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CONTRIBUTORS

Mark Vessely, William Robert, Scott Richrath, Vernon R. Schaefer, Omar Smadi, Erik Loehr, and Andrew Boeckmann; National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 903

Geotechnical Asset Management for Transportation Agencies

Volume 1: Research Overview

Mark Vessely
SHANNON & WILSON, INC.
Denver, CO

William Robert
Scott Richrath
SPY POND PARTNERS, LLC
Arlington, MA

Vernon R. Schaefer
Omar Smadi
IOWA STATE UNIVERSITY
Ames, IA

AND

Erik Loehr
Andrew Boeckmann
UNIVERSITY OF MISSOURI
Columbia, MO

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2019

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state departments of transportation (DOTs) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the National Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments, by committees of AASHTO, and by the Federal Highway Administration. Topics of the highest merit are selected by the AASHTO Special Committee on Research and Innovation (R&I), and each year R&I's recommendations are proposed to the AASHTO Board of Directors and the National Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

NCHRP RESEARCH REPORT 903, VOLUME 1

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Megan A. Chamberlain, *Senior Program Assistant*
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FOREWORD

By Camille Crichton-Sumners
Staff Officer
Transportation Research Board

NCHRP Research Report 903: Geotechnical Asset Management for Transportation Agencies provides an introduction and scalable guidance for state transportation agencies on how to implement risk-based geotechnical asset management into current asset management plans. Volume 1, *Research Overview*, details the scope, process, and findings of the study. Volume 2, *Implementation Manual*, assembles the research results into guidance that should be of immediate use to practitioners who maintain geotechnical assets including walls, slopes, embankments, and subgrades. Complementary downloadable files include planning tools, additional examples and models, and training slides to facilitate agency use of this planning approach.

The management of bridge and pavement assets has for many years garnered significant attention by state transportation agencies while the management of geotechnical assets—such as walls, slopes, embankments, and subgrades—has been elusive. Traditionally, geotechnical assets have been treated as unpredictable hazard sites with significant potential liability because failure of any geotechnical asset may lead to traveler delay, damage to other assets, or impact safety. Geotechnical assets are, however, vital to the successful operation of transportation systems and present an opportunity for system owners and operators to realize new economic benefits through risk-based asset management.

Under NCHRP Project 24-46, “Development of an Implementation Manual for Geotechnical Asset Management for Transportation Agencies,” the research team was tasked with the development of a literature review, case study synthesis, and guidance for state transportation agencies on developing and implementing geotechnical asset management (GAM) plans. Volume 1 of *NCHRP Research Report 903* provides background on the project and discusses the benefits of proactively addressing GAM. The accompanying Volume 2 provides a *GAM Implementation Manual*. Downloadable files that complement the report include a spreadsheet-based GAM Planner tool, a net present value (NPV) template, user guides for the tool and template, a GAM plan outline, and additional examples and models. Training slides also are provided to facilitate immediate implementation by state transportation agency practitioners. Both volumes of *NCHRP Research Report 903* and all of the downloadable files can be accessed from the report webpage by going to www.trb.org and searching “NCHRP Research Report 903”.

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Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Geotechnical Asset Management for Transportation Agencies, Volume 1: Research Overview

Even though bridge and pavement conditions receive much of the media attention and legislative directives for state departments of transportation (DOTs), the value and performance of other assets also are important to the effective operation of the transportation system throughout its life-cycle. One such asset category is geotechnical assets, which are the walls, slopes, embankments, and subgrades that contribute to the ability of a transportation agency to perform its strategic mission. According to the FHWA (2018), "transportation asset management [TAM] plans are an essential management tool which bring[s] together all related business processes and stakeholders, internal and external, to achieve a common understanding and commitment to improve performance." To truly drive performance, transportation agencies therefore need to look beyond the two legacy asset categories named in federal authorization and better understand the impact of all assets—including geotechnical assets—within the system that they must manage as responsibly and cost-effectively as they are able.

Implementing asset management practices for geotechnical assets enables an infrastructure owner to measure and manage the life-cycle investment considering performance expectations and tolerance for risk. Although geotechnical asset management (GAM) is not typically mandated through legislative processes, the reasons for adopting this practice are comparable to those that justify any other business practice that is directed at making smart investments with limited funds. Without employing GAM, organizations are accepting unknown magnitudes of undue risk to traveler safety, mobility, and economic vitality, while potentially making unfavorable life-cycle investment decisions.

Fortunately, for an owner of geotechnical assets, risk-based GAM implementation can build on the practices developed by successful programs. Two such programs in the United Kingdom have more than 15 years of implementation experience: Highways England manages 4,400 miles of roadways with 49,000 slope and embankment earthwork assets that are similar in age to many DOT geotechnical assets in the United States, and the UK's Network Rail system has more than 9,800 miles of railway with 191,000 earthwork assets, most of which are well over 125 years old. When combined with other international and domestic geotechnical asset and natural hazard management programs, these examples provide valuable information on the need for and benefits of GAM regardless of asset age, as well as implementation concepts that can enable rapid return on investment (ROI).

An early benefit of GAM implementation is the efficient use of taxpayer funds through leveraging existing practices that minimize the need for significant investment in new programs or re-allocation of resources. Drawing from existing risk-based asset management practices, Volume 2 of *NCHRP Report 903* (the *GAM Implementation Manual*) incorporates the use of a spreadsheet-based (Microsoft Excel) software tool, the GAM Planner. Together, the *GAM Implementation Manual* and the Gam Planner tool can enable an agency to implement a risk-based asset management program quickly and without requiring significant start-up costs or efforts. Once asset management has started, evidence from across the asset management spectrum indicates that a program will mature through justified process improvements that support ROI. Therefore, an implementation workflow for GAM can start simply and with an incomplete inventory that advances with time.

The goal of any asset management system is to logically align asset design, operations, maintenance, and upgrade decisions with agency goals and objectives. For GAM implementation to succeed across an organization, the program should relate how asset performance affects both customers and the decisions made by executives who focus on agency goals and objectives. For this to occur, asset performance measures should relate to high-level agency objectives such as common safety and system performance objectives. The GAM implementation process and the accompanying GAM Planner developed through this research center on performance objectives related to asset condition, safety impacts, mobility, and economic consequences, which are common objectives across DOTs and offer a means for connecting geotechnical asset performance to stakeholder goals and objectives.

In addition to alignment with stakeholder objectives, consistent use of definitions within a GAM taxonomy that is aligned with other asset management systems can enable communication across disciplines within the organization and among different agencies. Definitions of *asset* provided by both AASHTO and the International Organization for Standardization (ISO) support the recommended geotechnical asset taxonomy consisting of walls, slopes, embankments, and subgrades as physical assets within the right-of-way (ROW). Further, the basis for this taxonomy is validated by several years of applied GAM for transportation systems in the United Kingdom.

Some geotechnical assets involve ground improvements or inclusions such as steel anchorages and reinforcement, concrete materials, culverts, and geosynthetic grids and fabrics. Although these improvements and inclusions have geotechnical performance characteristics, their function is to enable the performance of the specific asset as a design element or component. As a result, management of these geotechnical improvements or inclusions is best handled within a framework, such as an emerging GAM program, that manages the overall asset performance in terms of higher-level agency objectives and goals.

Historically, many agencies in the United States have assumed management responsibility for geotechnical or geologic hazard events that originate beyond the agency ROW or other boundary. This practice can provide value to the agency performance objectives and to the greater economic region. Management programs provide an opportunity to distinguish between geotechnical assets constructed within the ROW and geotechnical features or sites beyond the ROW. This distinction should be discussed with executives and planning staff to achieve consensus on inclusion in the GAM program or defer to other agency risk management programs. For example, geotechnical features beyond the ROW boundary could be candidates for agency-wide resilience strategies that address other external agency hazards such as flooding, earthquake, or terror events. The topic of features beyond the ROW has been identified as an area for future study, as the information about GAM implementation and benefits gained from long-standing GAM programs in the United Kingdom focuses primarily on management of assets within the ROW.

Whether an agency formally implements a risk-based GAM program or defers to existing legacy approaches, asset treatments such as “do minimum,” “maintain,” “rehabilitate (rehab),” “reconstruct (or renew),” and “restore” will be executed by the agency on each asset. The GAM Planner provided with the *GAM Implementation Manual* provides initial recommendations for asset treatment as the inventory is developed, enabling an agency to develop long-term financial plans for the geotechnical asset category. As with existing asset management programs for pavements and bridges, the estimated program-level investment needs for geotechnical assets across an agency will likely exceed the available funds. Using a GAM program can improve the likelihood for successful implementation by incorporating additional risk management, risk prioritization, and life-cycle cost-investment prioritization approaches. These varying prioritization approaches can enable an agency to satisfy the most pressing investment needs in a framework that also is flexible to the objectives of executive and planning staff.

Through GAM processes, a geotechnical asset manager can collaborate with stakeholders across an agency to develop a "shelf," or candidate list, of beneficial geotechnical asset treatment projects that can be selected depending on investment level and risk tolerance.

CHAPTER 1

Background

1.1 Introduction

This volume of *NCHRP Research Report 903* presents the contractor's final research report for NCHRP Project 24-46, "Development of an Implementation Manual for Geotechnical Asset Management for Transportation Agencies." The purpose of this study was to deliver an implementation manual for transportation executives, TAM staff, and geotechnical practitioners to initiate GAM in their agencies. The final deliverables under this study included the following:

- This research overview;
- Volume 2 of *NCHRP Research Report 903* (the *GAM Implementation Manual*);
- A technical memorandum on implementation of the research findings;
- A spreadsheet-based GAM Planner;
- A spreadsheet-based NPV template;
- Appendix material that supplements the *GAM Implementation Manual*, including user guides for the GAM Planner and NPV template, and additional models and examples; and
- A slide (PowerPoint) presentation that can be used for training.

The GAM Planner, NPV template, appendix material, and slide presentation are available for download from the *NCHRP Research Report 903* webpage at www.trb.org. PDF versions of both volumes of the report also are available for download from the site. The technical memorandum on implementing the research findings of this study can be obtained from a link on the NCHRP 24-46 project page.

1.2 Research Need

Geotechnical assets are the walls, slopes, embankments, and subgrades that contribute to the ability of a transportation agency to perform its strategic mission. Historically, geotechnical assets have been treated as hazard sites that create unpredictable financial liabilities to operations and/or have been ignored until failure forces unplanned action. The literature contains numerous examples of direct and indirect economic consequences that have resulted from the adverse performance of a geotechnical asset. As a result, it can be shown that these assets—when they perform correctly—contribute measurable value to the transportation network. Walls, slopes, embankments, and subgrades are, indeed, assets, and they should be managed to realize the measurable life-cycle cost, risk-reduction, and performance benefits that are possible for owners and users. This conclusion is supported by examples from sustainable, successful risk-based GAM programs like those associated with passenger rail and highway networks in the United Kingdom.

Extrapolating the consequences from adverse performance and potential benefits from investment in GAM to all U.S. state transportation departments, federal land management agencies, and local jurisdictions, the purpose and need for GAM is measurable and substantial. Further, federal authorizations, such as MAP-21 in 2012 and the FAST Act in 2015, specify risk- and performance-based asset management for bridges and pavements while encouraging state transportation agencies to develop and implement transportation asset management (TAM) strategies for all assets within the ROW.

