Geotechnical Asset Management for Transportation Agencies, Volume 2: Implementation Manual (2019)

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 903

Geotechnical Asset Management for Transportation Agencies

Volume 2: Implementation Manual

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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 2

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Learn more about the Transportation Research Board at **www.TRB.org**.

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FOREWORD

By Camille Crichton-Sumners
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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 2 of *NCHRP Research Report 903* presents a manual that agencies can use to implement GAM planning. Volume 1 provides background on the research and discusses the benefits of proactively addressing GAM. 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.

PART A

Introduction and the "Why" of GAM

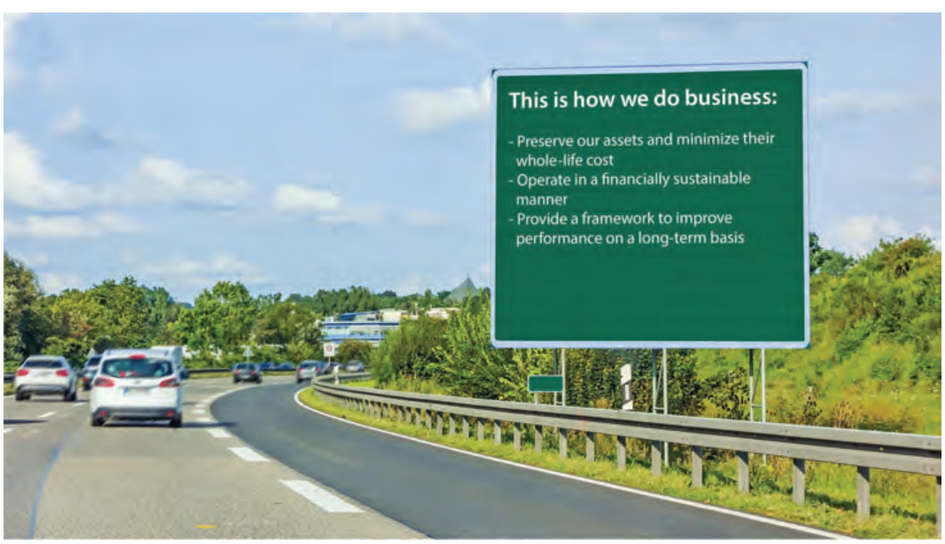
CHAPTER 1

Overview

Introduction

For a transportation infrastructure owner, geotechnical assets are the walls, slopes, embankments, and subgrades that contribute to the ability of an agency to perform its strategic mission. Legacy approaches often group geotechnical assets into the category of unpredictable liabilities or hazards. Worse, geotechnical assets may be ignored altogether until failure forces action. At the same time, functional life-cycle expectations exist for geotechnical assets, and these assets contribute measurable value to the transportation network. Thus, walls, slopes, embankments, and subgrades are indeed assets and should be managed to realize the measurable life-cycle and performance benefits that are possible for owners and users.

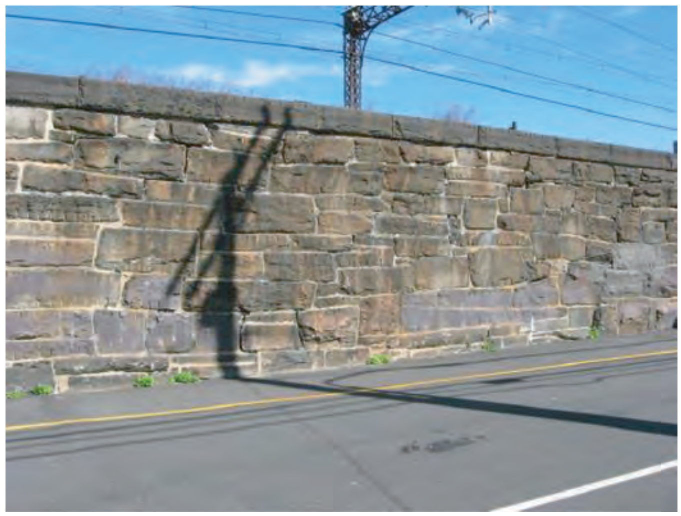
Across nations and across infrastructure systems, numerous examples of geotechnical asset management (GAM) implementation have resulted in life-cycle cost savings, reductions in performance and operational disruptions, and fewer emergency stabilization projects. *NCHRP Research Report 903: Geotechnical Asset Management, Volume 2: Implementation Manual* (the *GAM Implementation Manual,* for short) provides the guidance, tools, and supporting information for a transportation infrastructure owner to realize the benefits of GAM with a focus on quick implementation and value creation. Asset management is ultimately a life-cycle process and involves a culture that can be adapted through process improvements once the process has started. The most important step is simply starting; otherwise, value is lost. Readers seeking information about the research process and background information that informed the creation of this manual are encouraged to consult *NCHRP Research Report 903, Volume 1: Research Overview.*



