archived data for analysis	AVL system hardware and software, related database reporting and analysis tools Data transfer protocols

Building a Business Case for GIS/TAM Initiatives

Some of the initiatives in Table 9 can be put into practice relatively easily; others may require investments and coordination across different work units. Any initiative falling into this latter category will likely require a persuasive business case to move forward. The business case must address the questions: How will this help our agency, and what will it cost? For major initiatives, a projected return on investment (ROI) analysis can be conducted to determine high-value implementation areas, prioritize tasks, and determine feasibility. ROI requires the identification and quantification of costs and benefits over the implementation timeframe.

Figure 11 illustrates a methodology for establishing the business case for GIS/TAM investments. The elements of this methodology can be used to assess ROI.

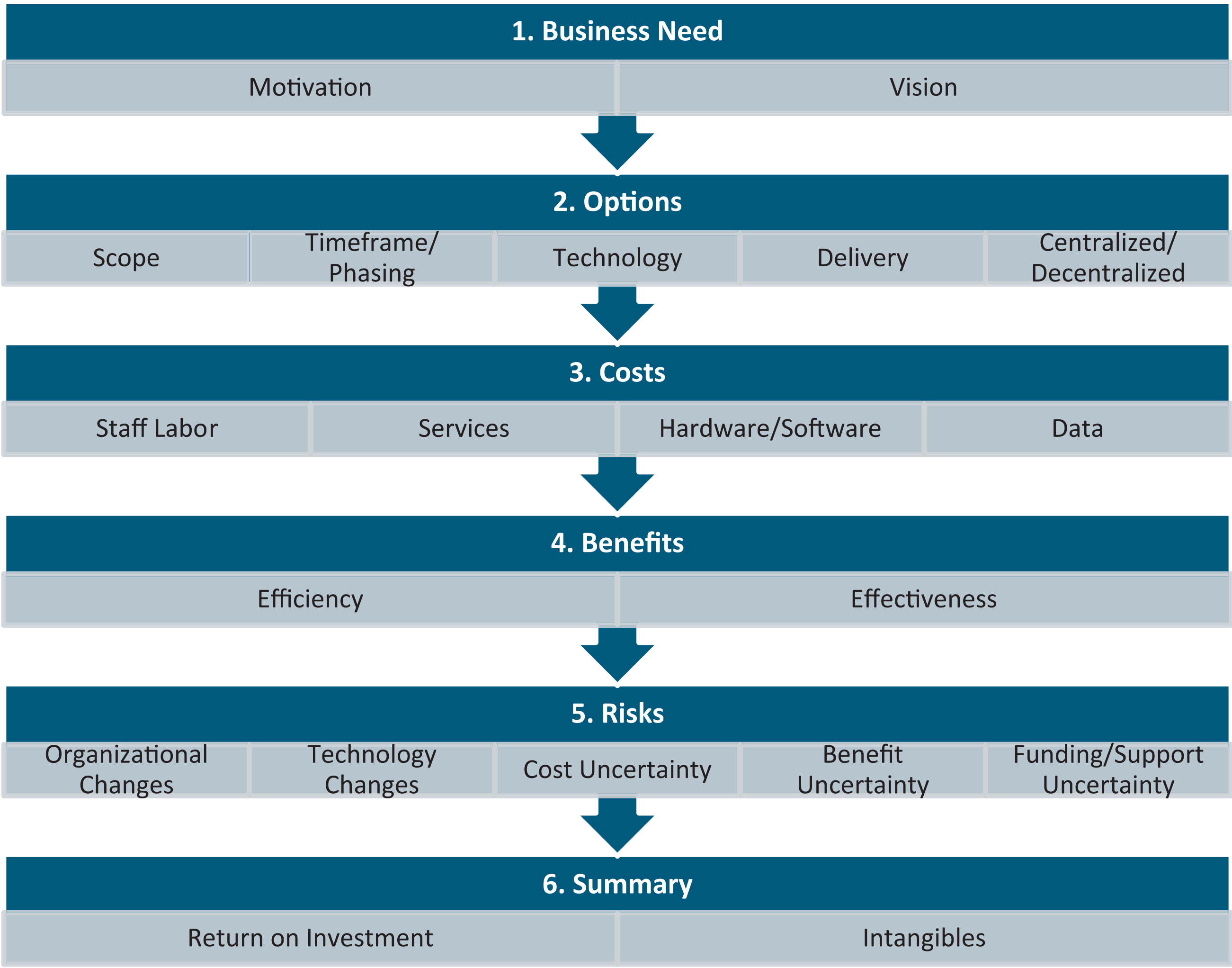


Figure 11. Building a Business Case for GIS/TAM Investment

Step 1: Articulate the Business Need

What do you want to achieve?

The first step in developing a business case is to establish a statement that communicates what the agency expects to accomplish. The idea for the initiative may have arisen from anywhere within the agency; however, defining the need is a collaborative effort of key managers and staff that will be responsible for implementing and living with the results of the effort.

Example statements of business need for a GIS/TAM initiative are:

- **Data-driven decision making**—Asset program managers and district staff need to have easy access to a variety of pertinent information in a spatial context that helps them to optimize use of available resources and select the right project in the right place at the right time.
- **Location awareness**—In order to effectively scope, plan, and prioritize their work, maintenance engineers and construction project managers need the capability to find out everything about a given location—what assets are there, their condition, what capital and maintenance work is planned, what work requests have come in over the past year, what the traffic patterns are, crash rates, etc. This will require the agency to standardize location

referencing across different information systems and provide tools for querying a variety of information based on location.

- **Situational awareness**—Field offices need the capability to track their equipment in real time in order to respond more quickly to needs and deploy resources more efficiently.
- **Efficient data integration**—The agency needs to reduce "islands of information" by providing the ability to integrate asset inventory, inspection, project, traffic, and safety data sets geospatially. This will eliminate the need for costly efforts to remedy issues of inconsistent (or non-existent) spatial referencing.
- **Transparency** —The agency needs to meet today's expectations for transparency and accountability by sharing detailed information about asset condition and planned work with stakeholders and the public.
- **Improved Program Development**—The agency's program development team needs to consider how best to allocate available resources to manage risk. They need to understand the implications of different funding scenarios to help the agency allocate resources in the best possible way. They need the capability to quickly produce compelling and meaningful spatial visualizations of how these scenarios will impact the highway system over time.

Washington State DOT (WSDOT)—Business Problems to Be Addressed by Asset Management Information System Improvement/Replacement (2009)

Lack of support for geospatial referencing—Locating assets or events on the transportation network is more difficult as a result of a lack of geospatial referencing capability in the current Transportation Information and Planning Support System (TRIPS) LRS. This complicates providing a range of management information to users based on geographic parameters including financial information by political or jurisdictional boundaries. It also creates the potential for incorrect assignment of project expenditures and taxes to jurisdictions and programs.

Potential for delays and quality issues in providing information to stakeholders—Due to difficulty and length of time required to obtain information from current systems; lack of integration across systems leads to potential for multiple answers or versions of the truth depending on which systems are used to obtain the information.

Lack of critical functionality needed to deliver programs—Much information about asset inventory and asset conditions, relevant to planning, programming, and project management, requires research in multiple systems or is not readily available in any WSDOT system.

Asset inventory is stored in multiple systems, impacting the department's ability to manage assets from an enterprise perspective—Comprehensive access to this information for planning, accountability, and performance reporting is very difficult. This limits the department's ability to implement an enterprise asset management business model.

Source: [5]

Asset Management Strategic Plan—Using GIS to Support TAM Strategic Goals (Oregon DOT)

Strategic Goals for TAM

- Foster integrated, strategic decision making.
- Sustain or establish a reliable statewide asset inventory.
- Build a fully integrated data system.
- Create integrated reporting and analysis tools.

GIS Initiatives:

- GIS-based TransInfo Tool—management of highway inventory and location referencing.
- GIS-based FACS-STIP Tool—web-based viewer for asset information.

Desired Outcomes from GIS Initiatives:

- Eliminate need for one-time, redundant asset data collection efforts by providing platform for collecting and sharing asset data.
- Consolidate data maintenance efforts.
- Leverage existing investments in GIS data and licensing to benefit the entire department.

Source: [6]

How does this fit with the agency's current GIS capabilities?

In establishing the business need for a new GIS-related initiative, it is helpful to consider how the initiative fits into the larger context of current agency capabilities. If there is a GIS strategic plan in place, how will this initiative support the elements of that plan? If a strategic plan has not been developed, it is worthwhile to assess strengths and weaknesses of agency GIS capabilities and formulate objectives for the initiative that take these into account. For example, if the initiative's success depends on existence of standards or capabilities that are not well established, these will need to be addressed in the project plan. The initiative may provide an opportunity to pilot new technologies or methods that can later be more widely deployed—but the costs of forging new territory will need to be anticipated.

Example: Business Need for a Geospatially-Enabled Sign Inventory

State DOT "A" is responsible for installation and maintenance of approximately 100,000 signs on its state roadway network. Sign maintenance is managed at the district level. Some districts do not keep an inventory; others track sign location using spreadsheets or desktop database tools. District inventories use varying methods to locate signs—including GPS coordinates, and route-county milepoints. As central office traffic engineering staff considered options for implementing a new program to maintain minimum retroreflectivity standards, they found it very difficult to obtain good information about the existing sign inventory. They requested information from each district, and were able to piece together some estimates of the number of signs by install date, type, and route, but the accuracy of the data was not high and gathering the data was a time-consuming effort for all involved. This experience led to a proposal for implementing a comprehensive sign inventory.

Central office traffic engineering staff met with district staff to understand their needs, and then with members of the GIS group in the planning division to discuss this initiative. GIS staff had recently assisted with deployment of another inventory application and suggested that this initiative might piggyback on this earlier one. They also discussed how to leverage existing GIS database and application software. Based on these meetings, the following objectives were established for the initiative:

Objectives

1. Obtain information on sign type, location, and installation date that can accessed across the department and used for:
   - Statewide analysis of different inspection and maintenance options.
   - Statewide analysis of different sign replacement cycles.
   - District management of sign inspection and replacement activities.
   - Safety analysis.
2. Make sign information easily accessible throughout the organization.
3. Leverage available tools and technologies.

Step 2: Define Options for Meeting the Business Need

Before moving forward with analyzing costs and benefits of the proposed initiative, it is useful to define alternative ways of meeting the need. At a minimum, a "do nothing" option should be considered in order to provide a baseline for comparison. Other options for defining lower-cost alternatives could involve:

- Varying the scope—in terms of which assets or which portions of the network are included.
- Varying the timeframe—how capabilities will be phased in over time.
- Varying the tools—relying on existing tools, enhancing existing tools, or moving to new tools.
- Varying the delivery approach—performing all or a portion of the effort in-house or outsourcing the entire effort.
- Varying the implementation approach—pursuing a decentralized approach that equips work units with tools and relies on standards for consistency versus pursuing a centralized approach.

In defining options, it is advisable to survey current technology options and consider opportunities that may not have been available when the agency implemented its current applications or toolsets. For example, many agencies are cutting costs by adopting cloud-based solutions, and crowd-sourcing development of mobile applications that provide self-service GIS capabilities for non-GIS experts.

Example: Alternatives Definition for a Spatially Enabled Transportation Improvement Program

State DOT "B" has a robust annual and multi-year program development process with both decentralized (district-level) and centralized components. Prior to publication of program updates, the agency's GIS staff updates a map that shows project locations. This update occurs annually, and is very time consuming because project locations are not consistently entered into the program database system.

The agency's public information office has received many comments from stakeholders about the accuracy of the program map. They have asked the programming division to create a more dynamic map view that allows the public to obtain up-to-date information about project scope, schedule, budget, and cost.

The programming division defined several alternatives for investigation:

1. Continue the current process—supply more recent information about projects to stakeholders as inquiries come in.
2. Require entry of project locations using a standard method for location referencing—enforce through the program database entry screens or through workflow rules that prevent funding approval when locations are missing—and switch to a quarterly map update process.
3. Same as 2, but also add a project mapping tool to the program database system in order to facilitate capture of project locations.
4. Same as 3, but automate the mapping process so that maps can be dynamically updated from the program database.

Step 3: Identify Costs for Each Option

The next step is to produce planning-level estimates of the costs for each option. An agency should estimate both initial costs and ongoing annual costs once the initiative or project is complete. Given the variety of potential initiatives that the agency may be considering, only general guidance on costing is provided here. Costs consist of hardware, software, personnel, technology support, and vendor costs. Personnel and external vendor support costs are typically the larger component and include the initial development and ongoing support.

Specific cost components to consider include the following:

- Labor and services.
- Project management.
- Planning and requirements development.
- Policy, procedure, and standards development.
- Custom map development/configuration.
- Data collection and updating.
- Application development, customization, or interface development.
- Hardware/software.
- Software licensing—for desktop, web, cloud, and mobile GIS solutions, data integration, and reporting tools.

- Tablets or smartphones for field data collection and access.
- Server upgrades or purchases.
- Plotters/printers.
- AVL technology deployment.
- Data.
- Spatial data set purchases or licensing.
- Data storage costs.
- Field data collection.
- Data conversion or quality improvement (staff and/or consultant labor).

Given rapid changes in technology, the best way to obtain a reasonably accurate idea of costs is to check in with peer agencies that have recent experience with initiatives similar to those an agency is considering. Useful resources for finding out who is doing what include:

- GIS-T Roll Call of States and Conference Proceedings—http://www.gis-t.org/.
- FHWA GIS in Transportation Webcast Series—http://www.gis.fhwa.dot.gov/webcasts.asp.
- URISA Annual Conference Proceedings—http://www.urisa.org/.
- FHWA, AASHTO, and TRB Asset Management Conferences, Webinars, nd Peer Exchanges—see announcements on the TRB Asset Management Committee web site (https://sites.google.com/site/trbcommitteeabc40/), the AASHTO Subcommittee on Asset Management website (http://tam.transportation.org/Pages/default.aspx), and the FHWA Office of Asset Management website (http://www.fhwa.dot.gov/asset/).