Advancement has been made in the overall practice of TAM to allow transportation agencies to focus strategically on the long-term management of government-owned assets. A few states have started GAM programs in conjunction with TAM, but the early efforts have focused mostly on the inventory and condition measurement steps. Among states that have yet to start GAM, many indicate a need and desire but also indicate several barriers to implementation. As a result, the benefits of asset management have not been fully realized for geotechnical assets in most U.S. transportation agencies.

The stated need of this research is for a GAM implementation process and manual that will provide specific direction on the following:

- Guidelines for managing geotechnical assets consistent with AASHTO's TAM practices;
- Examples of successful GAM strategies;
- Definitions for and a taxonomy of geotechnical assets to support communication and comparability among state DOTs;
- Performance-based goals and targets, and a means of measurement for geotechnical assets; and
- Ways to incorporate risk analysis principles and processes for geotechnical assets.

1.3 Benefits of GAM

Based on outcomes from established GAM programs and TAM practices in general, performing GAM yields the following benefits:

- Financial savings across the geotechnical life-cycle, with values reported to be greater than 30 percent by the U.S. Army Corps of Engineers (USACE 2013) and 60 percent to 80 percent per unit length of embankment in the United Kingdom (Perry et al. 2003);
- A process to measure and manage involuntary safety risk exposure across the entire asset class;
- Lessened traveler delay and closure times, resulting in improved network operational performance;
- Reduced adverse economic impacts to users, private enterprise, and communities;
- Fewer impacts and damages to other transportation assets;
- Demonstrated stewardship, including protection of environmental resources, which enhances agency reputation and improves sustainability;
- Incorporation of data and processes into informed decisions that support agency and stakeholder objectives;
- An understanding of current risk exposure levels and distribution, and the ability to manage those risks;
- Data and processes for prioritizing operations and maintenance (O&M) decisions;
- The ability to start very simply and adapt the GAM process over time as the economic benefits are realized; and
- An implementation process that does not involve compliance or reporting requirements, and for which the initial data collection stages can be directed at enabling O&M decisions.

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1.4 Research Objectives and Scope

The objective of this research was to produce a manual for implementing GAM that provides tools for a consistent management program that also is flexible for adaptations by differing agencies as they integrate their geotechnical assets into the TAM program. Given that (1) GAM is not a federally required process (beyond what is required in bridge asset management at this time), and (2) funds and staff resources are anticipated to be limited at the start of a program, the research team recognized that the implementation process must be simple and practical to enable broad adoption across agencies.

The scope of work activities performed for this research included:

- **Task 1: Kick-off Meeting and Work Plan Formulation.** A teleconference between the research team and NCHRP was completed to present the amplified Work Plan. Input from the panel members was incorporated into Tasks 2 and 3.
- **Task 2: Literature Review.** The literature review encompassed gathering and reviewing information from national and international literature based on sub-topics that included best practices; the integration of inventory, condition, risk, and performance in assessment; risk and risk-based management; and life-cycle costs and investment.
- **Task 3: Case Study Synthesis.** This task involved documenting and synthesizing a range of case studies of agency practices that represented differing geologic terrains, agency structures, levels of maturity of the asset management process, performance perspectives, risk tolerances, and investment capabilities. An outcome from the synthesis was identification of geotechnical, planning, and executive actions to enable implementation.
- **Task 4: Deliver Interim Report.** The Interim Report presented the findings of the case studies and the literature review with a synthesis of practices for enabling GAM.
- **Task 5: Host Interim Meeting.** A panel meeting was held to review the findings that were presented in the Interim Report and to present the Phase II Work Plan.
- **Task 6: Develop GAM Implementation Plan.** A GAM implementation process was developed that follows asset management steps for objectives and measures, inventory and condition, performance gap identification, life-cycle cost, risk management analysis, financial planning, and investment strategies.
- **Task 7: Data Management for GAM Implementation.** A spreadsheet-based (Microsoft Excel) worksheet template (the GAM Planner) was developed to enable an agency to implement GAM following the process described in Task 6.
- **Task 8: Deliver Final Deliverables.** The final deliverables included a draft implementation manual (now Volume 2 of *NCHRP Research Report 903*), a final research report (now this volume of the report), a technical memorandum on the implementation of the research findings (available from the NCHRP 24-46 project page), a slide-based (PowerPoint) training presentation, and additional training materials.

CHAPTER 2

Research Approach

The initial work for this project involved conducting literature reviews and case study interviews with agencies to synthesize the practices that can enable GAM. The outcome from the synthesis was used to develop the GAM implementation process and an accompanying manual to be provided as a separate research deliverable. The research team's approach to each task is summarized in the following discussion.

2.1 Literature Review

The literature review involved collecting and synthesizing information from national and international sources on topics related to best practices, assessment, risk and risk-based management, life-cycle costs and investment, and cross-asset interaction and decision support. The research team categorized and summarized information based on its potential practical application toward GAM implementation. Selected references were included in the *GAM Implementation Manual.* A brief summary of the literature review is available online as an appendix to this volume and can be downloaded from the *NCHRP Research Report 903* web page at www.trb.org.

2.2 Case Studies

The case study task involved the collection and synthesis of a range of case studies of agency practices that represented differing geologic terrains, agency structures and asset management maturities, performance perspectives, risk tolerances, and investment capabilities. The case study questions were formulated to capture geotechnical, TAM, and executive perspectives that can influence implementation and can either facilitate or create barriers to implementation success.

Case study responses were received from state DOTs in Alaska, Arizona, Colorado, Connecticut, Louisiana, Minnesota, Montana, New Hampshire, Oklahoma, and Vermont. Case study interviews also were completed with representatives from Network Rail in the United Kingdom and the Alyeska Pipeline in Alaska. The outline used to guide the case study interviews also is available as an appendix to this volume and can be downloaded from the *Research Report 903* web page.

2.3 Initial Findings

The team reviewed the findings from the literature review and case studies to synthesize the practices found; to identify effective implementation models, performance measures, risk and risk management processes, and steps to enable asset management; and to identify examples of demonstrated ROI. The synthesis, provided in the Interim Report, evaluated the role of people, processes, and systems and data in these findings. The Interim Report can be made available upon request to TRB.

The findings included international examples of successful GAM programs that exhibit a complete implementation process from setting objectives and measures through life-cycle cost and risk management analysis, financial planning, and investment decisions. These existing GAM programs are now increasing their asset management maturity level based on the realization of benefits made evident by the tracking of asset performance after implementation. A finding from the case studies of agencies yet to start GAM was a need for tools and guidance that can enable starting GAM, particularly given the anticipated near-term federal and state legislative environment, which will not require or fund GAM. In this environment, proposed expenditures of time and resources to implement GAM must be justifiable under a social or economic need rather than a regulatory requirement.

2.4 Interim Panel Meeting

An interim panel meeting was held to review the synthesis findings presented in the Interim Report, obtain concurrence on the Work Plan for the remaining tasks, and obtain approval of the annotated outline for the *GAM Implementation Manual*.

2.5 Development of a GAM Implementation Process

The GAM implementation process was developed using a cross-disciplinary combination of executive, asset management, and geotechnical practice perspectives. The implementation process followed the AASHTO TAM steps of: objectives and measures, inventory and condition, performance gap identification, life-cycle cost and risk management analysis, financial planning, and investment strategies. The implementation process has been documented in the *GAM Implementation Manual*.

Throughout the development of the implementation process, the research team emphasized formulating an approach that was directed at:

- Enabling a quick start to inventory and assessment without requiring a new program, specialized software, investment in inventory data collection, or significant staff or contractor support;
- Developing a risk-based GAM process directed at performance objectives for asset condition, safety impacts, and mobility and economic consequences;
- Enabling implementation by individuals other than geo-professionals, including TAM and other planning staff, bridge/structure inspection teams, and general engineering staff;
- Constructing flexible frameworks for prioritizing asset treatment decisions based on risk and/or investment considerations;
- Emphasizing connection with agency executives through business and investment cases for GAM;
- Promoting a consistent inventory and assessment process across geotechnical asset types;
- Starting GAM following a simple workflow that can be modified as justified through process improvement steps; and
- Developing recommendations for incorporating GAM at both the program and project levels and in both the operations and design life-cycle phases.

The proposed implementation process consists of a simplified workflow for:

- Identifying and locating assets;
- Selecting from a five-level category for the operation and maintenance condition of an asset;

- Assessing the asset performance consequences;
- Reviewing the recommended treatment recommendations;
- Analyzing differing investment levels; and
- Communication of initial results.

The *GAM Implementation Manual* recommends starting the GAM process with a small quantity of known assets as a means to quickly implement the complete asset management process before expanding the inventory or considering process improvements. Once started, suggested next steps include:

- Expanding the inventory of assets through various means and methods;
- Calibrating the default asset models;
- Developing new asset models, if needed;
- Including other agency staff in inventory development;
- Developing data management practices with agency staff to enable visual communication of asset characteristics and performance;
- Authoring a GAM plan document; and
- Adding objectives and measures based on stakeholder feedback.

2.6 Data Management for GAM Implementation

A supporting task to the GAM implementation process involved development of a non-proprietary spreadsheet-based (Microsoft Excel) tool to accompany the *GAM Implementation Manual*. This tool, referred to as the GAM Planner, provides a means to begin a consistent geotechnical asset inventory and assessment process that includes geo-spatial asset data and enables decision-making processes based on investment returns and a risk performance measure. The GAM Planner will enable GAM across staff levels to follow a workflow for inventory development and assessment using default asset model templates. The *GAM Implementation Manual* also provides guidance for developing agency-specific asset models if desired.

The GAM Planner was formulated for adoption by a state transportation agency starting GAM at a simple asset management maturity level. An agency that already has some form of initial geotechnical asset inventory could adapt the existing data in the GAM Planner if desired. In addition to the spreadsheet tool, and as a GAM program matures, implementation staff may wish to consider using more robust agency-supported enterprise software that might offer additional analysis capabilities, and may be more compatible with other TAM databases used within the agency.

The implementation process also provides guidance on data and data management practices. Because data management practices are emerging topics with agencies and more specific to the systems and processes of each agency, the data management framework provided for the GAM implementation process is directed toward enabling integration into DOT enterprise systems.

2.7 Final Deliverables

The final deliverables developed for this project consist of the *GAM Implementation Manual;* this research overview documenting the conduct of the research; a technical memorandum on the implementation of the research findings; the GAM Planner; a complementary, spreadsheet-based template for calculating the net present value (NPV) of assets; and training aids for agency-based training for GAM program implementation.