How to Use the *GAM Implementation Manual*

The *GAM Implementation Manual* introduces risk-based asset management concepts for geotechnical assets that can be used by departments of transportation (DOTs) and other transportation infrastructure owners at any stage of transportation asset management (TAM) implementation and at any point in the geotechnical asset life-cycle. Lack of prior asset management practices need not be an excuse for avoiding management of an existing asset, as there are benefits to starting at any time during an asset's life-cycle. The time to start is now!

The *GAM Implementation Manual* is organized into three parts, which are briefly described in the balance of this section.



Part A: Introduction and the "Why" of GAM

Part A of this manual introduces GAM and, more importantly, introduces why it is important to implement GAM. The "why" discussion provides introductory information that introduces the case for GAM to the various stakeholders, including department executive decision-makers, transportation asset managers, and geotechnical and geological staff (geo-professionals) who will lead and participate in the GAM process. This "why" discussion is intended as a high-level summary of reasons to perform GAM. Throughout the manual, the reader will find other examples of the reasons for GAM, many of which are supported by existing successful practices.

Part B: Starting GAM Implementation

Part B provides agencies and asset owners the opportunity to hit the ground running without having to get bogged down learning all the nuances of asset management or geotechnical assets beforehand. Part B teaches the basics of GAM through step-by-step implementation instructions. The "GAM Planner," a simple spreadsheet-based (Microsoft Excel) worksheet tool, has been created to supplement this section and will enable rapid creation of a real and functioning GAM inventory and assessment. Together with appendix files that supplement this manual, a slide presentation useful for GAM training, and a spreadsheet-based net present value (NPV) planning template, the GAM Planner can be downloaded at no charge from the report web page. To access these resources, go to www.trb.org and search for "NCHRP Research Report 903". A technical memorandum on implementation of the research findings also can be accessed using a link on the NCHRP 24-46 project page.

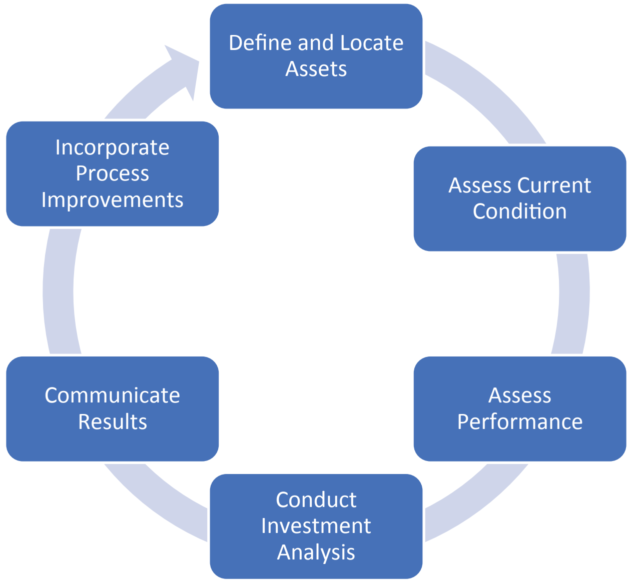


Figure 1.1. Implementation steps detailed in Part B of the GAM Implementation Manual.

Part B is structured for learning GAM by doing GAM; it will enable the geo-professional or asset manager to begin implementing GAM regardless of agency stakeholder interest levels and without requiring mastery of complicated processes and data.

As a process, GAM implementation as described in this manual proceeds using steps that have less precision than is typical in engineering design. The geo-professional is thus encouraged to move forward with GAM knowing that uncertainty is part of the process, and that this uncertainty will reduce with time and implementation experience.

The benefits of GAM justify starting now rather than waiting to develop expertise before beginning implementation. This "lean start" approach is supported by numerous case studies that have demonstrated it is better to start simply and improve with time than to invest in a complex approach up front without implementation testing along the way. When supplemented with continuous improvement over time, the lean start approach is a proven path toward realizing quick success for a GAM plan. Figure 1.1 illustrates the GAM implementation steps detailed in Part B.

Because asset management creates value, delaying implementation wastes resources and delays realization of benefits. Starting GAM is the first successful step an agency can take, and this manual will facilitate implementation whether it is done by a motivated individual or with support and input from across a department.