Step 4: Identify Benefits of Each Option

Whether an agency is looking broadly across its entire set of TAM functions, or has zeroed in on a specific area, it is important to build on a statement of business need and identify specific benefits to be achieved through advancing use of GIS. Two types of benefits can be distinguished:

- Efficiency Benefits—reducing the time or cost to complete a given task or work process.
- Effectiveness Benefits—improving the agency's capability to produce a desired set of outcomes and manage risk.

In short, to quote the well-known management expert Peter Drucker, "Efficiency is doing things right; effectiveness is doing the right thing."

Efficiency Benefits

Efficiency benefits associated with GIS/TAM initiatives may include staff time savings from:

- Automation of mapping tasks that were previously done manually;
- Reduced needs for on-site data collection and inspection—e.g., engineer or planner reviews videolog and recent inspection history for assets along a corridor;
- Faster access to and analysis of information required for special studies, and response to internal management and external requests—e.g., rather than a week-long project to find, acquire, transform, and load data, analysts use central GIS portal;
- Automated integration of data required to load management systems;
- Streamlined business processes for work order creation, inspection, and work recording—elimination of paper, automated transfer of data rather than re-entry; and
- Streamlined management of external work requests—e.g., geo-located work requests generate inspection work order.

They may also include:

- Reduction in software licensing costs (e.g., through shifting to cloud or software-as-a-service approaches) and
- Reduction in asset maintenance costs through initiatives that provide information that can be used to optimize deployment of maintenance resources—quantified based on reduction of down time and deadheading.

There are two ways to approach analysis of efficiencies:

- **Current products and services as the baseline.** In this approach, an agency assumes no fundamental changes in the quantity or quality of products and services provided by the agency's business units. The agency estimates the current level of resources to produce these products and services. Then, it develops a scenario in which it has implemented a GIS/TAM improvement and estimates the level of resources required to produce these same products and services. Efficiency benefits from the GIS/TAM initiative are equal to the difference in cost between the current or status quo situation and the scenario in which the agency has implemented the initiative.
- **Improved products and services as the baseline.** In this approach, an agency defines a new target level of products and services that it wants to provide. The agency defines two scenarios—one in which the improvements are provided without the GIS/TAM initiative, and a second in which the improvements are provided with the GIS/TAM initiative. Efficiency benefits from the GIS/TAM initiative are equal to the difference in cost between the two scenarios.

Efficiency Benefits—Using Current Products and Services as the Baseline

State DOT "C's" pavement management unit currently prepares an annual "state of the pavements" report with a map for each district showing pavement condition, using desktop GIS tools to prepare the maps. It currently takes a total of 40 hours of a skilled GIS professional to export data from the PMS, import it into a GIS database, manually fix location errors, create the maps, and format output for the report.

They estimate that they can cut this time down to one hour by developing a standard mapping function to produce the maps directly from their PMS, and enhancing the QA process for PMS data loading to check for valid location information.

Efficiency Benefits—Using Future Products and Services as the Baseline

State DOT "D" would like to begin producing decision maps for each district to help it scope rehabilitation projects, taking into account traffic, crashes, pavement and bridge condition, and results of safety studies.

They define two options for producing these maps: (1) a manual option in which an analyst downloads data from multiple systems and uses a desktop GIS tool to produce the maps and email PDF versions to each district; and (2) an automated option in which the relevant data layers are pulled in to a central GIS portal and a custom map view is set up to show the information of interest.

They estimate that for scenario 1, it would require 100 hours of effort to produce maps each time (once a year). For scenario 2, they estimate roughly 16 hours of effort per year to handle adjustments to data sources and updates to the standard maps.

Effectiveness Benefits

Effectiveness benefits from GIS/TAM initiatives are due to improvements in decision support capabilities. By integrating and analyzing data spatially and presenting it in an effective manner, the quality of information available to decision making is improved. Presumably, this enables better decisions that, in turn, result in lower risks, lower life-cycle costs for assets, and improved customer service. Additional effectiveness benefits are associated with increased agility in responding to executive and stakeholder queries and increasing communication capabilities, enhancing the agency's reputation.

Effectiveness benefits are generally more difficult to quantify than efficiency benefits. However, the following types of benefits can be quantified based on stated assumptions about how the new GIS/TAM capability might be expected to affect decision making:

- **Safety improvements**—if capabilities are used to better integrate safety considerations into project scoping and prioritization processes, agencies can estimate an effectiveness benefit based on risk reduction—quantified by projected decrease in the rates of fatalities, injuries, and property-damage crashes associated with the improved capabilities.
- **Asset treatment selection**—if capabilities are used to identify and prioritize optimal intervention points for preventive and restorative maintenance, agencies can quantify benefits based on risks of applying the wrong treatment—either too much (wasted resources for unnecessary work) or too little (deficiency reappears and needs to be re-addressed prior to normal life cycle for treatment). Agencies can also estimate reduced failure risks for critical assets, potentially leading to lower insurance costs.
- **Construction costs**—if capabilities are used to improve project scoping and to avoid delays and change orders associated with the late discovery of new information, agencies can estimate an effectiveness benefit based on average cost reductions for some percentage of projects.
- **Project coordination**—if capabilities are improved to avoid conflicts across projects or maintenance activities—e.g., coordinate paving and utility projects; avoid closing a main and alternative route at the same time; benefits can be quantified based on cost savings from combining projects rather than doing them separately, and reductions in lane closures and associated user costs.

Summary of Efficiency and Effectiveness Benefits by TAM Business Area

Table 10 summarizes the types of benefits that can be achieved through using GIS for TAM.

Table 10. Value Added by GIS-TAM Capabilities

Business Area—Function	Efficiency—"Doing Things Right"	Effectiveness—"Doing the Right Thing"
Understand State of the Assets—GIS Data Collection	*Lower data collection costs* by: • Collecting multiple assets in a single data collection effort • Automating location assignment using standard methods and tools • Optimizing inspection routing • Using mobile devices loaded with existing inventory to speed collection *Reduce risk of injury* to data collection personnel by: • Using in-office GIS tools for asset extraction from video or LiDAR data	*Improve accuracy of information*, reducing risks associated with decisions based on faulty information, and maximizing value for decision making by: • Using GPS to accurately capture location information • Using GIS to aid in quality assurance—visualize data gaps and anomalies
Understand the State of the Assets—Mapping and Communication	*Reduce staff time* by: • Providing self-serve maps that cut down on the need for staff to fulfill special information requests and allow new staff members (and consultants) to quickly get up to speed • Automating mapping tasks currently accomplished on an ad-hoc, manual basis	*Improve awareness of asset condition across the agency* by: • Providing a rich, easily accessible data source integrating imagery, asset characteristics, and condition

Business Area—Function	Efficiency— "Doing Things Right"	Effectiveness—"Doing the Right Thing"
Assess and Manage Risks—Risk Analysis and Disaster Recovery Planning	*Facilitate disaster recovery* by: • Providing a readily available data source on asset type, location, and condition	*Lower agency risk exposure to asset failure* by: • Developing and using a robust information base for risk assessment and mitigation *Lower insurance costs* through: • Demonstrating use of preventive maintenance to lower failure risks for critical infrastructure
Identify Needs and Work Candidates	*Reduce staff time needed for data manipulation and analysis* by: • Speeding integration of data from different sources using spatial overlays and automated partitioning/aggregation of linearly referenced data • Providing a platform for collaboration—common view of information across multiple work units—eliminating need to duplicate data integration tasks	*Identify and scope candidate projects* that extend asset life, improve safety, minimize traffic disruption, and reduce risks of adverse environmental impacts by: • Integrating data that allows for identification of root causes for poor performance • Integrating data that facilitates consideration of safety and environmental factors in determining maintenance and rehabilitation need • Using spatial views of asset needs to identify opportunities for efficient packaging of work
Develop Programs—Prioritization and Tradeoff Analysis	*Reduce staff time* needed for scenario analysis by: • Automating and speeding data integration and presentation tasks	*Maximize use of available resources* by: • Bringing together multiple data sets that facilitate priority setting • Providing capabilities for visualization of the implications of different fund allocation scenarios • Providing capabilities to easily review a proposed program for geographic balance

Business Area—Function	Efficiency— "Doing Things Right"	Effectiveness—"Doing the Right Thing"
Develop Programs—Internal and Public Outreach and Communication	*Reduce staff time* needed to support decision makers by: • Reducing agency staff time responding to information requests and preparing presentation materials for agency executives	*Enhance public image and increase support for funding* by: • Improving ability to communicate agency plans to customers and elected officials • Equipping agency executives with intuitive, self-service tools for "telling the story" about asset needs and program choices
Manage and Track Work—Proactive Work Scheduling and Coordination	*Reduce time and cost of maintenance activities* by: • Reducing the proportion of reactive maintenance through systematic planning of preventive maintenance using spatial data • Reducing need for return visits to bring additional equipment or materials due to proactive planning • Coordinating timing of activities involving similar skill sets and equipment within the same area	*Minimize customer impacts* by: • Packaging work to coordinate timing of multiple activities requiring lane closures • Reducing risk of asset failure impacting traveler safety or mobility through proactive approach to maintenance
Manage and Track Work—Work Request Management	*Increase efficiency in deployment of maintenance resources* by: • Facilitating location of work requests and assignment to the appropriate work unit • Automating work requests	*Enhance agency responsiveness to customers* by: • Providing easy ways to report issues (e.g., via mobile apps) • Providing maps showing status of work requests *Minimize customer impacts* by: • Reducing risk of asset failure impacting traveler safety or mobility through faster identification of issues

Business Area—Function	Efficiency— "Doing Things Right"	Effectiveness—"Doing the Right Thing"
Manage and Track Work—Real-Time Tracking and Mobile Apps	*More efficient deployment of available staff and equipment* by: • Using real-time location tracking information to identify the closest crew • Lowering administrative costs for record keeping • Improving ability to select most cost-effective delivery method—through comparing in-house unit costs to private-sector bids for similar work • Improving situational awareness for dispatchers and field crews	*Improve accountability* through: • Providing current information on work progress and status • Providing timely information on work accomplishment and budget status • Documenting work through "before" and "after" geo-tagged photos *Improve ability to optimize asset treatment* by: • Using a rich information base on locations with high recurring responsive maintenance costs • Improving access to work history information to help identify root causes for premature failure

Step 5: Identify Risks

Identification of risks is an important part of developing the business case for a significant GIS/TAM investment. It is important to identify risks for each of the options, including the no action option.

A risk analysis allows agencies to:

- *Examine assumptions* about how much the initiative will cost, examine what benefits will be realized, characterize the uncertainties inherent in these assumptions, and, if possible, quantify the impacts of higher and lower values of costs and benefits on project feasibility and worthiness;
- *Identify factors that could impact project success* or feasibility, and develop mitigation strategies and contingency plans for each identified risk factor; and
- *Highlight current vulnerabilities that an agency may have* that could be reduced or eliminated by undertaking the GIS/TAM initiative (e.g., ability to meet pending federal requirements).

Many agencies have established risk assessment and risk management procedures in place for major information technology projects that can be adapted to examine risks associated with significant GIS/TAM investments. The following types of risks should be considered for GIS/TAM initiatives:

- **Organizational change**—future changes in leadership, key personnel, or shifts in priorities may jeopardize the funding or management support for the effort. This is a particular concern for initiatives that will require several years to complete. Mitigation strategies include building a stronger base of support within the agency to reduce reliance on one or two key individuals, and/or pursuing a phased approach with concrete results after each phase.

- **Technology change**—rapid improvements in technology can mean that the tools or architectural approach selected at the start of the initiative may be obsolete or relatively inefficient by the time it is complete. It is important for agencies to be cognizant of where technologies are heading when embarking on a new initiative.
- **Cost uncertainty**—costs may be higher than anticipated to due unforeseen issues. For GIS/TAM initiatives, major risk factors include time required to clean up or convert legacy data sets, time to fix or work around data quality issues in the agency's linear referencing system, unanticipated complexities in integrating management systems and "scope creep" for custom application development when requirements aren't clearly defined or there isn't a process for iterative development built in.
- **Benefits uncertainty**—benefits estimates are necessarily based on a set of assumptions about what the initiative is expected to accomplish, and how it will impact efficiency and effectiveness of agency business processes. If these estimates are too optimistic, they won't be credible and will overstate the likely ROI of the initiative. If these estimates are too conservative, the ROI will be understated and the agency may miss out on an opportunity to improve.
- **Funding or support uncertainty**—the organization lacks the management commitment and alignment to ensure a successful implementation. It is important to confirm that the necessary level of support and internal cooperation required to implement the initiative is there.

Benefit-Cost Assessment Using Monte Carlo Simulation

The Oregon Department of Transportation conducted a benefit-cost analysis of nine GIS tools implemented as part of a major bridge delivery program. In order to reflect uncertainties, they represented some of their assumptions as probability distributions rather than fixed values, and employed Monte Carlo simulation to analyze how variations in benefits and costs would impact the analysis. They presented the results in terms of the most likely value of the benefit-cost ratio as well as low and high range values. For example, results for the nine tools showed a most likely benefit-cost ratio of 2.1 with a range from 1.8 to 4.1.

Source: reference [7]

Step 6: Put It All Together

The final step in assembling a business case is to pull all of the information together, look at the results, and determine which option(s) have the strongest potential to achieve an agency's objectives with a positive return on investment.

A quantitative ROI or benefit-cost analysis will strengthen an agency's business case. Based on the benefits and costs the agency has estimated in steps 3 and 4, it can develop estimates for each of the options. There are several templates available to help an agency—see, for example, reference [4]. In developing an agency's analysis, there are several challenges that the agency will need to recognize in presenting its results:

- **Acknowledging uncertainty.** Prospective (as opposed to retrospective) ROI analyses rely on a variety of assumptions about how the new capabilities will be used and what impacts they will have. Uncertainty can be incorporated into the analysis through defining high and low values for assumptions, or (as noted in the Oregon DOT example above) use a probabilistic approach employing Monte Carlo simulation.