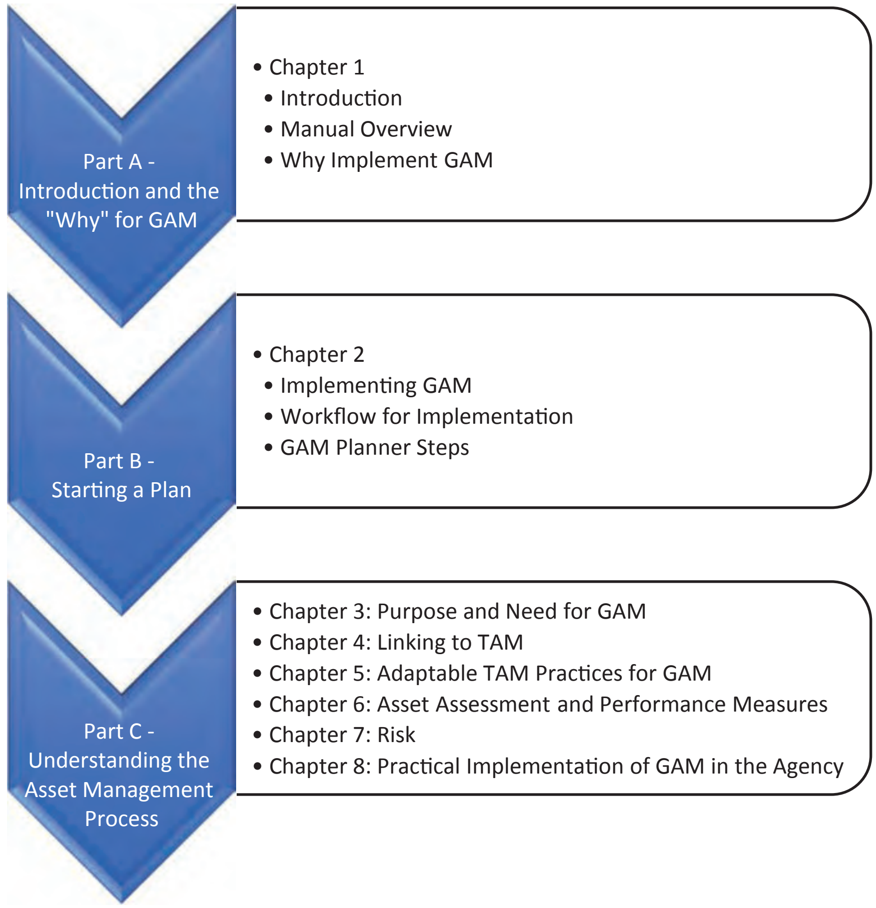


Figure 2.1. GAM Implementation manual, final organization.

Although the annotated outline content remained the same from the material presented in the interim report and interim meeting, some content was reorganized during development of the *GAM Implementation Manual.* The reorganization was intended to improve the readability of the document in a logical framework considering the implementation workflow and AASHTO TAM steps. Figure 2.1 provides an overview of the organization of the *GAM Implementation Manual.*

CHAPTER 3

Findings and Applications

3.1 Definition of the Geotechnical Asset Category and Types

The glossary in the *AASHTO Transportation Asset Management Guide: A Focus on Implementation* (2011) defines an asset as follows:

> An asset is the physical transportation infrastructure (e.g., travel way, structures, other features and appurtenances, operations systems, and major elements thereof); more generally, can include the full range of resources capable of producing value-added for an agency: e.g., human resources, financial capacity, real estate, corporate information, equipment and materials, etc.; an individual, separately-managed component of the infrastructure, e.g., bridge deck, road section, streetlight.

Issued in 2014, the ISO 55000 series of standards are used in asset management practices internationally and across infrastructure systems. The ISO 55000 standards define an asset as an "item, thing or entity that has potential or actual value to an organization; value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities."

In both definitions, an asset can be shown to be a physical object or component that contributes value to an organization, such as a public transportation agency. Bridges and pavements are examples of physical asset categories that are required to have asset management plans per federal authorization. However, bridges and pavements are not the only physical assets that contribute value to an organization tasked with providing public transportation infrastructure. The intended function of a bridge or pavement asset and ultimately the entire system can only be fully realized when the connecting and/or supporting assets also function. Geotechnical assets therefore can be identified as an additional asset category that provides value to an agency while also enabling the desired value from existing legacy asset management programs for bridges and pavements.

When reviewing the successful GAM programs for Highways England and Network Rail, geotechnical assets are defined as cut slopes (cuttings) and embankment assets within the agency boundary (Network Rail 2017, Power et al. 2012). Domestically, Thompson (2017) identifies rock and soil slopes, embankments, retaining walls, and material sites as geotechnical assets in the Alaska Department of Transportation and Public Facilities (Alaska DOT&PF) GAM plan; while Anderson et al. (2017), presents a summary of Colorado DOT GAM programs that consider retaining walls a separate unique asset, and, slopes, embankments and subgrade as a combined geohazards category.

The definition of geotechnical assets from Anderson et al. (2016) was adopted for the project *GAM Implementation Manual* where the geotechnical asset types are embankment, slope, retaining wall, or constructed subgrade within the ROW that contributes to the continuous operation of a transportation network. This definition was selected for the implementation process based on a connection across GAM efforts in multiple agencies across countries and following a taxonomic methodology for physical assets within the transportation corridors ROW (see "Taxonomy of Geotechnical Assets" in Chapter 5 of the *GAM Implementation Manual*). Per ISO 55000, these geotechnical assets can easily be shown to have value to an organization and are known to contribute risk to several organization objectives and measures.

A discussion of the different geotechnical asset types as presented in the *GAM Implementation Manual* is provided below. Additional discussion, schematics, and photographic examples are presented in Chapters 2 and 3 of the Implementation Manual and are not reproduced here for brevity.

3.1.1 Embankments

An embankment asset is constructed earth fill composed of rock and soil that enables a roadway to maintain a required design elevation above lower-lying ground. In general, an embankment is an asset that supports the roadway and some portion of the downslope or outboard ROW. As defined for the *GAM Implementation Manual*, the recommended threshold height for an embankment is a minimum of 10 feet (3 meters) above the adjacent grade. This threshold is based on similar criteria from Network Rail in the United Kingdom. For embankments below these values, an agency could define the embankment asset as a minor earthwork. Alternatively, an agency could establish its own criteria for defining an embankment.

3.1.2 Slopes

Slope geotechnical assets may involve either of the following slope features:

- A permanently excavated slope (a cut slope) that is incorporated into the roadway template and within the ROW, easement, or other property boundary; and
- A beyond-the-ROW natural geologic slope hazard feature (e.g., a natural hazard site) that can threaten other transportation assets or the operation of the transportation network. This type of feature would include natural rockfalls from geologic outcrops, landslides that originate beyond the ROW or in natural ground, or natural debris flows that enter into the ROW and disrupt operations.

Even though events or adverse performance from cut slopes and beyond-the-ROW geologic hazards may have similar operational consequences to an agency, in the GAM inventory it is encouraged to differentiate between constructed slope assets and natural hazard sites. Through this differentiation in the inventory, differing treatment planning and investment strategies can be developed depending on input from agency executives.

Slopes can consist of soil, rock, and mixtures of soil and rock. Cut slopes differ from embankments in that cut slopes are excavated into the terrain rather than created as a constructed fill feature. Similar to embankment assets, a 10-foot cut-slope height threshold is recommended in GAM implementation, unless the asset is judged to create an unacceptable hazard to the safety of users and maintenance personnel.

3.1.3 Retaining Walls

Retaining walls are a common type of geotechnical asset, usually consisting of constructed structures that hold back natural soil or rock or engineered materials to prevent sliding of material onto a roadway or other structure, or to support a roadway. Retaining walls also are referred to as *earth retaining structures* in some organizations.

Current design guidance for many wall types indicates that retaining walls will have vertical or near vertical face inclinations of 70 degrees or steeper. For consistency with wall design practices, a structure with a vertical face inclination of less than 70 degrees can be classified as an embankment or slope that likely relies on reinforcement improvements for stability. The recommended wall height for inclusion into a GAM plan is 4 feet of exposed face height, which is based on what commonly defines an engineered retaining wall.

In many cases, a retaining wall is associated with a bridge structure or approach to a bridge. As indicated in the *GAM Implementation Manual,* if a wall also functions as a bridge abutment that is integral with the bridge structure, the wall should be considered to be part of the department's bridge inspection and asset management program and should not be inventoried and assessed as an independent asset. All other walls associated with bridge approaches are encouraged to be incorporated into the GAM plan if they are not already managed in an existing asset management program.

3.1.4 Subgrades

Subgrade assets are made up of improved or unimproved earth material that lies below the engineered pavement section, which creates a life-cycle management need. Examples of subgrade assets include constructed earthworks and ground improvements to address swelling, compressible, or collapsible soil or bedrock, or to address threats from karst (sinkholes) and underground mining. A subgrade asset also can consist of an unimproved or natural hazard subgrade that generates a performance risk to the roadway.

3.2 Purpose of GAM

GAM enables an agency to measure and manage the life-cycle investment of assets such as slopes, embankments, walls, and unstable subgrades based on performance expectations and risk tolerance. In the absence of GAM, an agency accepts unknown magnitudes of risk to traveler safety, mobility, and economic vitality, while also potentially making less than optimal life-cycle investment decisions.

To provide evidence of the business case and potential investment and risk-reduction benefits, examples of successful GAM or related similar programs are provided here and in the *GAM Implementation Manual.* A key component of these examples is that risk-based GAM is providing benefits through processes that have existed for approximately 15 to 20 years, depending on the program.

- Network Rail manages approximately 19,200 miles of the rail network in Great Britain, much of which extends through gentle topography. The network includes many cut slopes and embankments that were developed between 1830 and 1880. Network Rail has established a GAM system that consists of risk-based inventory, assessment, and intervention processes that have resulted in documented improvements in safety and delay risk for their system since implementation 15 years ago (Network Rail 2017). The Network Rail system has matured with regard to several processes, with recent changes made to the risk assessment process based on asset performance data that enables informed model calibrations. Further, studies of the proactive management of embankment assets supporting railroad lines and motorways in the United Kingdom demonstrated realized life-cycle cost savings of 60 percent to 80 percent per unit length of embankment (Perry et al. 2003).
- The UK Highways Agency (now called Highways England) is responsible for approximately 4,400 miles of roadway throughout the United Kingdom, including about 45,000 geotechnical assets. In 2003, Highways England initiated GAM with the first strategy document. Geotechnical assets in the Highways England program consist of embankments and cut slopes, with the majority constructed from the late 1950s to 1990s. As presented by Power et al. (2012), Highways England operates from the perspective that roadway infrastructure construction is mostly complete, and the agency centers its efforts on system improvements, optimization, and

maintenance. The Highways England geotechnical program has matured in stages, starting from a program directed at producing specific outputs (e.g., inventory for geotechnical assets) to obtaining business outcomes, with a primary focus on providing assets that perform at the required service level for the user. The Highways England program is risk-based, with recommended actions based on five risk-level categories. Additionally, the asset inventory is re-inspected every 5 years.
- Switzerland formed the National Platform for Natural Hazards (PLANAT) in 1997. This national effort to address the country's considerable natural hazards risk is notable for the scope of its collaboration, which includes the federal government, the financial and insurance industry, and public agencies across various infrastructure sectors. The PLANAT mandate includes improving public awareness and efforts to share financial investment in mitigation according to risk-reduction benefits; (for example, multiple stakeholders may fund a project based on benefits received (Bründl et al. 2009). The program also has an online tool for evaluating risk reduction, the use of which is required for all projects costing more than approximately $1 million.
- The U.S. Army Corps of Engineers (USACE) Dam Safety Program is an aspirational example of GAM that uses risk to evaluate, prioritize, and justify safety decisions for more than 700 dams, more than 50 percent of which have exceeded the 50-year service life (USACE 2014). The program was initiated following federal authorization in 1996. Using risk-based analysis, USACE indicates that every $1 invested yields $8 of flood damage reduction. Further, the USACE asset management process for water infrastructure facilities subject to natural hazards (water/hydropower, navigation, and flood-related assets) successfully combines inventory, assessment, and risk-based multi-criteria decision analysis and financial planning, all of which are completed by staff using conventional spreadsheet programs (Connelly 2016).