Part C: Understanding the GAM Process

Once GAM implementation has begun following the simple steps in Part B (or should a GAM plan already be in place), Part C provides technical and supporting information about TAM concepts and the integration of GAM with TAM that can help an agency move toward a more mature level of GAM as justified by the return on investment (ROI) over time.

Why Implement GAM?

The benefits of GAM are real and measurable, and are increasingly being recognized by both public and private infrastructure organizations. Based on outcomes from successful programs around the world, performing GAM yields benefits that include:

- 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);

GAM is an opportunity for the geoprofessional to earn a "seat at the asset management table" when it comes to communicating investment needs, competing with other asset groups, and making measurable improvements to agency performance.

- 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;
- Optimized resources, improved sustainability, and well-maintained reputation;
- Enhancement of data-driven decisions that support agency and executive objectives;
- A greater understanding of risk exposure levels and distribution, and the ability to manage those risks; and
- The ability to start very simple and adapt the GAM process over time as the economic benefits are realized.

The outputs from even a simple GAM plan will enable individuals responsible for geotechnical assets to have a defensible basis for operational decisions, enhancing their ability to compete for resources and funds. Further, those responsible for geotechnical assets will be able to communicate to executives and planning staff the levels of risk and costs that an agency may be accepting through legacy design and maintenance practices.

Financial Responsibility for GAM

GAM enables an infrastructure owner 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. The reasons for implementing GAM are comparable to those that justify any other individual or business practice that is directed at making smart investments with limited funds. Using GAM, organizations will better manage risks to traveler safety, mobility, and economic vitality, and will be able to make knowledge-based life-cycle investment decisions.

The NCHRP study team reviewed case studies of agencies that had years of experience with GAM. When discussing GAM with agency staff, the study team received responses along the lines of "Why wouldn't you do GAM?" These agencies had realized such favorable benefits from GAM they could no longer envision operating without GAM.

Public agencies have a fiduciary responsibility to be good stewards of taxpayer-provided funds. Moreover, an agency's ability to function well and succeed in its mission depends greatly on whether it is viewed as a good steward of public funds. Consequently, agencies establish policies and procedures to ensure that public funds are used effectively, waste is minimized, and investments can withstand the test of public scrutiny. GAM is a value-added process that supports agency personnel in fulfilling their commitment to good stewardship of taxpayer funds.

Managing Risk

The consequences associated with adverse performance from geotechnical assets—impacts to traveler and worker safety, travel delays and closures, unplanned or urgent staffing needs, and direct expenses to maintenance and engineering programs—are well understood by many DOTs. System users experience the adverse geotechnical performance first hand, as they are impacted by delays and closures; they also may incur vehicle or property damage, or in the worst case experience, they may sustain injuries from an unfortunate safety event. When adverse events occur, the public often will question an agency's failure to prevent the event (i.e., to proactively manage the underlying situation), which leads to reputation issues.

The fact that readily identifiable impacts originate from geotechnical assets makes it possible to measure asset performance in terms of the asset's condition and the consequences to the owners and users of the asset. Each asset performance measurement will have a magnitude and a location reference, and will change with time, depending on the asset owner's investment and maintenance levels. When asset performance is measurable, the task of communicating the need for asset management to stakeholders and executives becomes much easier. For geo-professionals working in resource-constrained departments with limited executive involvement, a simple GAM system will help them compete effectively for resources by enabling them to determine and communicate risk levels and investment needs using data-driven processes. Even without executive-level GAM or TAM support in the agency, the geo-professional or TAM team can be confident knowing they are applying good business practices in the allocation of their work efforts and resources.

Decision Support

Even when implemented at a simple level, GAM processes can provide the geo-professional with data that enables operational decision-makers to make better-informed choices in order to:

- Reduce expenses and optimize investments for geotechnical assets at any point in the asset life-cycle;
- Reduce broader economic impacts associated with asset failures, (e.g., injury, loss of life, or property damage to citizens, businesses, and other governmental agencies);
- Lessen delays and closures associated with adverse performance of geotechnical assets; and
- Support environmental sustainability and public relations initiatives.

Starting Simply

A simple GAM implementation can be completed without a large investment while following a framework that can connect to a broader TAM program or performance improvement initiative. As has been demonstrated through successful asset management plans from around the world, continuous improvement is the recommended practice for reaching an advanced level of asset management maturity. In other words, it is an acceptable approach to start simply and increase precision over time with financially justified improvements to processes, data, and staff capabilities.

This manual provides an implementation framework for developing a simple GAM system. Considering proven examples from successful programs, this framework was formulated to enable a resource-limited staff to implement GAM without a sizable upfront program

A GAM system that connects with strategic objectives can stand on the basis of economic, operational, and social benefits without depending on regulatory requirements for implementation.