- **Quantifying intangible benefits.** Intangible benefits such as improved decision making and enhanced customer responsiveness. Time savings through automation of currently manual functions is the most straightforward benefit to analyze; other benefits do not lend themselves as well to prediction and quantification.
- **Accounting for changes in behavior.** Technology investments enable new types of analyses that would previously have been cost prohibitive to pursue. After implementing a new GIS system, one might find that staff are spending more time on analysis rather than less. However, their decisions are presumably being improved based on new information available.

Given the difficulty of quantifying improvements in effectiveness, an agency will want to feature a description of the qualitative benefits that it expects, including concrete examples where possible.

The following example illustrates the entire six-step process for developing a business case.

Example: Adding Agency-Wide Geospatial Capabilities for Program Development

Business Need

State DOT "E" has a robust annual and multi-year program development process with both decentralized (district-level) and centralized components. To assess roadway asset needs and performance, both districts and headquarters offices rely on data from management systems that are not integrated, including pavement management, bridge management, and roadway crash information. Although the agency has a functioning GIS and the roadway inventory, structure inventory, and pavement conditions can be mapped through the agency GIS, these systems are not fully integrated for access through the GIS view. In addition, the multi-year and annual program components are not currently geocoded through the agency's GIS, so there is no systematic way to map or analyze locations of programmed projects.

A new asset management committee was formed to develop a more integrated program development process involving a greater degree of coordination across pavement, bridge, safety, and traffic engineering improvement projects. Their goal is to provide a common view of asset condition, safety, and programmed projects that can serve as the basis for project scoping and prioritization that reflects multiple needs.

Options

The committee defined three options:

1. No change—continue current practice of regular meetings across the different asset managers and district staff to review needs and discuss coordination opportunities.
2. Modify the current program management software to require mapping of candidate project locations; task the central GIS group with producing a map showing needs and project locations based on data exports from each management system.
3. Build a GIS tool for defining candidate projects that enables each work unit to view needs from each management system.

Identify Costs

The committee estimated the following costs for the different options:

	Option 1	Option 2	Option 3
Initial Costs			
A. Planning	$0	$15,000	$30,000
B. Software Development	$0	$100,000	$150,000
C. Data Integration	$0	$0	$50,000
D. Training/Change Management	$0	$75,000	$100,000
Total Initial Costs	**$0**	**$190,000**	**$330,000**
Ongoing Annual Costs			
A. User Support	$0	$10,000	$20,000
B. Mapping	$0	$25,000	$0
C. Application Maintenance	$0	$5,000	$5,000
Total Annual Costs	**$0**	**$40,000**	**$25,000**
NPV of Costs over 10 Years (3% discount rate)	**$0**	**$531,208**	**$543,255**

NPV = net present value.

Example: Adding Agency-Wide Geospatial Capabilities for Program Development (continued)

Identify Benefits

Interviews with staff in the pavement, bridge, and safety units were conducted to walk through their current work process to prepare for program coordination meetings. In addition, interviews with district office staff were conducted to understand what data they used from the asset, safety, and program management systems and how much time they spent on data retrieval, reporting, and mapping tasks. Based on these interviews, the committee estimated the following efficiency benefits for options 2 and 3, relative to option 1 (the baseline):

- Annual savings in pavement, bridge, and safety unit staff time to prepare data for meetings and respond to questions about needs and plans: $30,000—savings of $255,906 over 10 years.
- Annual savings in district office staff time to prepare maps of project locations based on descriptions in the Program Management system: $15,000—savings of $127,953 over 10 years.

Differences between options 2 and 3 in terms of efficiency are related to the need for manual preparation of maps for option 2. This was accounted for in the cost analysis.

Total efficiency benefits were estimated at $383,859 over 10 years.

With respect to effectiveness benefits, the committee felt that having well-defined maps showing needs and project locations would result in improved project scoping that considers multiple needs—above and beyond what would be accomplished via the current process. They also felt that it this would result in more effective program development, providing the ability to account for needs of multiple assets as well as safety in project prioritization and tradeoffs. Finally, they felt that options 2 and 3 would improve the agency's external relationships, providing the ability to communicate agency plans to customers and elected officials. They hypothesized that option 3 would have the largest benefit since it integrated the GIS tool more directly within the project development workflow, and therefore would have relatively greater influence on decision making.

Identify Risks

The committee felt confident in the cost estimates and efficiency benefit estimates; the agency had carried out software development efforts of similar scale and complexity in the past, using similar technologies and drawing on the same pool of in-house and consultant resources as they anticipated would be available for this new effort. The major area of risk to be mitigated was to ensure that the intended users of the new capabilities were on board and were amenable to changing their current project scoping and prioritization processes. To mitigate this risk, they developed a change management plan including extensive user involvement in the application development and testing process.

Summarize

The team decided that rather than trying to quantify the effectiveness benefits, they would subtract the efficiency benefits from the costs and consider whether the effectiveness benefits were worth the net costs:

- Net costs for option 2: $147,349 over 10 years.
- Net costs for option 3: $159,396 over 10 years.

They compared these amounts to the scale of the pavement and bridge maintenance and rehabilitation program—projected to be $2.5 billion over the 10-year period. The net costs represented less than .06 percent of the program costs. They determined that the effectiveness benefits were worth far more than the net costs given the opportunity they represented to spend the available funds more wisely and enhance the agency's external accountability.

4. Getting It Done: Ingredients for Success

The Seven Ingredients for Success

The success of any *individual* GIS/TAM initiative depends on a sound project plan that ensures management support, involvement of the right people in the organization, selection of the right technologies, and a skilled and committed team. This section looks at the bigger picture and summarizes the essential ingredients for success in using GIS as an enabler for more integrated, spatially-enabled decision making.

Figure 12 below illustrates the building blocks for a GIS/TAM program that enables an agency to create and sustain a powerful set of spatially-enabled data for TAM decision support and communication—in a cost-effective manner.

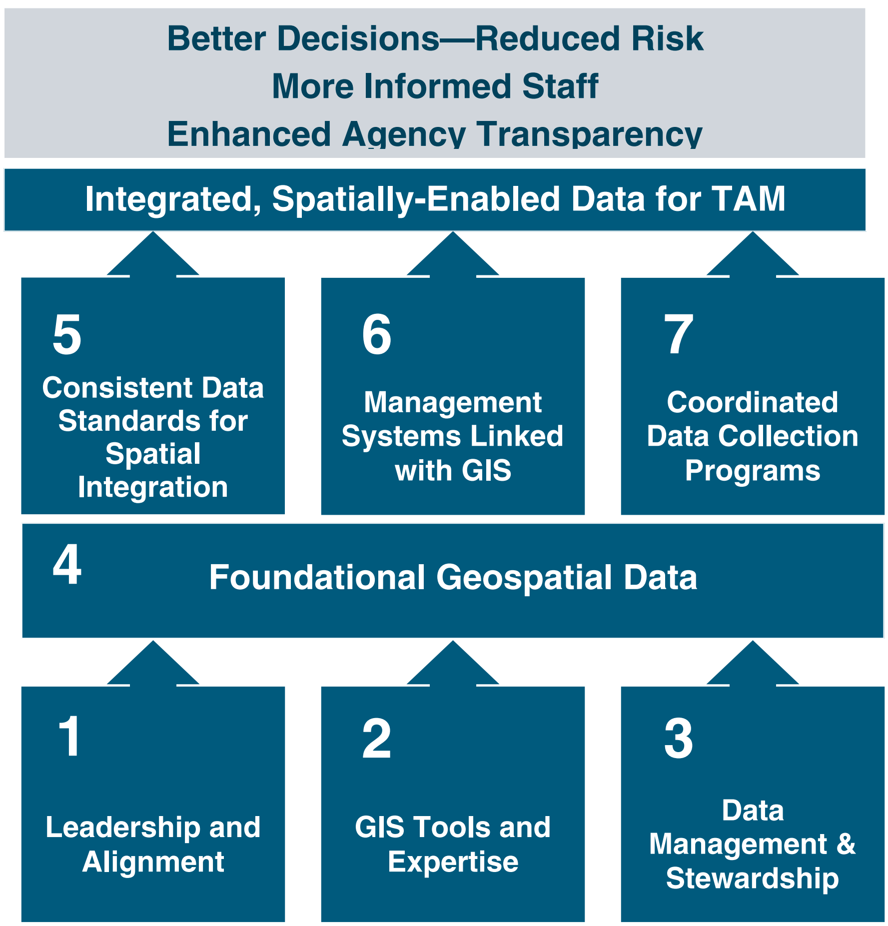


Figure 12. Ingredients for a Successful GIS/TAM Program

The three pillars at the bottom are required to support the program:

1. **Management commitment and organizational alignment.** An appreciation on the part of agency executives and division managers for how a spatial approach to asset management

can benefit the agency is essential, since they must provide the leadership to make something happen. A shared vision for use of GIS across functional areas is needed to achieve the integration across data sets and systems that leads to substantial payoffs. Achieving this shared vision requires education and discussion to build awareness of the different levels of GIS integration with asset management.

2. **Accessible GIS tools and expertise.** Individual work units that play a role in TAM must have access to GIS tools and expertise so that they can fully integrate use of GIS into their daily workflow. They need to have a comfort level that allows them to view GIS as a standard tool in their toolbox—in the same category as spreadsheets and diagramming software.
3. **Well-defined and proactive data management and stewardship.** The agency must have established roles, responsibilities for quality assurance and updating of spatially referenced data sets, and protocols for sharing them and making them available as map layers.

Once there is management support, a shared vision, tools and expertise, and a data management and stewardship framework, the work of preparing and integrating data and converting this data into information for decision making can proceed in an efficient and focused manner. Essential ingredients in making this happen are:

4. **Accurate and complete foundational geospatial data.** The agency must have accurate and complete geospatial data that provides the foundation for mapping, analysis, and location referencing.
5. **Spatially integrated data sets.** There must be standards and practices to ensure consistent spatial referencing across different agency data sets to facilitate integration for mapping and analysis.
6. **Management systems linked with GIS.** Many transportation agencies—especially state DOTs—make use of multiple disparate systems for road inventory, HPMS, pavement, bridge, traffic, safety, maintenance, program development, and financial management. Tight integration of these systems with a common GIS/LRS allows multiple data sets to be combined for analysis.
7. **Coordinated data collection across the agency.** A coordinated and consistent approach across business units to collecting asset inventory, condition, and work accomplishment data in the field enables the organization to achieve economies of scale and spread the cost of investments in new technologies across multiple data collection efforts.

These ingredients were identified because they represent areas in which agencies may need to focus attention in order to address common implementation challenges. Challenges can be related to leadership, personnel, data, technology, or general resource limitations. These challenges can present roadblocks to progress, but can also be viewed as opportunities for achieving true gains in agency efficiency and effectiveness. For each of these seven ingredients, potential strategies for success are presented that agencies can consider as they tackle specific challenges.

Ingredient 1: Management Commitment and Organizational Alignment

Essentials

An appreciation on the part of agency executives and division managers for how a spatial approach to asset management can benefit the agency is critical, since they must provide the leadership to make something happen. Asset and program management business unit managers need to understand and recognize opportunities for using GIS to gain efficiency and effectiveness and to manage risk.

In order to undertake initiatives requiring multi-year investments in foundational geospatial data, tools, and technologies, sustained executive support and a coordinated agency approach is required. A shared vision across the agency for use of GIS can help to build support and ensure the level of cooperation needed to achieve true integration of information and its associated benefits.

Common Challenges

Challenges faced by agencies that have not achieved management support and alignment include:

- A lack of management awareness within business functional areas (e.g., pavement, bridge, maintenance, program development) of potential value added through geospatial analysis.
- Independent and inconsistent or duplicative GIS efforts within individual business units.
- The inability to justify investment for new systems and data initiatives given resource limitations and competing priorities and perceived risks associated with implementation of new technologies.
- Difficulty of implementing initiatives with a multi-year payback horizon, particularly given limited tenure of agency leaders.
- An emphasis on day to day putting out fires rather than longer-term process improvements.
- A tendency to focus on the specific responsibilities of the business unit, even when greater collaboration with other units would result in greater benefits to the agency as a whole (e.g., safety and pavement management).

Strategies for Success

- **Education.** Build awareness and support for GIS initiatives across a broad coalition of middle managers to support sustained multi-year efforts across changes in senior leadership. Provide opportunities for business functional-area managers to learn about successful applications of GIS technology through training courses and peer exchanges.
- **GIS Strategic Plan.** Develop a strategic plan for GIS implementation (or build on an existing plan by developing a GIS element for the TAMP). Involve key stakeholders from multiple business units to build consensus on the approach.
- **Plan for the Long Term.** Define a multi-year program of GIS investments to spread costs over time and ensure agency capacity to absorb changes to processes and applications.
- **Business Case.** Document a solid business case for particular initiatives, demonstrating alignment with agency mission and priorities, and document (as well as quantify where possible) enterprise-wide benefits and costs.
- **Pilots.** Use pilots to demonstrate feasibility and benefits prior to a major commitment of resources.
- **Build Bridges.** Encourage opportunities for collaboration across the stovepipes where there may be benefits to the agency as a whole.

GIS in Maryland—the Power of Leadership

Support for GIS at the state level in Maryland has been strong due to a governor that has been quoted as saying, "If it isn't on a map, it doesn't exist." The governor learned firsthand about the power of GIS from his experience as mayor of Baltimore with the CitiStat program. Maps were the centerpiece of this highly successful performance management program, credited with achieving a substantial percent reduction in violent crime. The governor has brought together state and local government to build a statewide base map, providing the foundation for the state highway agency's enterprise GIS program that includes a spatial asset data warehouse.

Ingredient 2: GIS Tools and Expertise

Essentials

While most DOTs do have GIS software and skilled GIS professionals, successful integration of GIS within TAM business processes requires that staff within units responsible for specific assets (e.g., pavement, bridge, safety) as well as staff with cross-asset program development responsibilities have access to GIS tools and data, and the expertise to know how to use these tools to conduct analysis. They must have access to available agency GIS support resources including training and assistance with GIS software configuration and data access. There must also be open communication channels between agency GIS support unit and asset management staff to ensure that technology decisions are being made to maximize business value.