These sustained GAM practices are similar to bridge and pavement asset management programs in the United States. Although these program examples started in response to regulation, after several years of implementation each program has evolved into a more complex program that demonstrates sustained and measurable benefits.

Thus, the purpose of GAM is to enable an agency to obtain real, measurable benefits that are currently being recognized by other infrastructure organizations. Based on outcomes from successful programs around the world, the benefits of performing GAM can be summarized as:

- Financial savings across the geotechnical life-cycle, with as much as 30 percent in some cases;
- A process to measure and manage involuntary safety risk exposure across the entire asset class;
- Lessened traveler delay and closure times, resulting in improved network operational performance;
- Reductions in broader economic impacts due to injury, loss of life, or property damage to citizens, businesses, and other governmental agencies;
- Fewer impacts and damages related to other transportation assets;
- Demonstrated stewardship, protection of environmental resources, enhanced agency reputation, and improved sustainability;
- Data and processes for making informed decisions that support agency and stakeholder objectives;
- Data and processes for prioritizing O&M decisions; and
- An understanding of current risk exposure levels and distribution, and the ability to manage those risks.

3.3 Starting GAM

3.3.1 Successful Models to Emulate

Looking internationally, the previously discussed GAM programs for rail and highway systems in the United Kingdom exhibited a sustained success across the asset management spectrum with well over a decade of implementation and process improvements that have provided valuable concepts to emulate. Domestically, the literature review and case study findings showed that several transportation agencies and infrastructure owners in the United States are working toward GAM implementation, with progress most evident in processes related to inventory, condition measurement, and risk analysis. However, no domestic example of a public-sector transportation agency with a functioning GAM program comparable to the UK programs in duration or program size was apparent.

The implementation experiences of other agencies were considered throughout the development of the *GAM Implementation Manual* and processes. Table 3.1 summarizes the successful implementation strategies identified through this research.

For a U.S. DOT able to fund a complex GAM program at the start of implementation, custom plans could be adapted from those developed by agencies like those noted in Table 3.1, which have or are progressing to a high level of maturity. The research team determined that the greater need was to develop a template for a GAM plan at a simple level of maturity, which considers constraints on development and investment resources, and permits an agency to efficiently find favorable returns on the initial investment in GAM such that funding for implementation and future plan advancement will be supported across the organization.

Table 3.1. Examples of successful GAM strategies.

Agency Examples	People	Processes	Systems and Data
Highways England	Dedicated staff positions and organization structures that consider the role of GAM	Functioning GAM plan at complex level of maturity and based on safety risk management; long-duration inventory construction and use of process improvements	Started in 2003; mature GAM program; geo-referenced asset locations; evaluating cross-asset performance with drainage assets; 2.5-meter height definition
Network Rail	Dedicated staff positions and organization structures that consider the role of GAM	Functioning GAM plan at complex level of maturity and based on safety risk management; long-duration inventory construction and use of process improvements	Mature GAM program; geo-referenced asset locations; segment definition for assets; developing deterioration models for >100-year-old assets; 3-meter height definition
Infrastructure Maintenance Management Manual (multiple examples)	Guidance on organizational staff structures for functioning asset management programs	Risk-based asset management plans for other assets that are adaptable to GAM	Guidance on geo-referenced data management systems at levels of maturity from simple to complex
USACE Water Infrastructure Programs		Risk-based asset management practices for infrastructure systems that include geotechnical or similar assets	Transitioned from proprietary software to spreadsheet-based (Microsoft Excel) tools due to user familiarity and availability
Alaska, Vermont, and Colorado DOTs	Creating a culture change for GAM; implementation experience within a domestic DOT	Experimentation with early implementation approaches	Developing inventory and condition data for GAM in a TAM framework
Switzerland's PLANAT Program	Oversight panel with cross-agency, cross-disciplinary, and private- and public-sector representatives	Risk-based, cost-benefit decision process for natural hazard risk mitigation; investment shared among risk stakeholders	Geo-referenced risk-based inventory mapping tools and cost-benefit analysis software to standardize analysis

3.3.2 Development of a GAM Implementation Framework and Workflow

In the literature, discussions about asset management and GAM generally have covered strategic-level concepts or the agency-specific processes, systems, or data within an asset management program. The case study interviews performed for this project provided an opportunity to understand the perspectives of agency staff who may implement a new asset management program and how the cultures and relationships at differing levels of an agency can influence implementation.

For many successful GAM program examples (e.g., those in the United Kingdom, the USACE Water Infrastructure program, and the Swiss PLANAT program), a key trigger for implementation was some form of governmental requirement. This also has been true for the implementation success of bridge and pavement asset management in the United States. Once started, however, these GAM programs have yielded benefits and process improvements that demonstrate their business and risk-reduction utility independently from continuous governmental requirements. Among the state DOTs that have started early efforts toward GAM, implementation has occurred because of the motivation of a few key individuals who were willing to advocate for a program in the absence of regulatory requirements.

Many of the case study discussions suggested that federal requirements for GAM would be a means to start GAM. However, a few DOTs also reported that current federal authorization could be a barrier to GAM implementation because of the concern that a program could be penalized for not obtaining self-imposed performance goals in the absence of a mandate from the FHWA. Thus, given the anticipated legislative environment, the GAM implementation framework for this project was developed to satisfy economic and performance needs in the absence of directed regulatory requirements. Another conclusion, drawn from the case study discussions together with feedback from the project review panel, was that a GAM program that is simple to implement also would have the greatest likelihood for adoption.

As a result, the following implementation framework characteristics were identified as being most likely to enable GAM in state DOTs:

- Relatively simple to implement,
- Does not require legislative authorization, and
- Has low financial and other agency resource needs at initiation.

To evaluate implementation solutions under these constraints, a behavior model for persuasive design (Fogg 2009) was reviewed to guide workflow actions that could enable use of a GAM framework. The behavior model provided a systematic approach to understanding factors that can result in behavior change in professionals across industries. Fogg (2009) suggests that, for a target behavior to occur (in this case implementation of GAM), the relationships between motivation and ability (which often relate to simplicity) must be recognized and addressed for the individuals involved in the process. In general, the greater the level of individual motivation, the greater is the likelihood of the individual taking on difficult tasks to accomplish a call to action. Conversely, the lower the level of individual motivation, the more important it becomes to change the difficulty level (by making the work simpler). For example, the early DOT GAM implementation efforts shown in Table 3.1 are the result of highly interested (i.e., motivated) individuals and agencies that were willing to undertake a new and challenging task that required a high level of ability. Legislation and regulations are obviously highly motivating factors, but they are anticipated to have little value in the GAM implementation process at this time.

Fogg (2009) conceptualizes the relationship between motivation and "ability" (which is related to task difficulty or simplicity) using a graph, with motivation shown on the vertical axis, simplicity on the horizontal axis, and the *activation threshold* as a curved line plotted by the intersecting points at which an action (e.g., GAM implementation) transitions between being less likely to occur and more likely to occur in response to environmental prompts or triggers. Subcomponents of the Fogg Behavior Model can be used to guide formulation of a framework that considers both motivations and abilities. The application of this work to the development of the GAM implementation framework is presented in Table 3.2.

The research team's synthesis of literature and case studies indicated the need for a simple workflow that minimizes agency resources for starting GAM planning as a means of increasing

Table 3.2. Motivation and ability considerations for development of GAM implementation framework.

Factor*	Subcomponent	Application in Development of the GAM Implementation Framework
Motivation	Pleasure/Pain	Work to simplify processes and tools such that individuals do not view the implementation as being discomforting. Use familiar spreadsheet software (i.e., Microsoft Excel) to avoid frustrations that may occur with new or less familiar software systems.
	Hope/Fear	Adapt from and emphasize examples of implementation success to characterize favorable outcomes that will result, such as cost savings, fewer disruptions, and managed risk. The long-term success of GAM for UK transportation networks is an aspirational good outcome that can motivate others. Identify potential favorable outcomes at all levels of an agency, including motivating executives to better reach objectives, engaging planners, and enabling confidence in GAM through good outcomes for geo-professionals and maintenance staff.
	Acceptance/ Rejection	Make implementation inclusive of all geotechnical asset types, geographies, and agency structures to enable a broad acceptance rate. Within an agency, emphasize the need for processes and measures of GAM performance to connect with stakeholders across the organization, especially those most capable of supporting implementation (executives, TAM managers, public stakeholders).
Ability/ Elements of Simplicity	Time	Minimize the additional demands on staff time that come with implementation by allowing for the ability to start and stop inventory or work during short, available periods; using anecdotal information; and enabling staff to get started without first finding time for formal training or reading a manual.
	Money	Assume that agencies have limited to no financial resources to start GAM. Thus, GAM processes should start using existing systems and without requiring new tools, staff, or budgets. As a spreadsheet-based (Microsoft Excel) worksheet, the GAM Planner can be used readily.
	Physical Effort	Enable inventory data collection to begin at the desktop level without requiring mobilization to the field for new inspection or condition data. Although such inventory data are valuable, suggest beginning inventory development in the GAM Planner using existing department records, anecdotal information, and readily available online tools.
	Mental Effort	Develop initial implementation processes that minimize the need to think deeply or in unfamiliar ways. Develop a "quick start" chapter of the *GAM Implementation Manual* that allows implementation to begin before the manual delves into less familiar details about geotechnical assets, risk, and TAM concepts. Structure workflow so that knowledge of supporting TAM concepts is optional or not required to start implementation. The GAM Planner inputs have been developed to enable use of this tool without the need to learn about GAM and TAM in depth. Use the process of starting GAM as a means to teach GAM and supporting steps.
	Deviance from Rules	Provide examples of existing GAM programs and other asset management programs to indicate that asset management is a desired process in public agencies and across countries. With time, not performing GAM could be considered a deviation from practice (a strong motivating factor in the absence of "rules" such as legislative or regulatory requirements).
	Routine/ Non-Routine	Structure the implementation process to be simple and repeatable. To encourage routine use, the GAM Planner has been structured to require minimal data entry time for each asset and to involve minimal input steps.