Starting with a simple process that matures over time is a proven enabler of successful asset management.

commitment. Using the framework, the geo-professional can demonstrate the purpose and value of GAM, thus establishing defensible justification for further investment. This approach is of particular importance because GAM is currently not mandated; however, efforts are underway in at least one U.S. state to legislate implementation if voluntary agency actions are not adequate to enhance public trust. At present, GAM must be justified on the basis of real, measurable value and risk reduction. With time, continuous improvement through favorably justified investments can allow an agency to develop a more mature GAM program.

Just as an agency measures and reports on metrics such as annual budgets, traveler safety, and economic contributions, geotechnical asset performance can be communicated as an outcome of GAM implementation. Within any framework, communication of this performance is a key process to demonstrate the value proposition for obtaining limited funds based on a *sound business case* and a *favorable ROI*.

Unlike many procedures in traditional engineering and construction project delivery, asset management is not a task to be checked "Done." Rather, it is a continuous process. Further, asset management objectives will vary by agency and over time within an agency. Thus, GAM implementation is best started as a simple process that demonstrates the range in potential benefits and that can be adapted over time with feedback from executives and stakeholders. For example, one agency may realize its GAM system can provide measurable benefits to preserving asset condition, whereas another agency may learn that potential improvements can come in the form of reduced traveler delays. Starting with a simple GAM implementation allows each agency to use feedback from TAM and executive staff to improve workflows and identify activities that can be minimized. Rather than expending resources up front to execute a comprehensive but untested plan, a simple GAM implementation that matures over time can better match the specific objectives of each agency.

PART B

Starting GAM Implementation

CHAPTER 2

Starting GAM

Implementing GAM

At the simplest level, asset management is about managing physical objects with value. Regardless of asset type, even basic knowledge of an asset provides enough information to start asset management. There is no need to direct lengthy, time-consuming efforts to create manuals, conduct extensive planning, develop a detailed inventory, or conduct data-intensive analysis ***to start*** asset management. These steps all add value and process improvements as an agency's GAM process matures, but it is important to remove the perception that ***starting*** GAM requires large and complex investments of time and money that may not be available in most agencies.

Most maintenance-, technical-, and executive-level employees in a public-sector infrastructure agency likely perform some form of informal asset management as part of their typical duties. Knowledge of existing problems prepares an owner to prioritize assets to create a simple initial inventory for GAM. Assets that already suggest a higher level of risk (LOR) are excellent candidates to be included first in the GAM inventory, and the implementation process described in this manual takes advantage of this fact.

The purpose of this chapter is to enable a geo-professional or any other agency staff member to quickly start implementing GAM while learning the supporting asset management concepts at the same time. The process described, and the accompanying GAM Planner (available online) will assist an agency in ***starting risk-based GAM*** based on ***performance objectives*** related to ***asset condition, safety impacts, and mobility and economic consequences.*** Common across many public agencies, these performance objectives provide a simple means for the agency staff implementing GAM to connect with and gain support from stakeholders at various levels of engagement.

GAM can easily address agency objectives related to:

- *Safety,*
- *Mobility and economic consequences, and*
- *Asset condition.*

Following the steps in this chapter will yield a simple risk-based GAM inventory and assessment model. This simple model can be immediately deployed in decision-making while allowing for future inventory additions and model updates based on the agency's priorities. Thus, this chapter can enable an agency to obtain a "quick win" on the path toward integrating GAM into a risk-based TAM program. The chapters grouped in Part C of the manual present background information and optional process improvements that can be incorporated, either in parallel or following initial implementation of GAM. As they are incorporated into a maturing GAM process, the added information and process improvements will bring additional value and agency-specific components into the agency's GAM plan.

Readers progressing through this chapter are encouraged to complete the accompanying steps in the companion GAM Planner for a few initial assets. By doing so, GAM implementation will already have started by the end of this easy-to-follow chapter. (The GAM Planner, appendices that include a brief guide to using the GAM Planner, and other online resources are available for download from the *NCHRP Research Report 903* web page.)

Workflow for Implementing GAM

The implementation process described in this chapter is based on the simplified asset management workflow presented in Figure 2.1. Within this workflow, optional process improvement steps can be considered at any time. These optional process improvement steps are introduced in Part C of the manual. The goal of this workflow is to enable a quick start to GAM so that benefits can be identified as early as possible, thus generating stakeholder support sooner.