Common Challenges

- A lack of GIS skills within business units responsible for asset and maintenance management functions and/or lack of knowledge about potential applications that would save time or add value.
- Insufficient communication between central GIS units and the potential user community to understand application needs and priorities.
- A lack of tools that allow users without formal GIS training to view and analyze geospatial data.
- No centralized repository or catalog of available data from internal as well as external agency sources—making data discovery difficult or time consuming at best.
- A lack of tools for downloading and exporting data in suitable formats.

Strategies for Success

- **Central GIS Function.** Establish a focal point for GIS in the agency to set the strategic direction, prioritize investments, manage enterprise technologies and data, and provide support.
- **Provide Tools for Casual Users.** Build and deploy applications that automate access to GIS data and enable casual users to create maps and overlay data sets. Tailor GIS applications to the needs of specific user groups.
- **Central Data Catalog.** Provide a central GIS data catalog with standard metadata for each GIS data set. Allow users to download data in multiple formats.
- **User Group.** Establish a GIS user group for information sharing about technologies, tools, and applications. If a user group already exists, encourage staff from asset management–related units to participate in meetings.

- **Brainstorming.** Conduct informal brainstorming sessions involving asset management staff and GIS professionals in the organization to identify how to better leverage GIS capabilities.
- **Integrate the Experts.** Provide opportunities for central GIS staff to be embedded within business units or rotate across business units.
- **Hiring and Orientation Processes.** Include GIS and geospatial data management skills in staff job descriptions. Include an agency GIS data and basic applications course as part of new employee orientation.
- **Standard New User Setup Process.** Develop a standard process for setting up a new user and providing the training and documentation they need to get started using agency GIS tools.

Ingredient 3: Well-Defined and Proactive Data Stewardship

Essentials

Agencies are increasingly recognizing that data is an asset in and of itself, and needs to be managed as such. Prior to collecting data, there must be a well thought out plan for how these data will be used and by whom, what are the quality expectations and how they will be verified, where the data will be stored, when and how they will be updated, what other information needs to be integrated, and who will be responsible for day to day and policy-level management of the data. Because GIS data sets typically integrate non-spatial business attributes associated with spatial features, they are particularly susceptible to duplication and synchronization issues. Sound data management practices can be implemented within an individual business unit, but ideally they will be standardized agency-wide. This allows for an efficient centralized support structure to be established for data storage, data quality assurance, metadata management, and access.

Common Challenges

- Ambiguity in who owns the data—making it difficult to establish accountability for data quality.
- Dispersion of data sets throughout the organization, making it difficult to discover what data exists.
- Loss of valuable data sets due to employee departures or hardware failures.
- Outdated data sets with no clear plan or assigned responsibilities for updating.
- Multiple versions of data sets—lack of a single-source system of record.
- Lack of staff resources to perform data quality assurance and updates.
- Data sets in varying formats without sufficient documentation for users to understand the content and limitations.
- Lack of consistency in coding of fields needed for linkage across data sets—such as district, organizational unit, jurisdiction, fiscal/calendar year, project number, etc.

Strategies for Success

- **Data Business Plan.** A data business plan effort can be undertaken to systematically identify what data are needed by different functional areas and to lay out a coordinated plan for collecting, updating, managing, and providing access to the data.
- **Data Management Roles and Responsibilities.** Roles and responsibilities for GIS data management can be defined with a process to assign these roles to specific individuals for each data set—with the support needed to ensure that these individuals have the knowledge, time, and resources needed to meet their responsibilities.

- **Data Management Standard Practices.** Standard management practices for GIS data sets—including designation of the single source system of record, naming conventions, storage and backup protocols, metadata standards, cataloging, retention policies, and procedures for protection of sensitive information.
- **Geospatial Data Catalog.** Maintain an up-to-date catalog of geospatial data sets within the agency, providing access to standard metadata, including clear identification of the update cycle and responsible business unit or individual.

Ingredient 4: Accurate and Complete Foundational Geospatial Data

Essentials

Agencies embarking on GIS/TAM initiatives need to have accurate foundational geospatial data, including a base map, road centerlines, and an LRS that provides the backbone for integration of roadway and asset data. In addition, it is important to have high quality basic road inventory data including fundamental geometric and administrative characteristics, as well as accurate and up-to-date jurisdiction boundaries and district or regional boundaries that define maintenance responsibilities. Each of these foundational elements must have a regular and well-defined updating process, data management, and refresh processes that ensure use of the most current data from the designated source system of record.

Common Challenges

- The lack of a single, authoritative, and centrally managed LRS.
- The lack of a consistent approach to managing and coordinating changes in the LRS over time.
- Poor quality of foundation data (e.g., road centerlines and routes) is an impediment to mapping and integrating asset data.
- Gaps in geospatial coverage of road inventory data.
- Road inventory elements such as number of lanes and pavement type are maintained in separate databases and not kept in sync with a master source system of record.
- A lack of quality and consistency across other core geospatial data sets including jurisdictional boundaries, district/region boundaries, and road inventory data.

Strategies for Success

- **Standardize Core Data.** Implement a centrally-managed LRS with multiple referencing methods reflecting agency business needs, drawing upon commercially available applications as appropriate.
- **Collaborate.** Build foundation data utilizing both internal agency resources and coordination with external partners.
- **Investigate Commercial Data.** Negotiate with private data providers to determine whether data purchase may be more cost effective than in-house collection and maintenance.
- **Assess and Improve Quality.** Develop and report data quality metrics for core geospatial data sets including road centerlines, jurisdiction boundaries, district or region boundaries, and road inventory.
- **Implement Standard Update and QA Processes.** Define roles and responsibilities for updating road centerline and LRS information as the road network changes. Make use of field-collected data for asset management to check and improve road network data quality.

- **Incorporate Technology.** Utilize new technology to automate existing data collection processes and ensure accuracy.

> **Ohio DOT: Benefits from Common Spatial Referencing**
>
> "By analyzing business processes, the Ohio DOT realized that users at different levels were repeatedly making business decisions that required asset information that was stored in disparate systems. There were problems in decision making and delays in answering questions. The GIS area was getting an increasing number of requests for project maps that required tedious manipulation of data from different systems and the resulting data accuracy was questionable.
>
> The Ohio DOT recognized that having a common location referencing system is critical for integrating systems. The various systems all had elements of referencing systems, but all had problems with data integrity, domains, and consistency. The Base Transportation Referencing System (BTRS) was designed to address this data quality and integration problem. BTRS integrates application systems through a common identifier. The BTRS framework is the basis for consolidating the different inventories to a single linear referencing system."
>
> Source: reference [8]

Ingredient 5: Consistent Data Standards Enabling Spatial Data Integration

Essentials

Core data sets required for asset management such as asset inventory, asset condition, traffic, crash, capital projects, and maintenance work records need to include consistent location referencing that allows them to be spatially integrated. This is a major hurdle to overcome in many agencies. Tools for combining linear event data (e.g., pavement sections, traffic links, projects) based on different segmentations must be easily accessible to analysts supporting asset management units.

Common Challenges

- Variations in the location referencing methods across data sets that prevent data sets from being mapped or placed on the established LRS. Foundational GIS and LRS data may be in place, but this problem can be faced if LRS standards are not followed.
- Existence of data sets with varying levels of accuracy—collected by different organizational units using varying techniques at different scales and with different attributes.
- Programs for asset inventory or inspection may have been established prior to the development of agency-wide location referencing standards.
- The agency's central LRS is less accurate or less up to date than other LRSs, making business units unwilling to use the central system until data quality issues are corrected.
- A lack of automated tools for combining data sets based on different segmentations of the network.
- A lack of consistency in data collection processes, creating discrepancies in data collected at different times and on different versions of the network—data collected at different points in time may reference locations that have undergone changes in route designations.
- GPS data collected without following standard protocols to ensure an acceptable level of accuracy or precision.
- A lack of tools and methods to match up GPS-located data with the agency's road network data.

- Data collected without precise referencing (e.g., just a county and route) or using informal location referencing—e.g., with text references to mile markers.
- Data collected using street names rather than official route designations or referencing overlap routes as opposed to the master or primary route designations.
- Data referenced to jurisdiction boundaries based on signage that doesn't match with official boundary locations in GIS data sets.
- Lack of tools and procedures for QA and translation from coordinates to linear referencing.
- The agency lacks a designated function to perform proactive planning and coordination to identify business needs for data integration.

Strategies for Success

- **Standardize.** Develop policies and standards for new data collection, contractor-supplied data sets, and system development to ensure consistency with enterprise LRS.
- **Define Data Integration Requirements.** Review specific business requirements for integrating multiple data sets and establish necessary protocols for quality assurance, timing of updates, and geospatial level of precision.
- **Define Trend Analysis Requirements.** Review business requirements for location-specific trend analysis and other uses of historical data sets to ensure that requirements related to temporality are met.
- **Convert Legacy Data.** Undertake efforts to attach consistent geospatial referencing to existing data sets, using automated or semi-automated processes where possible.
- **Provide Tools.** Develop/acquire tools for converting across different referencing methods, dynamic segmentation, and partitioning across multiple linearly referenced data sets. Provide access to these tools to both GIS/IT staff and business users.

Ingredient 6: Management Systems Linked with GIS

Essentials

Asset and maintenance management systems—which serve as the focal point for review of asset conditions, needs, development of work candidates, and program/project management systems that maintain information about proposed and programmed projects—should be spatially-enabled to allow for convenient analysis. Each management system should be linked to the agency's core geospatial data, including its LRS. This allows for information from each system to be brought together for analysis and presentation, using the full array of GIS tools and applications that the agency has available.

Today's commercial asset and maintenance management systems include integrated GIS functionality or can be configured to integrate with an agency's GIS data and tools. Assuming that each management system uses one (or more) of the agency's standard location referencing method(s), the key challenge in making this integration work is keeping the management systems in sync with the agency's LRS as the road network changes. This is relatively straightforward for agencies that have a single integrated GIS-centric asset management system. However, when an agency has several different management systems (as most state DOTs do)—for pavement, bridge, road inventory, safety, traffic, signs, signals, etc.—keeping networks in sync can require considerable effort. Some agencies use a snapshot approach, refreshing spatial data across systems on an periodic (e.g., annual) basis. Live spatial integration across systems has been implemented, but involves greater complexity and must be carefully planned and orchestrated.

Common Challenges

- Asset and maintenance management systems were built with their own internal methods for location referencing and management, and are inconsistent with the agency's GIS/LRS maintenance systems.
- Data from different asset management systems cannot be easily integrated due to inconsistencies in location referencing and/or lack of tools to convert across referencing methods.
- Projects and maintenance activities are not spatially located in a standard way, making it difficult to overlay this important information with asset inventory and condition data.
- Location referencing for data within asset management systems gets out of sync with the agency's master network as updates are made.

Strategies for Success

- **Target Architecture.** Develop a target system architecture that integrates GIS/LRS, asset management, maintenance management, and program/project management systems. Develop a strategy for moving toward the target architecture as legacy systems are replaced or upgraded.
- **Software-Neutral Design.** Implement a database-centric, software neutral approach that maintains agency flexibility to utilize a variety of off-the-shelf tools and takes advantage of new products as they come available.
- **Standard Interfaces.** Develop standard interfaces to synchronize location referencing and to enable the management of asset and work locations within the central GIS/LRS while managing business data within the asset management system maintenance management system (MMS).
- **Standardize Practices for Locating Construction Projects and Maintenance Activities.** Integrate GIS-based interfaces into program and maintenance management systems that allow end users to specify locations for projects and maintenance activities on the agency's LRS.
- **Simplify.** Consider consolidation of asset management software packages to minimize the number of interfaces and simplify data integration processes. Benefits from simplification need to be weighed against costs of system transition, the need to meet specialized requirements, and the desire to avoid risks that may be associated with over reliance on a single vendor.
- **Leverage ERP Initiatives.** If an agency is undertaking an ERP implementation, use this as an opportunity to standardize interfaces between management systems for asset inventory, maintenance, and project/program management and the agency's GIS/LRS.

Ingredient 7: Coordinated Data Collection Across the Agency

Essentials

A coordinated approach to data collection across business units responsible for different assets can save the agency money and make it easier to ensure that data are collected using consistent and compatible spatial referencing methods. There may be opportunities to collect information for multiple assets at once (e.g., through use of video and remote sensing techniques) or to use the same field equipment and data collection software for several different assets. There may also be opportunities to update inventory and condition data based on work accomplished in a consistent manner across multiple assets.

Common Challenges

- Resistance on the part of individual business units to change longstanding data collection programs that meet their specific needs and feed decision support systems.
- A lack of incentives to coordinate data collection efforts across business units.
- Variations in requirements for data collection frequency, accuracy, and precision across business units.
- A lack of a one-size-fits-all data collection solution to meet diverse requirements for accuracy and precision.
- Inability to coordinate funding or timing for multiple special purposes or one-shot efforts that are not planned well in advance.
- A lack of coordination between business units planning data collection and central IT units to provide storage and access for new data sets, contributing to data silos.
- Network and telecommunications limitations preventing reliable communication between field devices and source or target databases.
- Costs associated with new data collection hardware and software acquisition.

Strategies for Success

- **Data Business Plan.** Develop a data business plan that reviews the cost, efficiency, and scope of data collection efforts and that identifies opportunities for consolidation and application of new technology while recognizing a need for multiple approaches to meet business requirements.
- **Standardize.** Develop centralized data collection standards, processes, and training along with consistent approaches to location referencing and links to existing asset inventory data across data collection efforts.
- **Data Collection Review Process.** Develop criteria for undertaking new data collection efforts and a phased approach for adding new data sets.
- **Consolidate.** Build on a single existing data collection program (e.g., video logging) to meet multiple needs.
- **Pilot New Technologies.** Pilot test new data collection technologies [e.g., light imaging detection and ranging (LiDAR)] with multiple business units.
- **Outsource.** Consider outsourcing development of data collection apps and/or data collection and quality assurance processes.
- **Cloud Storage.** Consider cloud-based data storage and access to reduce hardware demands.