*Fogg (2009) suggests that the subcomponents of ability are linked and work together, whereas the subcomponents of motivation can be independent. For example, a process that satisfies all but the money subcomponent of ability will likely not occur if an impractical investment amount is required. Conversely, a flu shot is representative of the trade-off between pain and hope of good health in the motivation factor.

implementation success. A more complex program or a higher GAM maturity level is best viewed as an outcome of a successful implementation that enables justified process improvements with time, a conclusion that is supported by the successful programs listed in Table 3.1. For the development of the *GAM Implementation Manual* and GAM Planner, the team worked to create processes and tools that would support starting simply. The behavior change model from Fogg (2009) provided guidance on specific factors to consider that are beneficial toward enabling individuals to change a behavior, which in this case was choosing to implement GAM. The following list summarizes the workflow and implementation processes that were selected for increasing the likelihood of success:

- Structure the layout of the manual so the user can quickly understand the purpose and value of GAM.
  - Part A, Chapter 1 of the *GAM Implementation Manual* briefly introduces GAM, addresses the organization of the manual, and includes a discussion of the reasons to perform GAM. Part A concludes with a discussion about "Starting Simply," which is intended to inform the reader that GAM does not need to be a complex and intensive process to start.
  - Part A purposely does not expand the discussion into TAM or other concepts potentially unfamiliar to geo-professionals.
  - Part A is only a few pages long, which allows for a quick read and minimizes time requirements.
- Enable a user of the manual to start GAM implementation quickly, without having to first learn supporting concepts for asset management, geotechnical engineering, performance measures, risk, and investment.
  - Part B, Chapter 2 of the *GAM Implementation Manual* provides a step-by-step guide to starting implementation using the spreadsheet-based (Microsoft Excel) GAM Planner tool that accompanies the manual.
  - The user is encouraged to select a few known assets and start GAM inventory and assessment using the GAM Planner.
  - The user can draw on existing records or anecdotal information to start GAM without having to mobilize the field to collect asset condition data. The inventory and assessment process in the GAM Planner minimizes the number of technical measures for each asset, thus reducing both time requirements and the need for specialized experience.
  - Part B presents a simplified GAM workflow without including optional process improvement steps or technical terms that could suggest a complicated new process.
  - Part B emphasizes a preference for starting at a simple level versus a complex level, and for avoiding trying to build a complete inventory before moving through the GAM spectrum.
- Enable a consistent management program that is flexible for adaptations.
  - The GAM inventory and assessment process is structured around the performance objectives of asset condition, safety impacts, and mobility and economic consequences, which are common objectives across agencies and are identified in federal authorization for asset management.
  - For the initial inventory and assessment process, geotechnical assets are evaluated as a single category under one framework rather than using separate frameworks for each geotechnical asset type. Should an agency not want to include a certain asset type, those assets can be omitted from the inventory.
- Provide a software tool that enables starting GAM implementation without formal training or the purchase of new software systems.
  - The GAM Planner is a Microsoft Excel file that can be used across an agency.
  - The GAM Planner has minimal input fields to reduce the time requirements for entry of asset data.

- Enable the user to learn supporting aspects of GAM once implementation has started, thus eliminating the barrier of having to learn new concepts before starting.
  – Part C of the *GAM Implementation Manual* follows the implementation steps in Part B and contains chapters that provide background on TAM, performance measures, risk, and practical considerations for implementation of GAM in an agency. Part C contains valuable material for progressing through the TAM spectrum, but this material can be read at the convenience of the reader.

3.4 Incorporating GAM into TAM and Across the Agency

As indicated in the project background and research objective, GAM implementation should occur such that the geotechnical assets can be incorporated into an overall, agency-wide TAM program. To enable this to occur, the research team has structured the GAM implementation process to align with established AASHTO TAM practices that prescribe the following elements for an asset management plan:

- Objectives and measures,
- Inventory and condition,
- Performance gap identification,
- Life-cycle cost and risk management analysis,
- A financial plan, and
- Investment strategies.

Chapter 4 of the *GAM Implementation Manual* is structured to incorporate these elements by introducing the background for each concept and developing the connections for geotechnical assets. The application of risk in asset management is introduced in Chapter 4 and expanded in Chapter 7, which provides a detailed background on risk and risk management, and in Chapter 8 as a means for prioritizing asset treatments.

3.4.1 Objectives and Measures

To align with TAM, the measurement of geotechnical asset performance should relate to TAM objectives in a way that is similar to the performance measurement of any other transportation asset. The process described in the *GAM Implementation Manual* is formulated around performance objectives for asset condition, safety impacts, and mobility and economic consequences, which connect with objectives contained in federal authorization for asset management plans.

Lessons learned from successful GAM programs and case study input from agency executives indicates that performance measures should relate to how the asset performance affects customers or executive decision-making. As presented in Chapter 4 of the *GAM Implementation Manual,* Network Rail geotechnical asset performance is assessed with respect to the following measures (Network Rail 2017):

- Train derailments,
- Train delay minutes,
- Temporary train speed reductions, and
- Earthwork failures.

Keeping the Network Rail experience in mind, the performance measures presented in the *GAM Implementation Manual* focus on (1) outward (or public-facing) measures that tend to be results-oriented *lag* measures that connect with agency executives and the public, and (2) inward and engineering-based *lead* measures that are used by the asset managers and technical staff to predict estimated future conditions.

The *GAM Implementation Manual* introduces an outward-facing, executive-level measure called "level of risk (LOR)." The LOR is a grade-based categorical measure for asset performance communication to executives. This measure provides a means to succinctly communicate the magnitude of current performance risk from the asset across multiple TAM objectives, such as asset condition, mobility, and safety impacts. The LOR is intended to be similar to the level of service (LOS) standards used in many TAM and maintenance planning programs. The concept of LOR is based on early GAM implementation experience at the Colorado DOT, which sought to improve communication about the "service" that geotechnical assets provide. Additionally, agency executives have indicated there can be difficulty with understanding technical condition scores specific to each asset type (e.g., understanding what are "good," "fair," or "poor" conditions for slopes, walls, embankments, and subgrades) and how these scores translate to the agencies' performance. LOR also is being incorporated as a performance measure for the Alaska DOT&PF GAM program.

The LOR measurement is intended to indicate a relative magnitude estimate of the risk exposure for an agency with geotechnical assets. The GAM Planner and *GAM Implementation Manual* present default LOR categories following a linear distribution of risk scores. Within the GAM Planner, the category values can be adapted based on an agency's tolerance for different risk consequence levels. For example, an agency could decide to increase the LOR category thresholds based on higher tolerance for risk from geotechnical assets. To facilitate developing an understanding of LOR categories, Appendix D to the *GAM Implementation Manual* (available online) presents a photographic matrix for different GAM sites that illustrates the range in performance.

For outward-facing customer-focused measures, the *GAM Implementation Manual* recommends that GAM programs consider measurement of total annual delays and road closures resulting from disruptions associated with geotechnical asset performance. These measures may be aspirational measures and difficult to capture in some agencies, but such measures will communicate an easily understandable performance aspect to the public and how that performance can be influenced by investment levels. At agencies for which this level of measurement is not currently feasible, it is suggested that the potential for instituting these measures be continually reevaluated, particularly as continuous traffic volume measurement accuracy increases through technology advancements.

The *GAM Implementation Manual* and the spreadsheet-based GAM Planner identify some simple inward-facing technical measures that (1) likely are already used in some form at many agencies and (2) can be used by agencies as they begin GAM implementation. Three such measures are termed the "O&M Condition Level," the "Safety Risk Consequence Level," and the "Mobility and Economic Consequence Level." For example, using the GAM Planner, an agency can identify:

- Percent of segments in each O&M Condition Level,
- Percent of segments in each Safety Risk Consequence Level, and
- Percent of segments in each Mobility and Economic Consequence Level.

The *GAM Implementation Manual* also indicates technical measures that should be considered as secondary measures for use by geo-professionals and/or asset managers. This collection of detailed technical measures is not essential for beginning implementation of the GAM process as described in the manual. Rather, increasing the use and complexity of technical measures is recommended as a process improvement that can be adopted within each agency as the relevance to performance measurement and management becomes evident.

3.4.2 Inventory and Condition

Information from the case study interviews indicated that collection of data for an asset management inventory could be a barrier to implementation because of the cost and time requirements, particularly if new data need to be collected through labor-intensive processes.

The *International Infrastructure Management Manual* (IIMM) presents a staged approach as a practical process for data collection that considers the investment constraints (IPWEA 2015). As stated in the IIMM, "a rule of thumb is often 80 percent of the data can be collected for half the cost of 100 percent. Seeking 100 percent coverage and accuracy may not be justified, except for the most critical assets."

Per the practices in the IIMM, the concept of staged data collection begins with identification of minimum data for compliance and reporting requirements, next moves to data for prioritizing O&M decisions, and concludes with optimizing life-cycle decisions (IPWEA 2015). As discussed in Power et al. (2012), a similar progression of data collection occurred with GAM implementation for the UK Highways Agency. GAM implementation does not have compliance or reporting requirements, which suggests that initial data collection stages can be directed at O&M decisions. Within a staged data workflow, all assets do not necessarily go to the final level of data collection; reaching the most-detailed state occurs only in situations for which the collection effort is justified. Thus, the investment in data collection and management should be compared against the level of detail required for decision support or to achieve any other benefits.

The *GAM Implementation Manual* introduces an approach that relies on differing levels of detail and a variety of collection tools for inventory and condition data. This allows a DOT to collect only the data required for the desired level and complexity of decision-making, versus an approach that requires significant investment and quantity of data that may or may not be used in the future. The GAM Planner enables an agency to start inventory and condition measurement in a simple spreadsheet register that also can be used for assessment models.

The data needed to start an inventory in the GAM Planner can come from both within and outside an agency. Data from within the organization may include corporate information systems, active and archived project records, enterprise accounting systems, operational technology systems (such as traffic data), or anecdotal staff sources. External data can come in various forms, from sources ranging from proprietary, vendor provided systems, outside stakeholder sources, and web-based freeware programs such as Google Earth. The *GAM Implementation Manual* encourages use of existing data as the first step in order to minimize a potential barrier to GAM.

3.4.3 Performance Gaps

For an agency starting GAM at a simple level of maturity, the *GAM Implementation Manual* recognizes that performance gaps will become evident once knowledge is gained about the current levels of asset performance. The manual recommends communicating a straightforward initial performance gap, such as the percent of inventory complete relative to estimated total asset inventory, and providing approaches to address this gap.

3.4.4 Life-Cycle Planning

In recently adopted asset management requirements, the FHWA defines *life-cycle cost* as "the cost of managing an asset class or asset sub-group for its whole life, from initial construction to its replacement" (23 CFR 515). Thus, the *GAM Implementation Manual* introduces the TAM principles for considering the life-cycle of geotechnical assets through the phases of design, construction, operation and maintenance, and decommissioning (if applicable). The TAM processes that include evaluation of the asset life-cycle include:

- Total cost of the asset over the life, or life-cycle cost;
- Risk management across the life-cycle; and
- Financial plans and investment strategies for a program of assets over a life-cycle.

In the *GAM Implementation Manual*, content and figures in Chapter 4 are included to provide an introduction to the concepts of asset life-cycles and their application to geotechnical assets. The manual then expands the life-cycle discussion to introduce the TAM concepts for what treatments can be performed on an asset following construction. These treatments are incorporated into the GAM Planner and discussed throughout the manual using the following terms:

- Do Minimum,
- Maintain,
- Rehabilitate (Rehab),
- Reconstruct (or Renew), and
- Restore.

The treatment discussion in Chapter 4 of the manual reviews these concepts in detail and provides specific example treatments for geotechnical assets in each category.

3.4.5 Financial Plans and Investment Strategies

Chapter 4 of the *GAM Implementation Manual* also includes an introduction to the TAM steps of financial plans and investment strategies. As presented in the manual, a *financial plan* is a multi-year projection of actual and desired funding, whereas *investment strategies* consider the allocation of resources within a plan, such as where funding will be directed following the treatment options for assets. The manual also emphasizes the importance of financial planning in the GAM spectrum because of the importance to executive decision-makers and illustrates which assets are treated and when within the planning cycle.

Based on the research team's review of existing GAM programs and information from the project case study discussions, it is suggested that agencies anticipate that the resources available will be less than those required to support a full geotechnical asset life-cycle plan. Therefore, the *GAM Implementation Manual* indicates the need for a financial plan to present what investments will be made and what will be deferred.