To start the GAM implementation workflow using the GAM Planner tool, the user first selects a corridor (or portion of a known inventory) to identify and locate specific geotechnical assets. By starting with a few assets (e.g., 10 to 20 assets), the outcomes of the initial workflow loop are easier to digest and understand. Once the user gains familiarity with the process, models, and inputs, the inventory development can progress more rapidly.

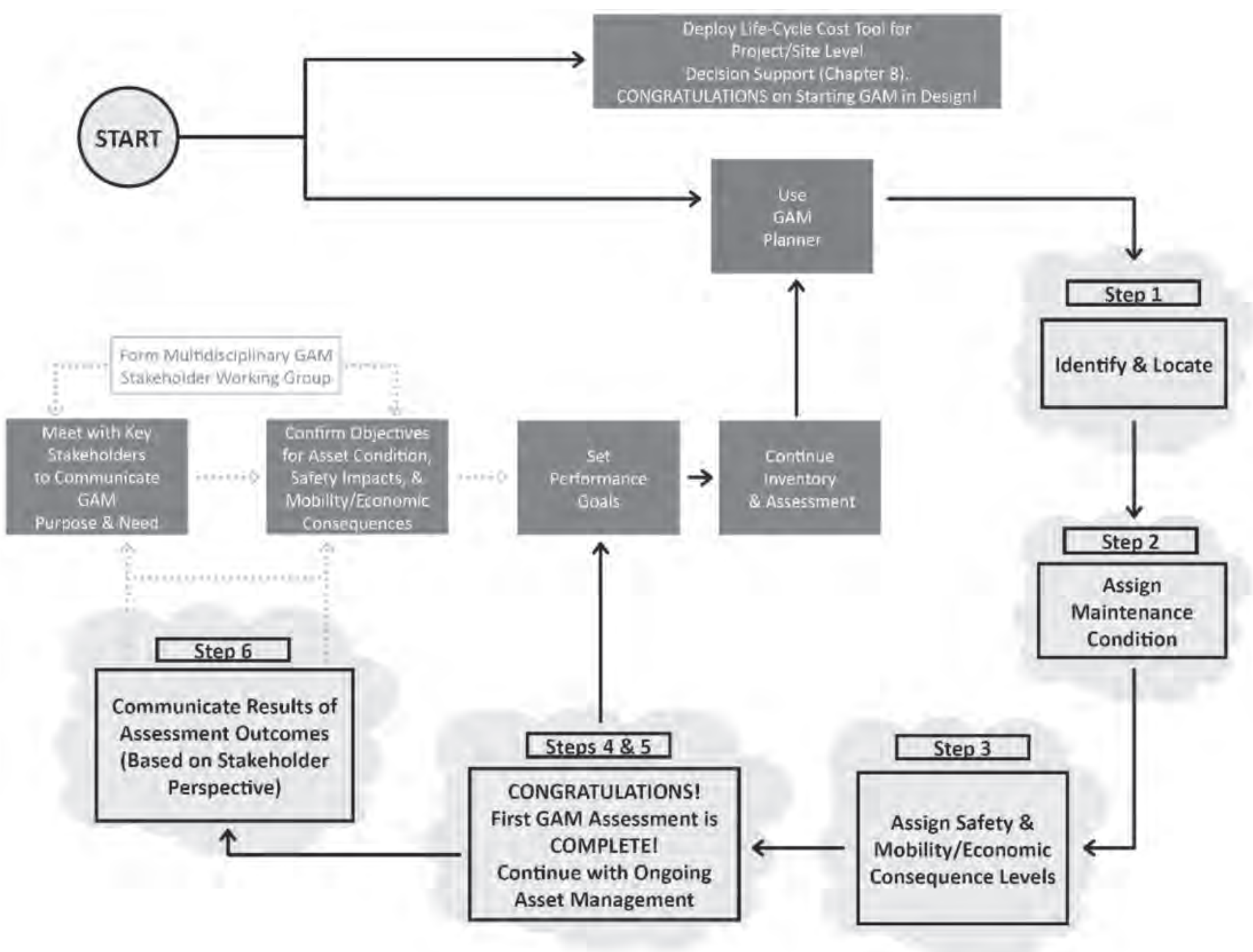


Figure 2.1. GAM implementation workflow.

Step 1: Identify and Locate Geotechnical Assets

Definition of a Geotechnical Asset

In this *GAM Implementation Manual,* a geotechnical asset is an embankment, slope, retaining wall, or constructed subgrade that contributes to the performance of your transportation system. These assets also contribute to the performance of the many culverts, pipes, and utilities that penetrate these engineered structures. Geotechnical components, such as ground reinforcements in a wall or embankment, groundwater drainage features, rock bolts, and structure foundations, are the improvements within many geotechnical or other structure assets that help the asset function through routine loading and extreme events.