Case Studies

The following case studies demonstrate how the ingredients for success have been utilized to advance asset management practices in several states. Each case study focus on a different aspect of GIS implementation and application.

West Virginia DOT: Integrating Leveraging ERP Implementation for Advances in Asset Management and GIS

West Virginia DOT (WVDOT) is responsible for maintaining almost 39,000 miles of roads, which represent the majority of the state's public roads. Until 2005, WVDOT did not have a GIS unit or any geospatial applications. The agency had purchased GIS software, but had not really begun to use GIS to manage its infrastructure or any of its assets.

> The introduction of GIS has had a very positive impact on WVDOT's ability to visualize and combine data in ways not possible before the agency adopted a geospatial foundation for data integration. GIS has provided the agency with large financial benefits resulting in the savings of several million dollars in tax payer dollars due to more efficient reporting and analysis. In addition, WVDOT is now working on integrating its geospatial technologies with the agency's asset management systems through the state wvOASIS project. This ERP project will result in the DOT's ability to be more proactive in addressing safety and highway improvement needs.
>
> - Hussein Elkhansa, Geospatial Transportation Information Section Head

In 2007, WVDOT developed a geospatial strategic plan to guide implementation of GIS both within the planning division and across the agency. Part of the plan was to adopt a consistent route ID format to be used as a unique identifier for each state-maintained route. This standard route ID was then required to be used in all of the DOT's business data systems, allowing for integrated viewing of assets and events in geospatial applications.

In 2012, the state of West Virginia began a major ERP project called wvOASIS. The goal of the project as stated in the mission statement is to "gain operational efficiencies and seamless integration across administrative business functions by fundamentally transforming how the State manages its financial, human resources, procurement and other administrative business processes." For WVDOT, the ERP project focuses on implementing several modules of a commercial asset management suite for maintenance, fleet, and safety.

While the wvOASIS project has been underway, WVDOT has made great strides on the geospatial front. The agency has developed a number of geospatial applications that allow for viewing, mining, reporting, and mapping of asset and associated business data. These geospatial applications include a straight-line diagram (SLD) tool with integrated mapping and video log components and a highway performance monitoring system (HPMS) console.

The SLD allows the DOT to view point assets (e.g., culverts, bridges, highway signs, and intersections) and linear assets (e.g., speed limit, functional classification, surface type, and guard rails) along its network. The SLD includes an integrated map that can display thematic information (such as color coding routes based on pavement condition), charting capabilities (pie charts, graphs), asset display and reporting, and redlining capabilities. WVDOT's video log images can also be displayed through the SLD.

The HPMS console provides WVDOT with the tools to track the processes associated with gathering and validating the information needed for the annual FHWA submission. The HPMS fields are displayed as a component of the integrated SLD.

Recently, WVDOT made the decision to implement a commercial off-the-shelf solution for managing its underlying LRS and associated business data. The SLD has been developed to integrate with this solution and will allow for editing data through the SLD format.

With all the advances on both the GIS and asset management fronts at WVDOT, GIS and asset management processes have remained fairly separate. WVDOT has therefore initiated a project to integrate their LRS solution with their commercial asset management systems, which includes packages from two leading vendors. WVDOT is part of a multi-state consortium that is working with leading GIS and Asset Management vendors to set standards that will allow for the exchange of data using modern technologies.

WVDOT made the decision eight years ago to become a leader in the geospatial industry by developing and deploying applications that integrate GIS and asset management technologies. Today the agency has set an excellent example for other DOT's for how to advance an agency's decision-making capabilities in a relatively short period of time.

Washington State DOT: Strong GIS Foundation for Decision Support

WSDOT has developed a mature GIS program that meets multiple business needs throughout the agency, including project planning, programming, design, construction, and maintenance. Key elements of this program include:

- Standard location referencing methods used for road-related GIS datasets—based on state route ID + milepoint—with translation tools for converting across accumulated mileage, milepost marker locations, and GPS coordinates. These translation tools are viewed as a major success factor for the GIS program since they allow for flexibility in data collection method while ensuring a straightforward integration path for data sets collected using different methods.
- A GIS Roadway Datamart containing geospatial data on roadways (lanes, widths, surface types), shoulders, medians, alignments, curves, intersections, speed limits, bridges, rest areas, weigh stations, and other elements. Because WSDOT's core highway inventory system is mainframe-based, the agency uses a data warehousing approach to facilitate access to pre-packaged data sets.
- The GeoData Distribution Catalog which provides web-based access for viewing and downloading spatial data sets, including those in the Roadway Datamart.
- The GeoPortal Map for viewing selected data layers in a web browser, including functional classification, jurisdiction boundaries, interchange drawing diagrams, and WSDOT region and maintenance boundaries.
- The Roadside Features Inventory Program (RFIP) for collecting, storing, and reporting roadside features such as guardrails, culverts, signs, and others in or near the clear zones of highways. This effort consolidated previous efforts within individual business units to collect data and provided a uniform approach that standardized and centralized collection and storage. This approach allowed WSDOT to improve data collection efficiency, data accuracy and consistency, and enhance data access and reporting. The data are used for a variety of purposes, including prioritization of maintenance and safety funds, and environmental regulatory compliance. Currently WSDOT is exploring cost-effective ways to collect and update roadside feature data by capturing information using GPS-enabled mobile devices as part of construction and maintenance processes. For example, maintenance crews update information on culverts while performing routing cleaning.

- The GIS Workbench that brings together an extensive set of GIS data layers in an ArcGIS (thick client) environment (including the roadside features data, collision data, traffic data, environmental data, etc.) and provides specialized tools for spatial analysis and access to as-built plans and imagery, and impact risk screening. This application was originally developed to support environmental analysis, but currently is used more broadly across the DOT and can be configured to meet specific needs. Standard processes have been developed for adding new data layers—including establishment of data owners and update cycles. The application is supported by GIS staff who update the data layers and associated metadata, provide training and support, and conduct periodic outreach to identify enhancement needs.
- WSDOT collects and displays real-time data from maintenance vehicles, including plow location, application of sand and de-icing chemicals, temperature, and surface condition. This information is used to manage winter maintenance activities and deploy trucks to where they are most needed.

Recent examples of how WSDOT has used GIS for decision support related to asset management include:

- Used GIS to analyze a proposal to lower the threshold for triggering pavement treatments to address rutting from 12 to 10 millimeters. Spatial data was assembled on fatalities (six years of data), paving projects with rut depth prior to paving, and rainfall intensity. An analysis of these data indicated that there was no evidence that shifting to the 10 millimeter trigger would have any significant impacts on fatality reduction. While the motivation for considering the threshold change was to reduce fatality risk, the analysis helped to show a negligible level of risk reduction for a change that would require a higher allocation of funds for paving.
- Used GIS to assess Americans with Disabilities Act (ADA) needs for development of a transition plan and targeted program. Spatial data on identified ADA needs identified in 2009 were overlaid with completed paving projects since 2009 in order to assist with identification of remaining needs.

Utah DOT: GIS as a Transformative Technology for Asset Management

Utah DOT (UDOT) provides an example of an agency that transformed itself from GIS skeptic to GIS proponent over a relatively short span of time. This transformation has changed the practice of asset management—enabling the agency to use available information to better target its resources.

Initial Efforts

The agency started with an application in the environmental area—creation of categorical exclusion documents. They succeeded in reducing the process from months to a few days by pulling together available data within a common GIS platform and automating standard processing and display tasks.

> GIS has really changed the way we do business at UDOT.
>
> - Stan Burns, UDOT Director of Asset Management

A second successful effort involved presenting the STIP on a GIS platform. While this was costly to achieve since the project data were not spatially referenced in a consistent manner, the result provided a highly useable tool that allowed legislators to understand the program—and represented a major improvement over the somewhat daunting 400 page STIP document providing tabular listings of each project. The format allowed UDOT to effectively tell the story in a way that they had never been able to before. Through this practice, Utah DOT was able to portray the agency as capable, forward thinking, pro-active, and worthy of consideration for revenue enhancements. GIS was not the single solution that helped to build public confidence in the agency, but it played an essential role in this process. Lawmakers responded extremely favorably to the GIS information provided—they asked "Why haven't you shown us this before?"

UDOT Today

After demonstrating initial success by leveraging existing data, UDOT worked to establish consistent location referencing across data sets. The agency's efforts to establish a disciplined approach to maintaining construction project locations paid off, when before it initially took weeks of effort to map the construction program, now an accurate program map can be created at the click of a button.

At the same time, UDOT pursued development of two applications: UGATE and UPLAN, providing centralized GIS data access and display capabilities. It also invested in obtaining a rich base of high-quality roadway and asset data utilizing LiDAR technologies. The LiDAR data collection effort has included:

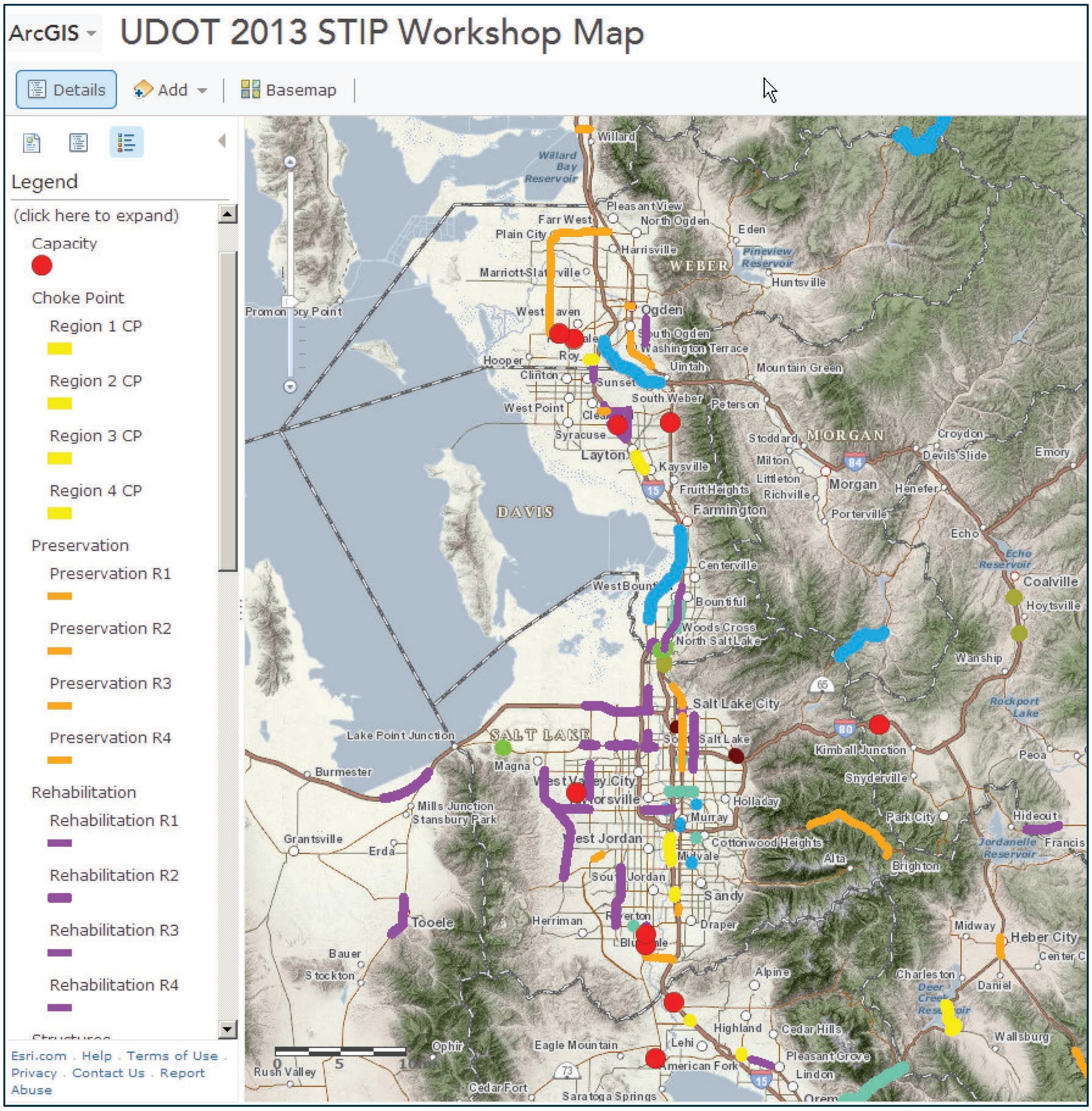
- Pavement surface area and width.
- Shoulders.
- Horizontal and vertical curves.
- Intersections (signalized and unsignalized).
- Bridges (including vertical clearances).
- Retaining walls.
- Bike lanes.
- Medians and barriers.
- Signs (inventory and condition).
- Culverts.
- Drop inlets.
- Guardrails.
- Pavement markings and messages.
- Rumble strips.

UDOT's UGate portal allows users to find and download data derived from the LiDAR collection and other sources in different GIS formats. In addition to the LiDAR elements listed above, data available in UGate includes pavement condition, pavement deflection, HPMS inventory information, jurisdiction boundaries, AADT, crash rates, annual planned paving projects, construction program projects, and long-range plan projects.

UDOT's UPlan provides an interactive mapping platform hosted in the cloud. UPlan features a series of special purpose map views, including:

- A STIP workshop map, providing access to information about proposed projects;
- A pavement management map showing historical and current pavement condition for Utah state roads as well as current, past, and forecasted pavement treatment projects;
- A culvert map showing culvert location, type, size, condition, and maintenance action recommendations; and
- A map supporting data quality assurance for sign retroreflectivity information.

Map 6 illustrates a GIS capability for providing access to information about proposed transportation projects.



Map 6. Provide Information About Proposed Projects

UPlan maps are interactive and customizable, and APIs are provided for development of mobile applications.