Although agencies likely will need to defer investments for existing assets, the manual discusses the importance of also considering life-cycle cost in the design phase of new assets. In manufacturing industries, it is a well-documented conclusion that up to 80 percent of the life-cycle cost is "locked in" by design decisions (Hurst 1999). A similar condition is acknowledged in the life-cycle management of wastewater facilities (WERF 2018). With respect to geotechnical assets, a similar trend is expected, and the manual recommends that agencies evaluate the whole-life cost over the desired performance life-cycle to determine preferred alternatives based on economic criteria. Chapter 8 of the *GAM Implementation Manual* expands on approaches to life-cycle cost analysis, and Appendix E presents a Microsoft Excel template that can be used to evaluate life-cycle costs.

In addition to life-cycle cost considerations for financial planning and investment, the *GAM Implementation Manual* addresses a need to evaluate the ROI in a GAM program. Determining the return on GAM investment requires calculation of benefits over time in comparison to up-front and ongoing costs. The manual introduces breakeven analysis as a means for providing the justification needed to validate investment in GAM. Chapter 4 of the manual references the outcomes from *NCHRP Research Report 866: Return on Investment in Transportation Asset Management Systems and Practices* to offer detailed guidance on demonstrating ROI in TAM. *NCHRP Research Report 866* is accompanied by a spreadsheet-based tool for calculating the ROI of an asset management system or process investment that can be adopted by an agency wanting to evaluate the program-level investments toward GAM. (Additional information about this report and a link to download the accompanying spreadsheet tool are available from the *NCHRP Research Report 866* webpage at www.trb.org.)

The existing research on TAM implementation discusses agency benefits in terms of changes in O&M cost or changes in data collection, processing cost, and analysis cost. The *GAM Implementation Manual* provides guidance for using these categories when making comparisons between an incorporation of GAM into the TAM program.

3.5 Taxonomy and Definitions for GAM

3.5.1 Taxonomy Introduction

The research objective for this project indicated the need to provide a definition and taxonomy of geotechnical assets that will support communication and comparability among DOTs. Chapter 5 of the *GAM Implementation Manual* discusses the recommended taxonomy for GAM in detail. The taxonomy is based on guidance presented by Anderson et al. (2016), who researched and presented a geotechnical taxonomy for transportation infrastructure assets with the goal to facilitate communication and advancement in the management of both geotechnical and transportation assets. The taxonomy also considers definitions that align with current state of practice with TAM and the requirements of MAP-21. This includes terminology such as elements used in the FHWA Specification for the National Bridge Inventory (2014b). The proposed GAM taxonomy also is similar in structure to the general taxonomy used for geotechnical assets managed by Highways England and Network Rail. This commonality in taxonomy can enable communication and comparability both among domestic DOTs and with the existing international practice. As noted by Anderson et al. (2016), the purpose of the proposed taxonomy was to clarify language and ideas so that geotechnical engineers, practitioners of other disciplines, and asset managers can communicate effectively within an organization and between different organizations.

Figure 3.1 presents the development of GAM taxonomy presented in Chapter 5 of the *GAM Implementation Manual.* Detailed discussion on the distinctions within the taxonomy are provided in the manual and are not reproduced here for brevity.

3.5.2 Role of Agency Boundary in GAM Taxonomy

Based on information from the DOT case studies, most agencies treat geotechnical assets in a reactive manner once there is a known threat or consequence to safety or operations. Additionally, asset boundary or ROW considerations often are secondary, as the primary actions relate to specific performance impacts. For example, agencies will treat a rockfall originating from natural slopes beyond the ROW similarly to an event that occurs within the ROW. Likewise, some assets that are adjacent to the ROW but owned by others (e.g., private retaining walls) can significantly impact the operations of an asset.

The need to consider ROW or agency asset boundaries can be a distinguishing condition for geotechnical assets, as most bridge and pavement assets under existing asset management plans are easily recognized as being within the ROW or easement boundaries of the agency. For these types of assets within the ROW boundary, the agency has control over how they are built, maintained, and managed, in addition to full access rights. Clear expectations for both ownership and O&M responsibility also exist for assets that are clearly identified as being within the ROW.

As a result, the *GAM Implementation Manual* recommends consideration of geotechnical asset location relative to the ROW as a distinction in the GAM taxonomy in addition to investment and risk management prioritization steps. Geotechnical features beyond the ROW are likely related to natural hazard sites (in contrast to designed and constructed transportation assets), so the deterioration and event details of these features can differ from those of the constructed assets inside the ROW. Access and ownership constraints also may limit the ability of an agency to

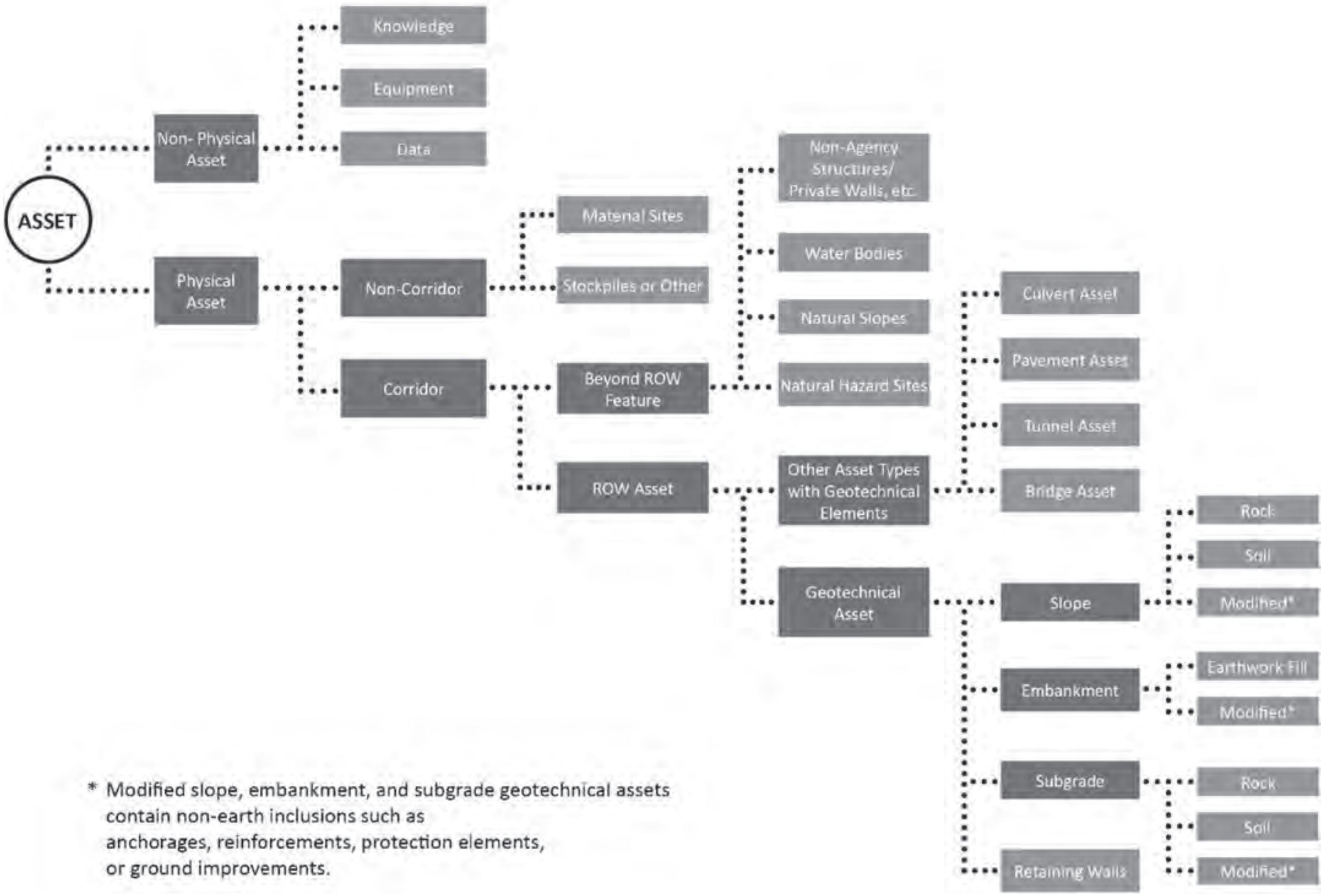


Figure 3.1. Recommended taxonomy for GAM.

manage these sites using the same design, maintenance, rehabilitation, or replacement treatment concepts that are applied to geotechnical assets in the ROW. Given these considerations, an agency generally has limited control over the factors that contribute to asset deterioration or events precipitated by beyond-the-ROW features, but must address the consequences once an event occurs that affects operations and assets within the ROW.

The management approaches used for beyond-the-ROW features can mature as an agency's GAM implementation evolves. In the United Kingdom, for example, agencies have primarily focused GAM on assets within the ROW. Following several years of established GAM experience for these assets, in 2017 Network Rail identified management approaches to beyond-the-ROW features as an area for future process improvements. The taxonomy used in the *GAM Implementation Manual* and the GAM Planner has been constructed to build in the distinction by designating geotechnical assets that occur "within the ROW" or geotechnical features that occur "beyond the ROW." For purposes of GAM planning, it is helpful to think of assets as being within-the-ROW things (assets built and owned by the agency), whereas beyond-the-ROW features are something else (i.e., natural features or assets owned by someone else).

3.5.3 Defining a Geotechnical Asset Segment

Due to the variable geographic extents of geotechnical assets, the *GAM Implementation Manual* recommends the use of the term "segment" as a means for standardizing asset location practices.

This use of the term is not unique to geotechnical assets, and the location references for all assets can have differing levels of complexity depending on agency data resources, capabilities, technology, and the precision needed for decision-making. In general, three methods of location referencing can be used simultaneously, depending on data management functions, including:

- One-dimensional (1-D) location referencing in relation to a known location such as a mile point or offset point from stationing;
- Two-dimensional (2-D) shape referencing using *X* and *Y* lateral dimensions, similar to a polygon outline on a plan view; and
- Three-dimensional (3-D) referencing, which extends 2-D referencing by incorporating an elevation (*Z*-dimension).

Although location precision is valuable in certain applications, an agency starting GAM implementation can use an existing agency location referencing system (e.g., mile point, mile marker, or reference point system). This approach also is supported in established TAM practices for other assets.

In 2014, the FHWA issued guidance for all states to develop an All Roads Network of Linear Referenced Data (ARNOLD). Within this guidance, two approaches are discussed for creating 1-D linear location references: *route-based networks* and *segment-based networks* (FHWA 2014a). A route-based network includes the route and milepost information and is considered the more traditional form of linear referencing. A segment-based (or segmented) reference system is more commonly used with GIS-based referencing systems and involves designating segments that can be either fixed in length or defined by lengths between roadway system features such as intersections and interchanges.

Within the practice of pavement management (which involves continuous linear assets), data collection intervals often are standardized at intervals or segments of 1/10 mile. The pavement management system then aggregates data into management sections and performs analysis at this level. Segment-based referencing also has been used in establishing GAM programs in Alaska, Montana, and Colorado, and is used internationally within the Network Rail and Highways England GAM programs.

As discussed in Chapter 2 of the *GAM Implementation Manual* and applied in the GAM Planner, a default segment length of 500 feet (approximately 0.1 mile) is recommended. The GAM Planner user function allows the asset manager to change this value if desired. Shorter segment lengths will result in more assets and complexity, whereas greater lengths can result in a more granular inventory. For geotechnical assets that are longer than one segment, additional segments can be added (e.g., two segments = 1,000 feet of asset length); users can assess the total asset length along the roadway by combining segments if needed. Chapter 2 of the manual discusses this process and provides supporting figures to explain the concept in detail.