For more on the definition of ***geotechnical asset*** *(and other definitions) see the taxonomy discussion in Part C, Chapter 5.*

Although an agency's definition of geotechnical assets may include assets that involve right-of-way (ROW) aspects, it is suggested that during the initial stages of GAM implementation the inventory should focus on compiling the assets, deferring consideration of GAM inside or outside of the ROW to a later step.

A brief review of what defines each geotechnical asset type is presented in the following sections.

Embankment Assets

An embankment asset is a type of geotechnical asset that consists of a constructed fill comprising rock, soil, or other engineered materials that enables a roadway to maintain a required design elevation above lower-lying ground. This *GAM Implementation Manual* encourages use of a threshold embankment height of 10 feet (3 m) as delineation between a minor earthwork and an embankment asset, unless existing site conditions (e.g., complex geologic terrain) merit a lower height. Figure 2.2 presents example embankment asset schematics.

The 10-foot threshold height for embankment and slope assets is based on more than 15 years of successful implementation experience for 240,000 geotechnical assets on highways and railways throughout the United Kingdom.

Slope Assets

Slopes are a type of geotechnical asset involving cut excavations that enable a roadway to traverse through surrounding ground with acceptable design profiles. For some agencies, slope

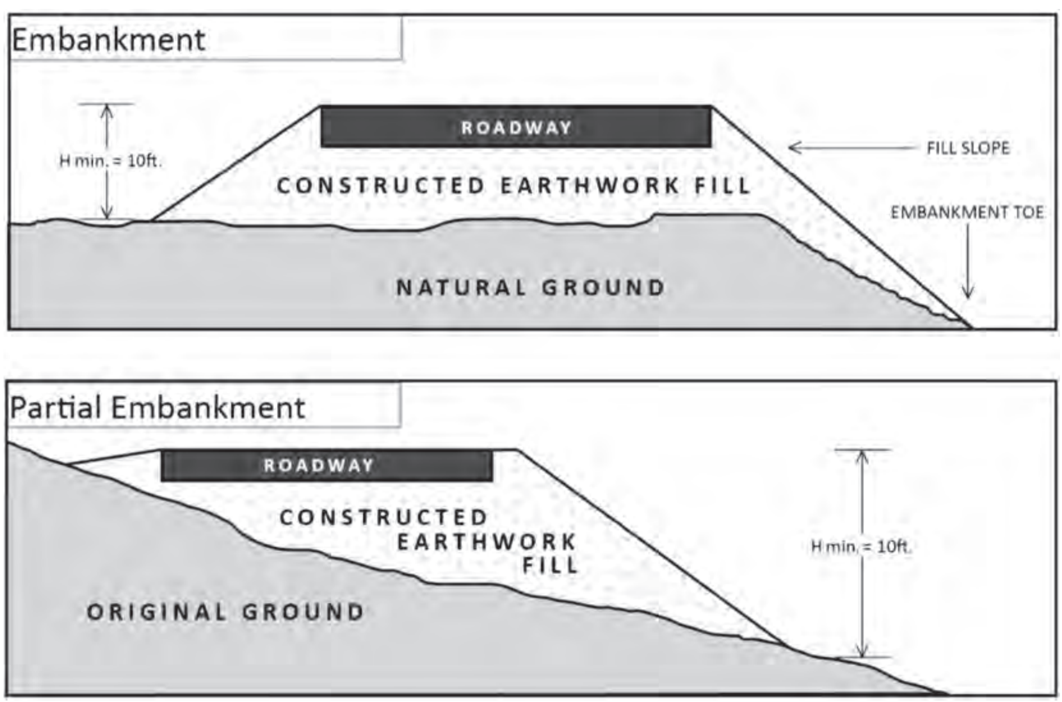


Figure 2.2. Embankment geotechnical asset examples.

assets also may include natural slopes adjacent to a roadway. Slopes differ from embankments in that, rather than being constructed fill features, slopes are excavated into terrain or may consist of a natural slope that potentially generates a hazard. Slopes can consist of soil, rock, and mixtures of soil and rock, as shown in Figure 2.3. Similar to embankment assets, a 10-foot height threshold for cut slopes is recommended in the GAM inventory, unless the asset is judged to create an unacceptable hazard to the safety of users and maintenance personnel.

Some roadway segments include both slopes and embankments. In these situations, for purposes of the inventory, the segment consists of two assets: the slope and the embankment. Similarly, if a road segment includes a slope (or embankment) and other assets, each asset is considered separately. This concept is discussed in more detail later in this chapter.