Currently, GIS at UDOT is an essential tool not just for displaying the end result of the program development process, but also for developing the program itself—and telling the story of how it was developed:

- UDOT is now able to make use of integrated AADT, crash, geometric, elevation, and asset condition information to target resources where they will have the greatest payoff considering needs for safety, mobility, and preservation.
- Using integrated GIS data, UDOT is able to identify specific locations where asset replacement, rehabilitation, and preservation activities can be coordinated. As an example, the agency created a sign and culvert management program that provides funding for sign and culvert

replacement or repairs that are linked to paving projects. Tailored GIS views are provided to assist in targeting locations based on condition of pavements, culverts, and signs.

- GIS applications are used to assemble data for developing project concept plans considering multiple assets. These applications are used interactively at program development workshops with the Transportation Commission to provide an overview of each candidate project and to zoom in to show road imagery, current conditions, and project details. DOT staff have also used UPlan to distribute maps before meetings, cutting down significantly on time spent reviewing project plan elements and other details.

Use at the Regional Level

Although the technology and tools are still new, UDOT regional offices are already finding GIS to be a valuable tool in conduct of their day-to-day activities. Region 4, in particular, has championed GIS usage for a range of applications and found that it has really supported their ability to do more with less (in terms of resources and staff). Because this region covers a very large area spanning the entire southern half of the state, planning, scoping, and coordinating work is a significant challenge. GIS has helped staff to reduce time spent in the field. They have deployed smartphone apps that allow staff to easily geo-reference information. This information is then made available for statewide access. Some of the ways Region 4 is using GIS include:

> Like most DOTs, we have a finite number of employees. We can't do more with less if we keep doing things the same way—it is necessary to embrace new technologies like GIS. That is the only way to be more efficient.
>
> - Monte Aldridge, Preconstruction Engineer, UDOT Region 4

- Tracking rumble strips—the region has been a leader in application and installation of rumble strips to improve traffic safety. They have compiled GIS data on current rumble strip locations and types (shoulder or center line), locations that have been evaluated for potential application with conditions that preclude installation (e.g., bike route or no shoulder), and locations not yet evaluated. This information is shared widely and used for safety analysis and project planning.
- Identifying wildlife crossing locations—Region 4 is engaged in an ongoing effort to reduce the number of wildlife–vehicle collisions on its roadways through the addition of wildlife roadway crossings. They use their smartphone app to geo-reference sites where animal carcasses are picked up. They use UPlan to display these data along with data on location and characteristics of existing culverts and bridges. This analysis helps them to quickly hone in on candidate locations for new crossings. Prior to availability of easy-to-use GIS tools, this type of analysis was outsourced—now it can be done in-house. This results in an estimated cost savings of roughly $30,000 per analysis.
- Preparing for project scoping visits—Region 4 engineers, designers, and surveyors use UDOT's Linear Bench SLD tool to review existing asset data in preparation for site visits. They have found that this allows them to reduce the amount of time spent in the field and avoid the need for repeat visits. This is extremely helpful given the large size of the region—it may take three or more hours of travel time to reach a project site. Rather than spending on-site time collecting new data, they simply confirm the accuracy of data and assumptions that will be used for scoping and design. Corrections and updates are recorded utilizing smartphone apps.

- Reducing project delays and permit approvals—Region 4 has already seen examples of approvals moving much more quickly through the permitting process because the locations of concern (e.g., environmentally sensitive areas) can be accurately mapped and easily shared with partner agencies. In a recent case the U.S. Fish and Wildlife Service approved a request for a project in one day because of the display of GIS data; prior to having this in GIS, the approval process could have taken up to two months. In another case, staff were able to utilize data derived from design files for a project to see that a planned guardrail was located within a known cultural site. Based on mapping information, they were able to adjust the guardrail location by a few hundred feet and avoid the need to conduct a costly and time consuming (months long) environmental review.
- Designing projects—Region 4 designers are finding that the GIS data is accurate enough for use in preliminary design work. Without much work, the DOT can have an accurate estimate of a potential project. Availability of accessible, high-quality data has allowed staff to reduce the number of trips to the field, resulting in substantial cost savings for the agency.
- Sharing notes from the field—as surveyors, inspectors, or engineers are in the field, they are able to upload their notes about condition, etc. directly to the GIS database using a smart phone or other mobile device. These notes are then accessible to anyone else working on the project.

In Region 4, a pre-construction engineer serves as a strong champion for GIS adoption, and technical support is provided by a GIS specialist housed within the regional office. These two individuals were crucial to the success of GIS adoption and realization of associated business benefits. Once initial capabilities were introduced, region staff identified many other ways in which GIS could add value.

Payoff from GIS and Open Data

UDOT was recently selected by the National Association of State Chief Information Officers (NASCIO) as a finalist for the State IT Recognition Award in the Open Government Initiatives category.[1] They were honored for their efforts related to open transportation data with UGate and UPLAN. Per NASCIO's project description, UDOT estimates the following cost benefits relevant to this project:

- Improved asset inventory using LiDAR Point Cloud: $250,000/year.
- Improved workflow and data visualization in the planning process in FY2012: $300,000.
- Streamlined NEPA data collection and categorical exclusion documentation: $100,000 in first year.
- Elimination of need for (state) redundant or similar systems and data through effective sharing: $5 million one-time and $1,600,000 ongoing.

Success Factors

The following elements have been instrumental in the agency's success to date in applying GIS for asset management:

- A common LRS – like many agencies, UDOT houses business data in separate systems. A common LRS is critical for pulling it all together for display and analysis in UPlan. Five or six years ago, there were several different ways of locating information on the road network. It took senior leadership and management to get everyone on the same page.

[1] http://www.nascio.org/awards/nominations2013/2013/2013UT9-NASCIOOpenGovernment2013uGate(2).pdf

- Emphasis on collaboration and sharing data across the agency, and with partner agencies – this was a "mantra" used to help break down the tendency for each business unit to want to collect and manage data sets tailored for its own specific uses. UDOT is currently sharing data layers with many agencies throughout the state, and they look forward to expanding data partnerships.
- GIS leadership and technical capabilities—UDOT was one of the last DOTs to establish an agency-wide GIS manager position, and a strong business case analysis was required before the agency moved forward with that hire. This person is in charge of managing the quality of the data, maintaining the server, and the process of using it and sharing it. Now leadership understands the importance of not only centralized GIS management to provide a coordinating function, but also of establishing strong in-house GIS expertise throughout the agency. For example, when the agency recently filled a vacancy in the HPMS team, leadership established GIS skills as a prerequisite for candidates for this position. Understanding of the importance of GIS skills has grown over the past two years, coinciding with the agency's ability to demonstrate value added through GIS/TAM applications.
- Recognition of the importance of data management, including disciplined planning for updating and linking data sets after initial collection.
- Training and communication on GIS. It is important to get the word out and establish two-way communication with staff across the agency. UDOT has conducted focus groups with regional staff to educate them about the capabilities of GIS and discuss potential uses.
- Mentality and attitude—a positive attitude is essential, with the ability to approach issues as challenges to be overcome rather than roadblocks to action.

Maryland State Highway Administration: Enterprise GIS for Better Decision Making and Communication

The Maryland State Highway Administration (SHA) is working toward a vision of a fully integrated, GIS-enabled asset management process. They have put in place the foundation building blocks—including data, applications, and change management elements—and have a framework for filling out the rest of the picture over time. The agency is already reaping the benefits of what they have accomplished to date in the form of improved collaboration, efficient information sharing and dissemination both internally and externally, and high-quality decision support.

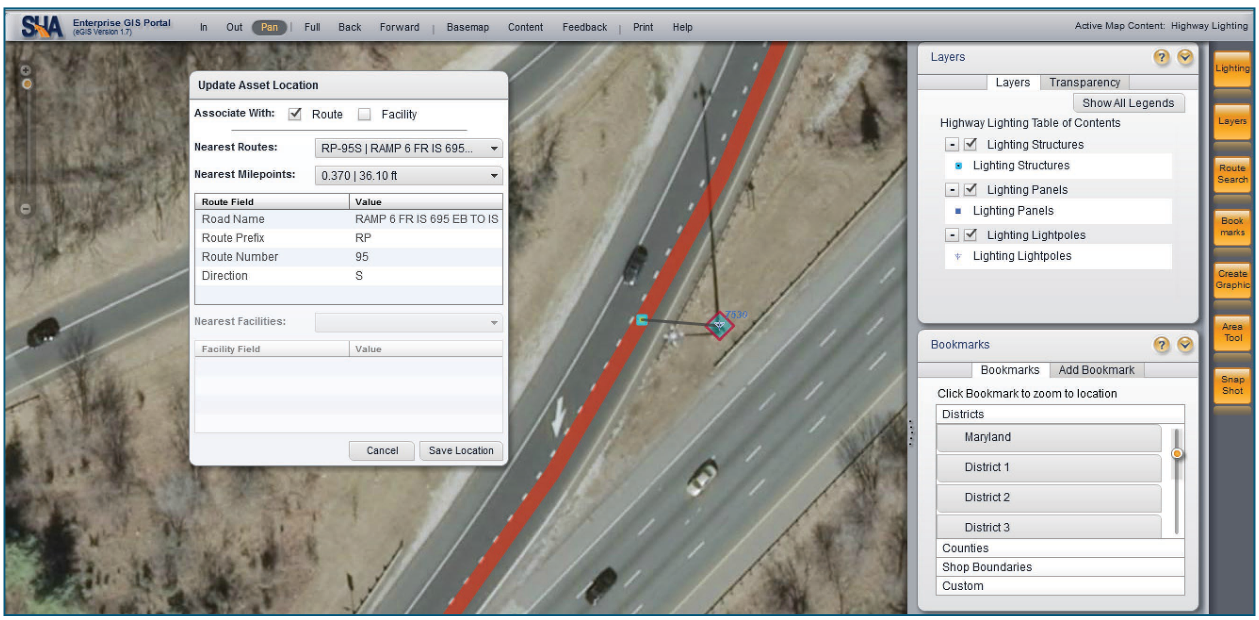
SHA has geospatial inventory data for pavements (including mainline, ramps, turn lanes, and shoulders), bridges, retaining walls, culverts, noise walls, stormwater facilities, highway lighting, and signs. The agency is in the process of building inventory for several additional assets. SHA uses either latitude/longitude or the county-route-milepoint LRS to locate each asset. These locations are used to build spatial data layers that can be shared and integrated into a variety of applications. Data are collected using a combination of methods—some asset information is extracted from videologs; other asset information is collected in the field using mobile devices.

SHA's enterprise program (eGIS) has established a GIS technology-based data architecture that serves information needs of multiple business purposes—addressing both executive and operational functions. eGIS is managed by the planning office and provides an standard application framework for management, display, and analysis of spatial information. The system provides access to all of the agency's spatial data layers, as well as several external data layers from other agencies. eGIS integrates over 61 spatial data themes, including asset data, construction project data, unstable slopes, and outputs from the statewide model. In order to improve the quality of construction project location data, SHA recently put in place a requirement that all projects must have a GIS location entered in order to receive funding approval. This requirement was implemented as a business rule within the agency's electronic funding approval form.

eGIS includes an asset data warehouse (ADW) used to manage data on highway lighting, line striping, signs, traffic barriers, and rumble strips—with web-based editing and reporting features. For example:

- For rumble strip planning, districts view a map showing where there are qualified roads for rumble strips and where there are already existing rumble strips. They can add planned or exception records (where rumble strips are not recommended). This information goes to the office of traffic safety for approval, and is used to plan contracts for new rumble strip installation. Reports are available showing the total qualified rumble strip mileage without existing treatments by route prefix.
- "Canned" reports show total assets by district and asset type; custom reports allow for queries of asset quantities by type on specific routes.

Map 7 illustrates a GIS capability for using asset information to serve both executive and operational functions.



Map 7. Maryland SHA eGIS—Highway Lighting Inventory

SHA plans to add traffic signals and park-and-ride lots to the ADW next. The agency is also planning a new data collection effort for sign retro-reflectivity and will build in requirements for the data collection contractor that will ensure that new data can be integrated with the ADW.

SHA has developed an "Asset Management Matrix" that tracks implementation progress for 13 different asset categories. Progress steps include establishing a documented asset management process, a plan for collecting and managing inventory data, and housing the data in the ADW. Data for some assets (e.g., pavements and bridges) are housed in specialized management systems; these data are currently integrated with eGIS through a combination of batch processes and live database linkages. As older applications are replaced, SHA will consider transitioning inventory data into the ADW.

One of the eGIS applications allows staff to assess and track ADA compliance—e.g., missing sidewalks—and identify paving projects to address deficiencies. Another allows SHA staff to identify asset vulnerabilities related to climate change—e.g., based on erosion potential and flooding risk.

As part of an FHWA-sponsored pilot project, SHA is conducting outreach with field staff and getting input on areas where frequent flooding occurs and the resulting impacts on assets (e.g., buildup of sedimentation, loss of drainage functionality, pipe deterioration due to salt exposure). This information is being located on GIS and combined with other available data (floodplains, FEMA flood depth risk groups, weather-related road closures from the incident management program, road elevations from the pavement condition assessment vans, and available asset location and characteristics data). This collection of spatial data will be used to evaluate options to reduce risks through asset replacement/retrofit, changes in asset siting and design criteria and standards, and changes in maintenance practices. SHA is working to develop a routable network in order to better understand and prioritize risks and support emergency evacuation planning.

GIS has been used as an instrument for changing the culture of SHA toward more data driven decision making. The eGIS program has been able to break down the silos across program and project managers. GIS is also viewed as essential for performance-based planning and programming, bringing together safety, congestion, and asset condition data. GIS provides the necessary integration platform to tell the story of what is needed to meet agency goals—and of the gap between current needs and planned investments. Examples include:

- SHA conducts an annual analysis of safety corridors using GIS to identify what projects have been completed, which are planned, and what else is needed.
- GIS is used to assess the adequacy of existing corridor planning efforts based on current bottlenecks and areas of unreliability (derived from real-time traffic data).
- GIS has been used to link corridor planning, asset management, and NEPA activities. For the Capital Beltway project, the eGIS provided a central base of information that could be used by representatives of planning, construction, and design; as well as by individual asset owners to identify issues and needs to be addressed and help determine how to phase NEPA activities.
- GIS is used to identify where work on different assets can be scheduled together in order to minimize traffic disruption on high-volume facilities.