3.6 Data and Data Management

For an agency starting GAM, data will be available that have been collected as an outcome of activities such as inventory, measurement and reporting, and financial planning. Because each agency will have different practices for data and data management, the *GAM Implementation Manual* does not contain a recommended best practice. Rather, Chapter 6 of the manual introduces the data and data management concepts that can support GAM implementation, such as data types and function, sources of data, methods of collection, level of detail, and georeferencing concepts. Chapter 6 also presents summaries of information from international and NCHRP reports that represent the range in available frameworks and guidance for data and data management.

Based on the research team's synthesis of case study interviews, data and data management aspects of GAM were identified as potential barriers to implementation success because of their perceived complexity, the need for training in new concepts, and the variability of existing agency systems and practices. To overcome these potential barriers, the GAM implementation framework and GAM Planner were developed to minimize the complexity of initial data management, thus allowing agencies starting GAM to focus on implementation without having to expend time, energy, or training resources learning new or difficult data management concepts or software programs.

To make it easier for agencies to start GAM as soon as possible, the research team also opted to formulate the GAM Planner and GAM implementation framework by adapting existing TAM practices. This approach does not require up-front investments to enhance or change an agency-specific data management system prior to starting GAM. It is suggested that implementation of GAM begin at a simple level of maturity using the GAM Planner in conjunction with a simple level of data collection processes. Once GAM has started, the data from the GAM Planner can be integrated into the agency's enterprise data systems if justified by ROI.

3.7 Processes for Enabling GAM Implementation Success

The *GAM Implementation Manual* provides for the user to further develop knowledge of the supporting concepts at a separate pace after starting a basic implementation. Even with a partial inventory, once the GAM process has started, an asset manager and agency have the flexibility to further develop the GAM program and outcomes based on justified investments and executive support.

To enable these process improvements to occur, Chapter 7 of the manual presents a detailed introduction to risk and risk management concepts and includes background on their connections to GAM. The synthesis of case studies suggested that training on the topic of risk would be beneficial for enabling risk-based GAM, as formal risk and risk management practices are not routine across agencies and disciplines.

In Chapter 8, the *GAM Implementation Manual* develops the concepts for risk management and TAM investment practices into a flexible guidance framework an agency can use to realize the benefits of GAM under different levels of engagement and investment. The implementation guidance in Chapter 8 has been presented purposely as a flexible process that is adaptable to the people, processes, and data in each agency. In order to improve the potential for successful GAM implementation, Chapter 8 provides guidance for agencies to:

- Consider differing organizational structures,
- Prioritize treatments based on risk and investment criteria,
- Incorporate GAM in design, and
- Implement training and/or develop an agency-specific GAM plan document.

3.7.1 Considering Organizational Structures for GAM

The research team's review of the organizational structures of successful TAM and GAM programs indicated that the individuals responsible for these programs have full-time or nearly full-time assignments to asset management and are not assigned to overlapping design or construction duties. Asset management staff focus almost entirely on asset management and have organizational connections to executives, financial directors, and/or maintenance managers within the agency. Based on the structures of the existing and mature asset management programs examined, the research team recommends this type of organizational structure as an aspirational structure for a new GAM program.

The staff organization structure for existing TAM programs varies by DOT, but typically involves some form of a senior-level enterprise asset manager working in parallel with or within other functional disciplines, such as design, construction, O&M, financial, and administration. For development of the *GAM Implementation Manual,* it was anticipated that most DOTs would not be able to formally establish a high-functioning GAM implementation team at the start of GAM implementation. In these situations, the manual indicates that a GAM implementation team can be as simple as a single individual who starts the inventory and assessment process using the accompanying GAM Planner. At this level, this could be a duty added to the existing TAM function of staff within the engineering or geotechnical design divisions, incorporated into bridge or pavement management groups, or even within the maintenance and operations function.

The *GAM Implementation Manual* emphasizes the cross-disciplinary nature of asset management, which is supported through the review of existing TAM programs and information contained in IIMM (IPWEA 2015). As presented in the manual, the staff dedicated to a GAM program should expect to interact with other disciplines within an agency, including:

- O&M staff, to understand work performed or needed for geotechnical assets;
- Budget and financial planning staff, for development of short- and long-term financial plans;
- Traffic and safety staff, to understand what opportunities exist for measuring the traffic disruption or potential safety incidents that result from adverse geotechnical asset performance;
- Enterprise IT or other agency staff responsible for tracking expenses associated with geotechnical assets (this may also be a function of O&M staff);
- TAM and other planning staff charged with asset management and strategic performance planning;
- Engineering and project delivery staff who are involved in design or influential decisions for geotechnical assets;
- Data management and/or GIS staff, for developing compatibility with established data systems and improving communication of results through mapping or geo-referenced data systems used by the organization;
- Other asset groups, such as bridge and pavement, that can support cross-asset management options; and
- Executive management, for agreement on performance objectives, building consensus, and program support.

To assist with building consensus and communication, the *GAM Implementation Manual* suggests a geotechnical asset manager form a cross-disciplinary GAM working group or steering group that enables the cross-disciplinary relationships necessary to support GAM. The purposes for such a working group include:

- Developing a wider base of support in the agency,
- Sharing of information, and
- Coordination with other activities that influence asset management, and developing the business cases for GAM across several disciplines.

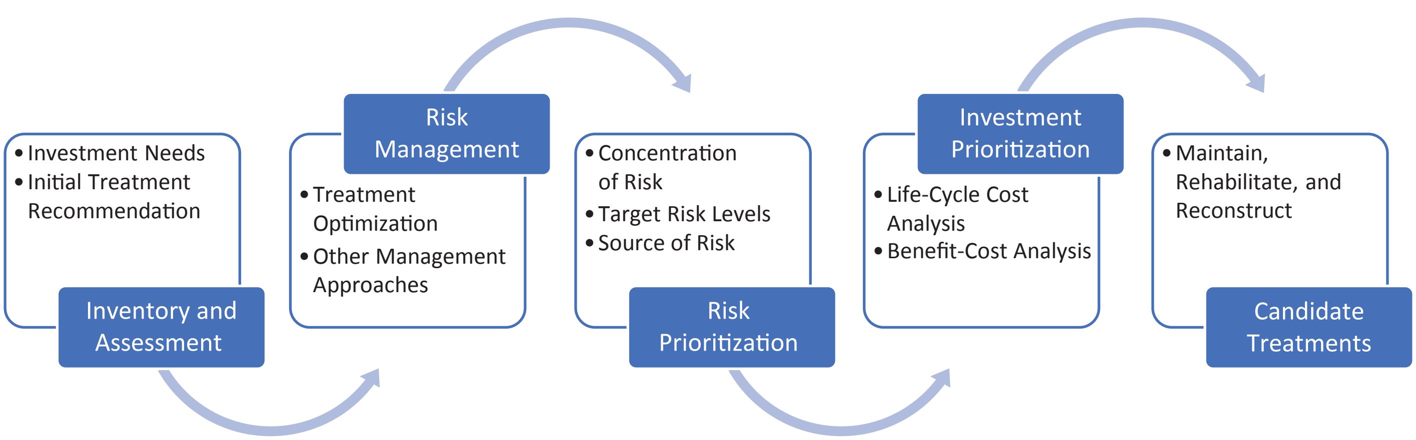
3.7.2 Prioritizing Treatments Based on Risk and Investment Criteria

The case study synthesis indicates that only a few DOTs currently fund some form of GAM program, and for those that do, the investment amounts do not achieve desired needs. For the remaining DOTs, funding for GAM occurs as a course of standard reactive maintenance activities or unplanned encumbrances from existing budgets. Information from the successful and long-standing GAM programs in the United Kingdom indicates that investment needs exceed available funds, even for a mature program. As a result, prioritization approaches are beneficial within a GAM program to ensure that the program satisfies the most pressing investment needs. Simply stating a program-level investment need that shows a favorable ROI does not guarantee enabling program funding, given that every asset group is likely in a similar investment need condition. Additionally, bridge and pavement asset management programs will have federally authorized requirements that must be followed and a new program, such as GAM, will need to demonstrate the benefits that will result from a reallocation of limited funds within an agency.

To overcome the challenge of limited funds for GAM implementation, the *GAM Implementation Manual* presents risk and investment prioritization steps directed at the asset or project level to identify specific candidate projects. The goal of this prioritization process is to develop *shelf-ready* treatment projects that could be delivered based on some level of partial GAM program funding. This process is conceptualized in Figure 3.2 (which also appears in Chapter 8 of the *GAM Implementation Manual*). Like the general implementation approach of Chapter 8, this project-level prioritization process should not be viewed as a rigid series of steps; rather, it offers flexible options to consider that may enable GAM acceptance—and, ultimately, investment support—from executives. The treatment projects can involve efforts to maintain, rehabilitate, or reconstruct geotechnical assets, and they can be structured at different levels of investment.

The details of the prioritization process developed in Chapter 8 are:

- **Inventory and Assessment:** Select candidate assets for project-level treatment planning based on recommendations from the GAM Planner. The *GAM Implementation Manual* emphasizes that treatment planning can occur at any time once inventory has started, and it should not be delayed by a separate goal of inventory completion. To realize the benefits of GAM, agencies will need to move quickly through the entire TAM process as quickly as possible, and evidence from existing programs indicates that this can occur with only a partial inventory.
- **Risk Management:** It is suggested that agencies first evaluate the potential feasibility for management of risk considering concepts such as treatment, transfer, termination, or acceptance. This approach, first developed under NCHRP Project 08-93, "Managing Risk Across the Enterprise" (Proctor et al. 2016), has been published in the first edition of the *AASHTO Guide for Enterprise Risk Management* (AASHTO 2016). Based on the assumption that most agencies will follow a practice of risk treatment, the *GAM Implementation Manual* was developed to provide guidance for considering a range of asset-specific actions and the resulting risk and investment considerations for each treatment subcategory (e.g., maintain, rehabilitate, reconstruct).



Note: Restore does not appear as a "candidate treatment" because restoration is triggered only if the asset has failed.

Figure 3.2. Proposed project-level GAM treatment prioritization process.

- **Risk Prioritization:** The *GAM Implementation Manual* presents a discussion of differing prioritization concepts that can be considered when communicating needs with executive stakeholders who can enable program funding. These risk prioritization areas include selecting treatment candidates based on concentration of risk, acceptable risk exposure levels, sources of risk, type of risk, cross-asset risks, critical routes or high-value assets, or risks to outside compliance needs.
- **Investment Prioritization:** Candidate projects can be evaluated based on the anticipated ROI when considering the life-cycle costs and benefits. The *GAM Implementation Manual* discusses the processes for life-cycle cost analysis using NPV and cost-benefit analysis to identify those treatment projects with the greatest ROI. Within this process, the manual also suggests evaluating opportunities for cross-asset collaboration as a means to realize benefits from shared investments across asset groups.
- **Candidate Treatments:** The success of GAM implementation will depend on having the flexibility to adjust to differing levels of investment capacity, agency risk tolerance, and performance. Using the prioritization process described in the manual, the asset manager can identify and develop candidate projects with differing investment needs that are data driven, that consider differing levels of risk and performance benefits, and that can adapt to agency TAM culture.