Retaining-Wall Assets

As there is not federal guidance on wall asset management, this manual can be used to quickly incorporate this expanding asset type into the larger TAM program.

Retaining walls, or earth-retaining structures, are structures that hold back soil and/or rock materials to prevent material from sliding onto a roadway or other structure, or to retain material in place as needed to support a roadway. This type of geotechnical asset includes gravity walls, soil nail walls, concrete cantilever structures, or mechanically stabilized earth (MSE) walls.

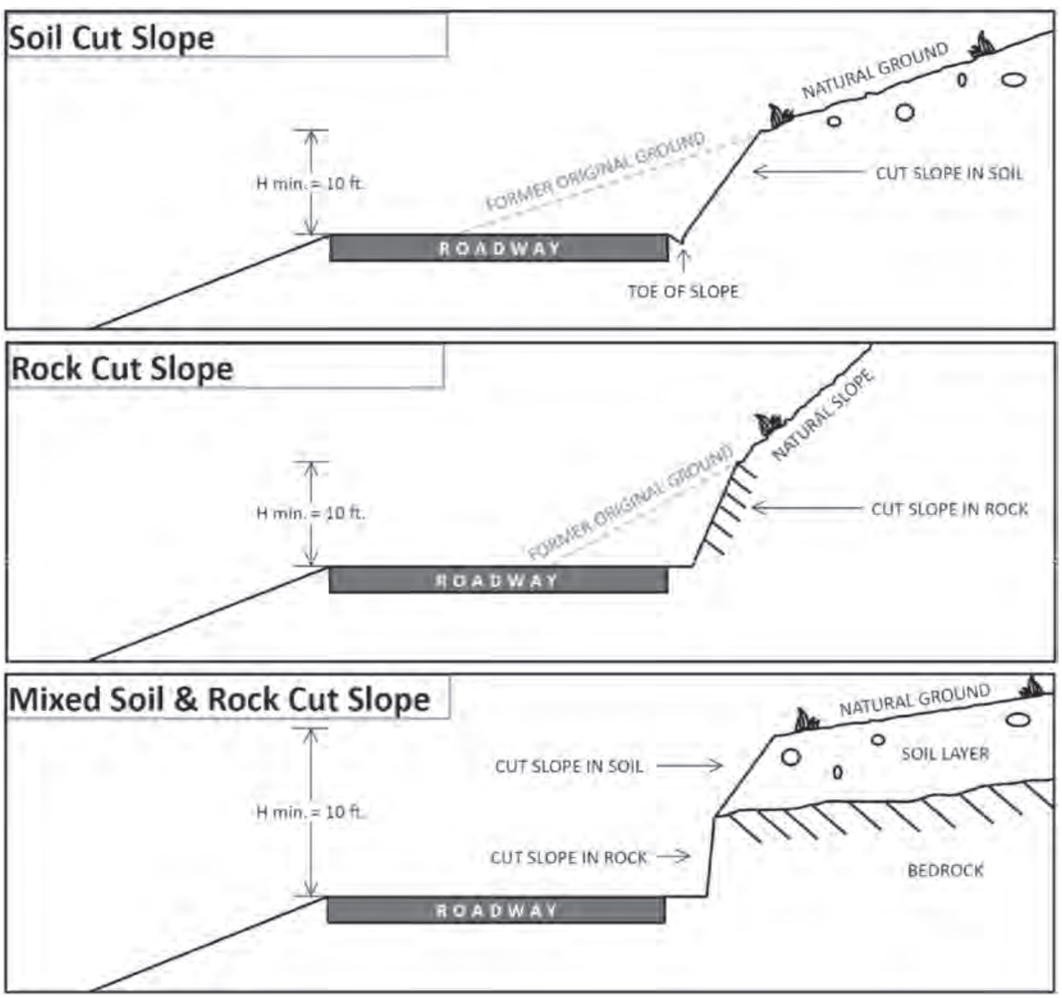


Figure 2.3. Geotechnical slope asset examples.


Figure 2.4. Retaining-wall asset examples.

Generally, retaining walls will have vertical or near-vertical faces and the recommended threshold inclination is 70 degrees between a wall and an embankment or slope that relies on inclusions for stability. The recommended wall height for incorporation into a GAM inventory is 4 feet, which is based on many examples of what defines a retaining wall in the engineering design process.

Many retaining walls are associated with bridge structures or approaches to a bridge. For the purpose of the inventory process in the *GAM Implementation Manual,* if a wall is also a bridge abutment that is integral to the bridge structure, the wall should be considered part of the agency's bridge inspection and asset management program. It is encouraged that all other walls associated with the bridge approaches be considered for incorporation into the GAM plan if they are not already managed in another asset management program. Figure 2.4 and Figure 2.5 show examples of retaining-wall assets.