GIS has been used to enhance the efficiency of decision support for key management meetings at SHA. For example, at system preservation meetings, staff used to prepare presentation slides for each candidate project based on compilation of data from multiple sources. This preparation was very time consuming. Now, with eGIS, advance preparation needs are minimal—staff zoom to the project location and use aerial photos and safety and asset data to establish priorities. GIS is also now used at bi-annual administrative project reviews to address executive questions on specific projects. Before this tool was available, about 25% of the projects would require staff research, adding effort and delay to the review process.

GIS is also being used as an external communication tool. SHA is using ArcGIS online to create a map showing projects to be funded with the newly passed 7% gas tax increase. A map service is also being created indicating the status of all public roads (open, closed, under construction) for emergency management purposes. The agency plans to build on its one-stop-shop model within eGIS to develop additional targeted GIS applications that are tailored to meet specific business needs and/or user communities.

SHA has developed a strategic plan for further integrating the eGIS program into SHA business processes, adding value through the analytical assessment of business data in a geospatial context. For example, one new “widget” candidate would be used to analyze crash data hotspots in relationship to roadway projects to determine whether crash-prone locations are improving or decreasing incidents due to modifications applied to these locations. SHA is also beginning to use GIS to assess geographic balance in the pavement program. This has been valuable for assessing potential impacts of a purely data-driven pavement prioritization approach on local economies in rural portions of the state where paving contractors are major employers.

With the spatial asset inventory as a foundation, SHA is turning its attention to the asset work tracking function. The agency recently deployed 160 tablets to maintenance crews, who will be using these devices in the field to record completed work. These data will enable tracking of expenditures by asset, activity, and route location. Future goals include implementation of a more complete GIS-based maintenance management function. The ability to link work history information to asset condition data is essential to establishing relationships between maintenance activity and asset life extension, which is a key criterion for determining federal eligibility.

While the focus to date has been on implementing asset management processes for individual assets, the intent is to develop capabilities for balancing investments across assets based on risk. This would involve establishing minimum condition or performance thresholds for each asset class. GIS tools could be used to visualize which assets are meeting (or exceeding) these thresholds and identify opportunities for adjusting the balance of investment.

Key success factors in SHA’s GIS/TAM efforts include:

- Management support for GIS at multiple levels of the agency.
- Extensive GIS training across the agency, including in district offices to build familiarity with GIS tools and applications.
- Recognition of the value of GIS for helping asset managers to look across programs—both statewide and in the context of major corridors, and for letting the public know that the agency is putting the available dollars where the needs are greatest.
- Commitment to strengthening data-driven decision making—with a focus on safety, mobility/economy, and system preservation/asset management—and understanding of how GIS can help in this process.
- Business-driven planning and prioritization of GIS investments—with close coordination between planning and IT units to coordinate project requests and integrate business and spatial data components.
- GIS-centric data collection, storage, presentation, and analysis technologies, architected so that one system can serve multiple business purposes within the agency, from strategic to operational functions.
- Phased approach to building a core platform that can be extended to meet a variety of business needs.

Illinois DOT: Building a GIS Foundation with an Outsourced Approach

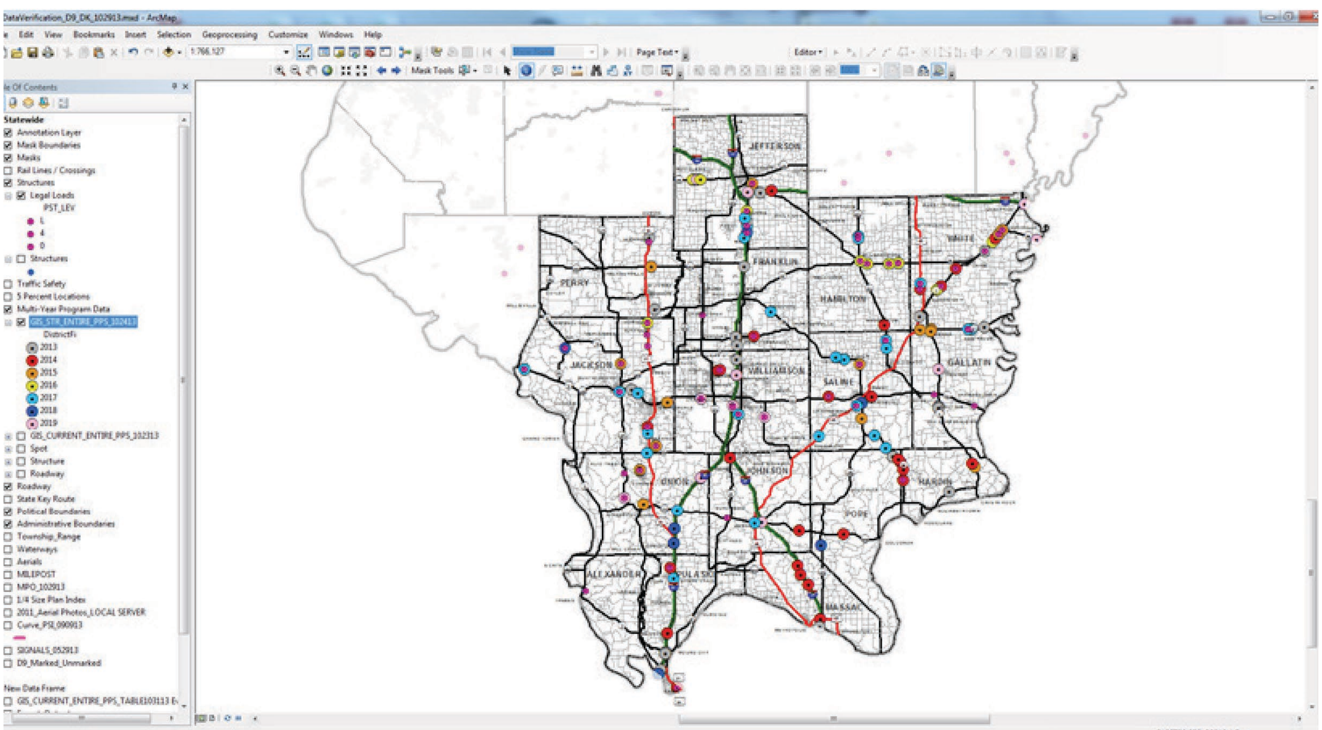
The Illinois Department of Transportation (IDOT) experience provides an example of an outsourced approach to building a GIS foundation for asset management and other DOT applications. An initial network design provided a flexible basis for migration to the outsourced approach and integration with a variety of existing systems for asset management.

In 1996, IDOT completed development of a digital link/node base for its road network, with integration to their completely redesigned legacy mainframe roadway inventory systems. Scanned county maps (to approximately 1:64,000 scale) provided the basis for the network, which encompassed 224,000 digitized link segments representing over 107,000 miles. The network included centerline coverage of all state, county, and township jurisdiction roadways and federal-aid municipal jurisdiction routes. However, approximately 35,000 miles of the municipal street network were not included due to the high level of effort for identification.

Over time, IDOT gradually improved the accuracy of the digitized links and integrated the link/node base with additional databases to support asset management–related applications as follows:

- Roadway, structure, rail/highway crossing inventories.
- Traffic data collection and management.
- Operations and maintenance activities.
- Annual and multi-year planning and programming activities
- Individual and high crash location identification.
- Video inventory and condition assessment.
- Project management.

One recent example of IDOT's application of GIS for asset management is shown below in Map 8. This map was prepared to identify structures for improvement to accommodate overweight truck activity due to new "fracking" activities. They display the deficient structures and identity by program year those that will be improved. The map view provided the ability to link structures and the program with travel need corridors.



Map 8. IDOT District 9—Deficient Structures by Program Year of Upgrade

A valuable characteristic of IDOT's spatial information systems infrastructure is the direct linkage of data to the underlying LRS using a variety of system identifiers including differing milepost referencing and project numbering schemes. This direct linkage enables the complex integration of asset management–related data files across the enterprise and also provides access to historical asset information. Changes to the route referencing systems are readily accommodated without loss of integrative capabilities. Newly available internal and external spatial information layers can be accommodated when referenced to IDOT's LRS or to state plane coordinates. Outputs include a variety of user-developed asset management identification and analysis products.

IDOT uses data warehouse functionality to provide access to historical data through the creation of year-end archives for the roadway inventory files and the LRS. These archived files can be accessed for historical information on traffic levels, pavement condition, and roadway rehabilitation projects in support of pavement network analysis and research activities. Thus, comparisons can be made over the same section of roadway by using the LRS reference, even if the route name or milepost convention has changed.

Upgrading the LRS

In 2005, IDOT made the decision to reference road network information from an outside source in order to fill gaps in the existing roadway geometry and network capabilities. Primary motivating factors were:

- Recognition that better accuracy was needed for multiple purposes including federal reporting, external communications, safety analysis, and truck permit routing;
- Increasing demand and use for IDOT all-public-roadway–GIS layer for sharing with other state agencies and local agencies for functions such as crash location;
- Insufficient internal staff resources to perform full county-by-county or city-by-city analysis to verify existing routes and locate missing roads; and
- Lack of a timely and accurate resource to verify roadway data—particularly for local roads. Video inventory information was available primarily for state-maintained roads. Aerial photography was up to seven years old and missing in some locations. Field verification of the extensive local road network was cost prohibitive.

Illinois entered into an intergovernmental agreement for sharing NAVTEQ roadway information in collaboration with GIS Solutions and ESRI to provide a statewide comprehensive digital road network database. Under this agreement, NAVTEQ delivered quarterly updates of the map database to GIS Solutions, which was responsible for integration and deployment of the data within the IDOT environment. The original plan was to "convert" the NAVTEQ geometry and make it the underlying spatial linear reference. However, during the conversion process, constraints were discovered that forced an alternative path. Instead, IDOT staff conflated various characteristics of their roadway inventory with the NAVTEQ data, allowing the dynamic segmentation of event data onto the new roadway geometry, when applicable. In 2010, IDOT migrated to a roadway inventory system fully maintained in a relational database environment, both events and geometry, implementing a route system in polyline-M. Taking advantage of the versioning and storing capabilities offered by ArcSDE, multiple editors were able to work on versions of the data, which were subsequently reconciled, creating a production dataset stored and accessed in ArcSDE on an IDOT server.

IDOT has used the NAVTEQ roadway base for a variety of applications. For QA, IDOT was able to locate and verify over 5,000 miles of additional local roads, which had not previously been included in the Illinois roadway inventory. The roadway base also provided a QA check on the roadway inventory network and served as a reliable source for identifying and/or verifying new roadway segments. The intergovernmental agreement also supported sharing of the NAVTEQ roadway base with state and local units of government for roadway management and crash location activities.

The roadway base also enabled roadway routing applications by adding dual carriageway centerline information for divided roadways. IDOT used this base for the development of its recently completed truck permit routing system for oversize and overweight trucks on the entire 15,000 mile plus state roadway network. Achieving a comprehensive, navigable GIS roadway base represents a significant milestone in terms of GIS deployment and use in Illinois. The robustness of the data enables the development of multiple applications, all based on a common set of features, allowing for a common display and analysis base for all of the state's governmental agencies.

Benefits of the outsourced approach were:

- More efficient QA for entire public roadway network (>145,000 miles);
- Easier identification of new public roadway segments;
- New base for permit and access routing applications;
- More reliable roadway network for integration with external datasets, providing additional valuable input for asset management analysis;
- More accurate, precise, and complete local agency roadway information for data sharing and communication; and
- Improved location-addressing capabilities.

References

1. Even Keel Strategies, *Introducing a Maturity Model for Enterprise GIS*, 2008.
2. Sonnen, David, J. Moeller, and D. LeBranche, *Geospatial Enterprise Integration Maturity Model*. Northrup Grumman, June 24, 2009.
3. URISA GIS Management Institute. *GIS Capability Maturity Model,* April 2013, Public Review Draft.
4. Maguire, David J., Ross Smith, and Victoria Kouyoumjian. *The Business Benefits of GIS: An ROI Approach*. ESRI, Inc., 2008.
5. Dye Management Group. *Transportation Asset Management Feasibility Study.* Prepared for the Washington State Department of Transportation, 2009.
6. Oregon Department of Transportation, Asset Management Strategic Plan, November 2011.
7. Ford, Mark, Robb Kirkman, Jim Cox, and David Ringeisen. Benefits of GIS to Manage a Major Transportation Program: Evaluation and Lessons Learned. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2291*. Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 1–7.
8. Adams, Teresa M. *Synthesis of Best Practices for the Development of an Integrated Data and Information Management Approach*. Midwest Regional University Transportation Center, No. MRUTC 03-02. 2008, page 14

Appendix A: Applications Catalog

TAM Business Process	Agency	Application
Manage and Track Work	Rhode Island DOT	The Rhode Island DOT is implementing a CMMS to manage its roads and highways asset base. The DOT is leveraging its statewide GIS data to allow work orders to be attached to assets spatially, allowing the DOT's maintenance programs to be tracked as they would be in any other work order management/CMMS system but with the critical additional ability to track where the work is happening by asset type. The project involves integration of the new ESRI linear referencing GIS data model and work flow for roads and highways.
Understand the State of the Assets **Assess and Manage Risks**	Ohio DOT	A single data collection vehicle collects highway data on the entire network. Data types include super HD videolog (native resolution of the roadway at 7500 X 2000 pixels, as well as an additional rear-facing camera), international roughness index (IRI) smoothness data, transverse profile for rutting, surface macrotexture, GIS, vertical and horizontal curvature, grade, cross slope, and many others. All data is collected in a single pass and shared over a local network or Internet browser. Recently, the state spearheaded a project to extract asset data from the high-resolution images to locate, assess, and deploy a statewide database of all asset types of interest. Using the very same desktop application they use for pavement management decisions, they were able to measure, locate, and store any asset that can be seen from the images (and display those that can't, such as culverts and subgrade). More importantly, that data is now tightly integrated with all state data through the use of GIS tools. The result is that all data collected by the state in the past 100 years (of any kind) is available in a GIS environment, complete with up-to-date photos of the roadway and condition information.