3.7.3 Incorporating GAM in Design

Most established and long-standing design methods for geotechnical assets have been developed based on safety margin and reliability concepts. Because these methods were established before the development of asset management practices, the focus of the safety and reliability framework is generally directed at complete asset failure or total loss of service life. Consequently, the incorporation of asset management considerations during the design process of new geotechnical assets is an important step in a GAM implementation. The *GAM Implementation Manual* presents a series of questions and guidance to enable geo-professionals to incorporate asset management considerations into the design practice.

3.7.4 Training Considerations for GAM Implementation

Both the case study and literature synthesis indicated that training in asset management concepts would be beneficial for those starting GAM programs. Suggested training topics include:

- Introduction to TAM;
- Introduction to GAM and the *GAM Implementation Manual*, including:
  - Purpose and need for GAM;
  - Implementing GAM (including discussion of the list of steps and model in Chapter 2 of the manual);
  - Linking TAM to GAM;
  - Examples of GAM practices;
  - Getting started; and
  - Overview of the GAM Planner, with examples;
- Risk and risk management; and
- Life-cycle cost analysis.

3.7.5 Developing a GAM Plan Document

The *GAM Implementation Manual* differentiates between GAM implementation, which consists of the processes that enable asset management, and a GAM Plan, which is simply the document or other means of communication used to summarize the processes of the program. Given this distinction, an agency does not need to develop a GAM plan prior to GAM implementation. Evidence from the long-standing GAM programs for highway and rail agencies in the United Kingdom indicates that asset management plans are regularly updated documents that summarize performance and present process improvements over prior plans. For example, "The Earthworks Policy for Network Rail" was issued first in 2011, well after GAM implementation had started. The current plan document is the seventh issue, which was released in March 2017.

For an agency starting GAM, the *GAM Implementation Manual* recommends that the initial GAM plan be a brief document that can function as a communication tool directed at maintaining the connection with executive and TAM representatives while emphasizing the benefits of GAM across the spectrum of all transportation assets.

The manual presents a framework for a GAM plan that is directed toward gaining executive and TAM stakeholder support through communication of risk acceptance levels and identifying "quick wins" that create investment benefits and value to the agency. Appendix F to the *GAM Implementation Manual* (available online) provides an example annotated outline for a simple GAM plan document. The framework and outline follow the TAM steps of plan objectives and measures, inventory and condition, gap analysis, life-cycle cost and risk management analysis, and financial planning and investment. The framework also includes example objectives and measures that could be adopted for an agency starting GAM using the *GAM Implementation Manual* and accompanying GAM Planner.

CHAPTER 4

Conclusions and Suggested Research

4.1 Conclusions

As a general conclusion, applying TAM concepts to geotechnical assets is a beneficial process for managing life-cycle risk, performance, and investment for assets such as embankments, slopes, retaining walls, and subgrades. Fortunately, information from the few long-term and sustainable GAM programs in other countries and from existing infrastructure systems indicates that state transportation agencies can be confident of the benefits without having to undertake new research or implement untested processes and systems. **It is certainly possible for agencies to start implementing GAM now regardless of investment capacity and expertise**.

For an agency to begin recognizing the benefits of incorporating geotechnical assets into TAM, it is suggested that the primary goal should be starting GAM implementation and progressing inventoried assets through the TAM steps without delay. Evidence from currently successful GAM programs indicates that benefits are possible without having to first complete the asset inventory or finalize all the processes and data systems that support implementation. Rather, agencies can benefit from starting with a simple asset management strategy and relying on justified process improvements with time. This approach is both preferred and supported by evidence from successful programs. In the United Kingdom, Network Rail's inventory completion took more than 11 years, and the first GAM policy document was not released until almost 6 years after the start of the program.

The implementation framework developed for this project is structured to encourage agencies to begin GAM implementation. The approach is intended to trigger engagement for performing GAM without requiring a high level of motivation or technical ability. Cross-industry research indicates the importance of considering the components that underpin motivation and the ability to succeed at a new task. Considering these factors is essential to increasing the likelihood that the necessary behaviors will be adopted. This is not a reflection on the individuals who may undertake GAM, but rather a recognition of the challenges of implementing new processes and efforts in complex organizations consisting of individuals who already have high demands on their time and resources.

Once GAM implementation has started and initial treatment recommendations have been developed, geotechnical assets will still need to compete for investment among the other asset groups and programs of the DOT. Thus, treatment planning is necessary to identify project-level options that incorporate the range of risk and investment priorities that are of interest to agency executives. The recently published *NCHRP Research Report 885: Guide to Creating and Sustaining a Culture of Innovation for Departments of Transportation* provides many helpful suggestions (Lorenz et al. 2018).

4.2 Suggested Research

The objective of this research was to produce an implementation manual for developing a GAM program. Once empirical data obtained through the actual execution of GAM implementation across the United States are made available, there likely will be several future research directives that can support process improvement in GAM programs. As a result, maintaining an emphasis on starting implementation is a strongly recommended outcome from this project as implementation results are necessary for guiding future research.

To support the initiation of implementation across DOTs and across varying geologic terrains, suggested future research could focus on actions that can increase motivation and ability for GAM. Suggested topics for research and the connection to motivation and ability are:

4.2.1 Motivation

- **Developing acceptance for GAM through existing federal and state programs:** A federal mandate or other authorization that would create a strong motivation for GAM is not anticipated in the near future. Opportunities may exist, however, to increase agency motivation to begin GAM through process improvements to existing programs. Research into approaches to adapt existing programs to motivate or incentivize GAM may facilitate a more rapid adoption of GAM across the nation.
- **Developing a national database for sharing of geotechnical asset performance:** Like the National Bridge Inventory, a national inventory of geotechnical assets could be researched and developed to enable information sharing among agencies. This process would increase motivation for agencies to participate in GAM based on a need to stay current with trends in national practice.
- **Incorporation of federally supported guidelines for ROW considerations in GAM:** For many agencies, treatment of features beyond the ROW has been approximately equivalent to treatment of assets within the ROW. This legacy approach is a worthy action that likely contributes favorably to the reputation of an agency; however, a direct cost trade-off exists for agencies that voluntarily undertake 100 percent of the financial liability for management of features beyond the agency boundary. Additionally, even though the operational consequences can be equivalent, the treatments and risk management approaches chosen to address features beyond the ROW may be different. Thus, agencies can benefit from standard guidance for managing geologic hazards and natural slopes beyond the ROW. This topic also has been identified as a performance improvement topic for the established GAM programs in the United Kingdom. It is anticipated that research into this topic may provide motivation for GAM at the executive levels of agencies by identifying opportunities for additional risk-sharing or funding options.
- **Treatment of natural hazard risk sources:** For many agencies, recovery from natural hazard events such as flood-induced ground movements or landslides following extreme weather events has been considered equivalent to adverse events for geotechnical assets within the ROW. However, natural hazard risk is not unique to geotechnical assets, as all agency assets can be impacted by natural hazards. DOTs would benefit from research that establishes guidance for management of risk that originates from natural hazard sources, whether rockfall from natural features beyond the ROW or regional events such earthquakes and floods. Similar to ROW considerations in GAM, this topic is anticipated to generate motivation among executives who are interested in identifying opportunities to improve cost recovery and reduce risk.
- **Developing practical guidance for risk management of geotechnical assets:** By default and through legacy practices, agencies typically manage the risks related to geotechnical assets through acceptance or treatment. However, other management options (e.g., "transfer,"

"terminate," or "take advantage of") could be considered. A synthesis of case histories and recommendations advancing risk management approaches that offer alternatives to the legacy approaches could benefit GAM implementation. This research might increase motivation among executives by providing actionable guidance for new risk management approaches on geotechnical assets.

4.2.2 Ability/Simplicity

- **Model development to support use of the GAM Planner and deterioration estimates:** The GAM Planner that accompanies the *GAM Implementation Manual* contains default models for common asset types in a DOT GAM program. The manual also enables agencies to develop additional GAM Planner models based on agency-specific subject matter expertise and judgment. Research toward deterioration rates for geotechnical assets would be beneficial in improving GAM Planner modeling accuracy and treatment recommendations. This research would increase the simplicity of GAM by providing geotechnical asset managers increased confidence in model outcomes without having to undertake separate research programs.
- **Incorporation of UK geotechnical asset performance results:** The GAM programs for highway and rail networks in the United Kingdom present an opportunity to accelerate model reliability for embankment and slope assets in domestic GAM programs. These international programs have several years of geotechnical asset performance data that are enabling process improvements in the Markov Models for UK geotechnical assets. The value and applicability of these data should be evaluated to enable the GAM maturity advancements to occur rapidly for similar U.S. geotechnical assets. This research could save money for domestic agencies through the incorporation of useful data for similar assets while simplifying model development.
- **Measuring performance for geotechnical assets using automated or other simple collection methods:** The rapid pace of technological advancement is enabling DOTs to measure system performance through automated means. For example, many DOTs can precisely measure traffic volume and disruptions using enterprise-level software systems. The resulting data can be valuable for measuring distributions that are attributed to geotechnical asset performance and can be obtained with less effort than manual techniques. Alternatively, remote sensing and emerging photogrammetric and satellite technology is enabling historical measurement of ground movements. Research into these topics may enable simplicity in GAM through the availability of low-cost regional data coverage that saves time in the asset management process.
- **Life-cycle cost analysis for geotechnical assets:** Research toward approaches that improve reliability in NPV and benefit-cost models would be valuable for supporting the financial planning and investment steps described in a GAM plan document. As life-cycle cost analysis is not a common practice among geo-professionals, research that enables this process to occur at a low ability level would be beneficial.

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Appendices (Available Online)

Two appendix documents accompany this research overview. Together with the appendix documents and tools that accompany Volume 2 (the *GAM Implementation Manual*), they are available for download from the *NCHRP Research Report 903* web page at www.trb.org. The complete list of documents and tools is:

- **NR903_V1_Appendices.pdf**
  This file contains the two appendix files that accompany Volume 1. Appendix A summarizes the literature review prepared during the research, and Appendix B presents the outline used for the case study interviews.
- **NR903_V2_Appendices.pdf**
  This file contains the seven appendix files that accompany Volume 2:
  - Appendix A: Using the GAM Planner,
  - Appendix B: GAM Inventory Start Example,
  - Appendix C: GAM Model Formulation,
  - Appendix D: Geotechnical Asset Condition and Level-of-Risk Examples,
  - Appendix E: GAM Asset-Level Net Present Value Framework Worksheet,
  - Appendix F: GAM Plan Outline, and
  - Appendix G: GAM Implementation Barrier Mitigation Strategy Matrix.
- **NR903_GAM_Planner.xlsm**
  This file contains the spreadsheet-based (Microsoft Excel) tool. User information for the GAM Planner is provided in Volume 2, Appendix A.
- **NR903_NPV_Template.xlsx**
  This file contains a spreadsheet-based (Microsoft Excel) worksheet template for a life-cycle cost investment analysis tool. The template supports the process of selecting project-level treatment alternatives in GAM and can be used for investment-based treatment alternative analysis that considers asset or project life-cycle costs including design, O&M, and any potential rehabilitation or reconstruction treatments. User information for the NPV Template appears in Volume 2, Appendix E.
- **NR903_GAM_Training_Slides.pptx**
  This file contains a slide-based presentation (created in Microsoft PowerPoint) that can be used during training for GAM.

A technical memorandum on the implementation of the research findings also is available and can be accessed separately using a link on the NCHRP Project 24-46 webpage: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4065.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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