TAM Business Process	Agency	Application
Understand the State of the Assets **Assess and Manage Risks** **Identify Needs and Work Candidates** **Develop Programs** **Manage and Track Work**	Kentucky Transportation Cabinet	In 1999, the Kentucky Transportation Cabinet (KYTC) implemented software that enabled it to integrate spatial and tabular road data for the first time. Since then KYTC has made constant improvements to the data, which incorporates all roads in Kentucky and interfaces to other systems to enable it to provide a foundation for enterprise asset management. Data are integrated from the bridge, pavement, traffic, accounting, operations and maintenance six-year plan; highway design project archive; and construction management systems. All data are linkable through the county route and milepoint LRS. The tightly integrated network, asset, and spatial data mean that any records, regardless of where they are maintained, can be mapped and analyzed spatially based on LRS location. KYTC has built a sophisticated network update process using their spatial data management and asset editing software. Network changes needed by multiple state agencies, including the transportation cabinet and public safety, are captured at the local level then added to the statewide highway database by the transportation cabinet. KYTC recently acquired high speed data collection vans to collect pavement condition and images that can be used to capture other asset data. Images are captured every 26 feet in both directions. KYTC worked with its software and data collection vendors to update the milepoint locations of images and pavement data. This allowed for images to be used together with any other data located using the KYTC LRS. New asset records can be added to the highway information system (HIS) based on the images. KYTC uses a range of powerful tools to analyze and extract data based on network locations. This ranges from simple internal strip map views and reports to spatial data extracts for complex data sets like the HPMS report and SUPERLOAD vehicle routing networks.

TAM Business Process	Agency	Application
Understand the State of the Assets **Assess and Manage Risks** **Identify Needs and Work Candidates** **Develop Programs** **Manage and Track Work**	Oregon DOT	The TransInfo project was jointly sponsored and led by the planning, maintenance, and IT offices at ODOT and was designed to support both the planning and maintenance business functions, significantly reducing duplication of asset records. This project replaced legacy mainframe roadway asset inventory databases with a consolidated modern GIS-enabled relational database with built-in map as well as form-based data maintenance applications. Three critical data sets were integrated: the state highway milepoint location control database, the features inventory database used for maintenance activity budgeting, and the GIS state highway network database. The project enabled ODOT to update its network asset data and linear referencing data model as it migrated data from the legacy system to the new database. The new data model supports multiple LRSs, temporality (history), and data validation based on network locations. The system includes a thin client with an interactive map interface, and a GIS-based desktop application providing functionality for map-based network asset maintenance as well as GIS display and analysis. All of the network and asset data editing applications make use of network location for data validation during editing, based on user-configurable rules. While the quality of ODOT's network asset data was good to begin with, this transactional validation, as well as the map display, has significantly improved the quality of ODOT network asset data, without the need for constant data quality reporting and checking. Historically, this has consumed significant staff resources. The TransInfo system tools provide a foundation for integrating additional data sets in the future. Integration of small yet important data sets like bicycle and pedestrian facilities and barriers were included in the scope of the project, but the ODOT team was also able to add other data types like pipe outfalls, to meet urgent needs that arose after the project started.

TAM Business Process	Agency	Application
Understand the State of the Assets **Identify Needs and Work Candidates** **Develop Programs**	Oregon DOT	The agency developed the FACS-STIP Tool to provide easy access to useful asset information (location, attributes, and condition) and communication of new or updated asset information with one easy-to-use application. This web-based tool allows users throughout the agency a single site to compare over 60 datasets to aide in project planning, inventory, and project delivery. Users can create custom reports and spreadsheets for field inventory updates and verification. Additional functionality allows users the option to upload field collected data to the site along with project specific comments. FACS-STIP is designed to enable ODOT to effectively move toward a series of business systems that will integrate and store GPS/GIS-based field data inventories using GIS applications while being supported by spatial interoperability data management tools for the extraction, translation, and loading (ETL) of GPS field data back into ODOT environment databases.
Understand the State of the Assets **Identify Needs and Work Candidates**	North Carolina DOT	The agency uses GIS-enabled software on tablets to collect statewide maintenance condition data at a statistically significant level within each county. Sampling is accomplished by subdividing the LRS and selecting appropriate samples within each region/county for each road system. This data is collected throughout the year and feeds a department performance dashboard for maintenance. Data collected includes the inventory and condition of ditches, shoulders, pipes, vegetation control, pavement markers and markings, etc.
Understand the State of the Assets **Identify needs and Work Candidates** **Develop Programs**	North Carolina DOT	The North Carolina DOT (NCDOT) implemented an integrated asset management system that included an MMS, PMS, and bridge management system (BMS) as well as an asset trade-off analysis module. Data from each asset group is leveraged to prioritize maintenance needs and to define performance thresholds. The system features an integrated GIS framework with the ability to publish maps to enhance analysis, reporting, and decision optimization. For example, GIS reporting can be used to view estimated remaining life for bridges on a map, identify a specific bridge and its structural details on a map, or view current pavement ratings on a map.

TAM Business Process	Agency	Application
Identify State of the Assets	Utah DOT	The agency contracted for a comprehensive asset data set, including photolog, GPS, pavement, and LiDAR for over 14,000 lane miles plus ramps. The asset inventory included signs, walls, shoulders, paint stripes, pavement messages, intersections, rumble strips, and bridges, as well as lane area and pavement width measurements. The effort included deployment of desktop asset processing software and web-enabled viewing software that allows each department to access the data. Users are able to filter the data to find individual asset types, add new assets to the inventory, and make measurements on those new assets that are instantly updated for other users to see. At the heart of the data collection vehicle is a robust positional system that is used to synchronize all of the other datasets. The real-time differential system was able to handle a wide variety of terrain found in Utah, including mountainous regions with sub-optimal satellite coverage. 100% of the positional data was post-processed to achieve the best accuracies possible. The processed data was then synchronized with the imaging, LiDAR, and pavement datasets, allowing for the precise measurement of clearances and roadway assets.
Identify Needs and Work Candidates **Manage and Track Work**	Somerset County Council (UK)	A GIS-enabled mobile infrastructure management system is used to facilitate the process of reporting, responding to, and tracking maintenance work. With 30,000 road defects reported each year, the GIS-based solution has enabled the agency to respond more efficiently to faults. This has resulted in 98% of all highway defects being repaired within their target response time. Inspectors report maintenance issues in the field and send the exact location of the fault back to the infrastructure management system. The information is automatically relayed to the agency's safety defect controllers, who are then able to allocate the most appropriate work group to deal with the problem. A before and after photograph of the work is taken and uploaded to a secure shared website, where the highway team can virtually inspect the repair and sign off on the job. The system enables highway works to be programmed and planned in advance rather than being purely reactive, and provides real-time visibility into the state of the highway network. Improved understanding of the condition of highway assets also means Somerset can more accurately allocate budgets to the right areas.

TAM Business Process	Agency	Application
Understand the State of the Assets **Identify Needs and Work Candidates**	Westlink Services—M7 Motorway in Sydney, Australia	Westlink Services deployed a GIS-based asset management system to track the condition of all the assets along the 40 km stretch of motorway, including the road surface, barriers, embankments, bridges, lighting points, and the systems for toll collection. The asset inspectors use the software on laptops and tablets. They use the integrated mapping function to quickly locate any asset at any point along the motorway. This visual aspect speeds the inventory and inspection process. Another benefit of the system has been the capability to collect and organize data to produce very accurate historical records of maintenance work. For example, bridge inspectors are able to cross check all the elements using the historical data. Westlink notes that they have used the system to speed up decision making, which assists with planning and reporting processes.
Understand the State of the Assets **Manage and Track Work**	St. Johns County Public Works Department, Florida	The agency deployed a GIS-based enterprise asset management system, built around a geodatabase containing an inventory of assets within the county-maintained right of way. The geodatabase was designed to facilitate improved information management across multiple departments. The inventory was built from a combination of extraction from orthophotography, new field data collection using real-time differential GPS technology, and migration from existing databases. A van equipped with video cameras created a visual inventory of traffic signs, traffic barriers, sidewalks, and street lighting. The vans were configured with six cameras to collect a complete panoramic view of all assets as technicians drove the vans down the roadway. Wide angle cameras faced the front and back to capture complete right-of-way views. Technicians then extracted the data using the best camera view and made the video and still photos accessible through the GIS interface. The inventory is integrated with an MMS, which is configured to track cost-to-work performed on transportation-related assets, which include the integration to a pavement management interface.
Understand the State of the Assets **Assess and Manage Risks**	City of Indianapolis, IN	The city used mobile LiDAR and imagery from a mobile mapping system to create an inventory of all regulatory signs within the city's 400 square miles. Automated feature recognition and extraction routines were used to rapidly compile information about each sign required for Manual on Uniform Traffic Control Devices compliance.

TAM Business Process	Agency	Application
Manage and Track Work	St. Louis County Public Works	Faced with an aging transportation infrastructure, St. Louis County Public Works was constantly making repairs and performing construction projects involving multiple cities to ensure the safety and reliability of the county's road and bridge systems across a 6,741 square mile area. Its staff managed several projects in tandem using a string of different systems, which caused confusion and inefficiencies. With growing budget constraints, the department needed a more efficient way to manage its transportation infrastructure assets—from construction projects to ongoing maintenance. St. Louis County Public Works gained improved control of its transportation infrastructure, including work orders and assets, by using a geospatially-enabled linear asset management solution. The system has a single interface for all phases of project activities and is alerted if a project is approaching its purchase order limit. Any time during the course of a project, the staff can visualize the assets and access information to determine what work is in process, how much time and money has been spent, and what has been paid for and to whom. They can even divide the cost out for each segment of a road project based on its location. With a near real-time, comprehensive view of more than 3,682 transportation assets, from graders to air compressors, the staff uses the new level of visibility to proactively schedule preventive maintenance and predict equipment breakdowns, significantly improving asset reliability while reducing costs. Key benefits realized: • Advanced by 100 percent the ability to accurately split project costs by using linear reference points for roads and bridges. • Boosted organizational efficiency by using a single interface for all phases of a project. • Improved budgeting and planning through the ability to accurately track costs. • Enhanced asset reliability through increased preventive maintenance.

TAM Business Process	Agency	Application
Understand the State of the Assets **Assess and Manage Risks** **Identify Needs and Work Candidates** **Manage and Track Work**	Sacramento Area Sewer District	The district's wastewater collection system relies on more than 400,000 assets including 52 miles of forced mains and pressure systems, 3,000 miles of gravity sewers, and 279,000 service-level connections. The district is implementing a new asset management system, integrating information from its GIS and observations from live video footage of the pipes themselves. The solution will enable the sharing of data across agency departments, including maintenance and operations, regulatory compliance, business planning, and capacity planning to improve forecasting. When problems do arise, the software will allow engineers to understand how the asset failed, why it failed, and when so they can develop the necessary maintenance strategies to prevent future asset failures. The system will also track all costs associated with operating and maintaining each asset, enabling staff to identify opportunities for cost savings.

TAM Business Process	Agency	Application
Understand the State of the Assets **Assess and Manage Risks** **Identify Needs and Work Candidates** **Manage and Track Work**	City of Corpus Christi, TX	The city lacked a centralized system to manage its separate water, wastewater, utility, and storm-water services departments. Despite the city's established GIS, keeping operating costs low while still providing excellent service to citizens remains difficult, because work requests were not interfaced with the GIS system and thus could not be spatially analyzed. Corpus Christi implemented a work and asset management system to improve management of its public works and utility departments, along with other areas of city administration, including park management, airport operations, and traffic engineering. The solution integrated asset information, work orders, accounting information, and geographical data for tens of thousands of physical assets such as water mains, traffic lights, bridges, park lawns, fire hydrants, garbage trucks, and storm-water ditches. Citizen calls, which used to be handled and recorded manually, are now routed to a city-wide call center so that staff can deploy resources based on urgency and service level requirements. The system also enables the locations of problems to be visualized geographically, so that trends (e.g., frequent water main breaks in a particular area) can be identified and addressed much faster than in the past. Standardized location and priority codes in the system help staff deploy resources based on urgency and service-level requirements (for example, maintenance crews must respond to gas leaks within 30 minutes). Because the software is integrated with the city's geographic information system, city staff can spatially view problem areas and planned work, as well as proactively identify areas with serious infrastructure problems. For example, the wastewater department found that many wastewater backups were not caused by rain, signaling an issue with the pipes themselves. Staff members then used the spatial analysis capabilities to pinpoint which areas experienced problems in dry weather and implement a repair strategy.

Appendix B: Resources

GPS Data Collection Standards

State of North Carolina: http://www.ncgicc.com/Portals/3/documents/GNSS_Standard_Version4_Adopted2014.pdf

Kentucky Transportation Cabinet: http://transportation.ky.gov/Planning/Documents/GPSMaintenanceStandardsall_rev.pdf

New York State DOT: http://gis.ny.gov/coordinationprogram/workgroups/wg_1/related/standards/documents/GPS_Guidelines_FINAL.pdf

New Jersey DOT: http://www.state.nj.us/dep/gis/GPSStandards_2011.pdf

Oregon DOT: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_301.pdf (Appendix C)

Geospatial Data Policies

West Virginia DOT: http://www.transportation.wv.gov/highways/programplanning/planning/grant_administration/wvtrails/Pages/gps.aspx

Maryland: http://imap.maryland.gov/Documents/Data/MDiMap_DataSubmissionPolicy.pdf

Oregon DOT (Road Centerlines): http://www.oregon.gov/DAS/CIO/GEO/docs/transportation/roadcenterlinedatastandardv5.pdf