Note the presence of embankment and slope geotechnical assets in the background.

Figure 2.5. Geotechnical explorations on distressed wall asset for Montana DOT.

Subgrade Assets

Geotechnical subgrade assets consist of an earth material below the engineered pavement layers that creates a life-cycle management need. Examples of subgrade assets include constructed earthworks and ground improvements to address:

- Swelling;
- Compressible, frozen, or thawing ground;
- Collapsible soil or bedrock; and/or
- Threats from karst (sinkholes) and underground mining.

A subgrade asset also may include an unimproved subgrade that presents a measurable hazard from geologic conditions below the roadway. Figure 2.6 presents conceptual views of subgrades.

Starting Inventory in the GAM Planner

The simple implementation process provided in this manual has been designed to interface with the companion GAM Planner for inventory, assessment, and investment planning. Within the process of asset management, models are applied to the assets that are included in the inventory. The models allow the GAM Planner to project future performance and provide guidance for possible treatment and budget scenarios. When setting up the geotechnical asset inventory in the GAM Planner, the user must select an initial asset performance template for each asset. This process is not difficult, and the tool provides seven pre-defined default definitions. As an agency's use of GAM matures, new and more refined models can be developed and added to the GAM Planner if justified.

Additional information on using the GAM Planner is provided in Appendix A, and a companion work example for starting GAM using a hypothetical corridor is provided in Appendix B. Background material to assist GAM Planner model formulation is provided in Appendix C.

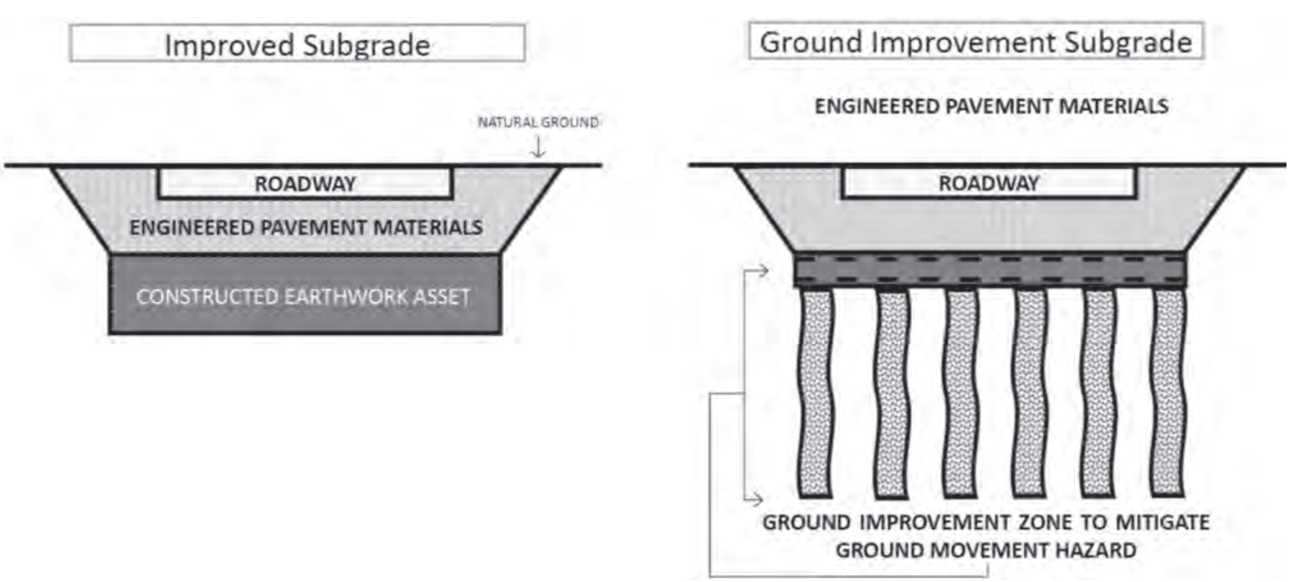


Figure 2.6. Example geotechnical subgrade asset concepts.

Asset Identification

When establishing an asset inventory, it is first necessary to identify each geotechnical asset type. Each asset will need to be assigned a unique asset identification number (e.g., GA1, GA2) for reference purposes. An asset identification system that can assign unique numbers and distinguish each asset from any other geotechnical and transportation asset is preferable. Alternatively, other agency-specific identifiers can be used. It is possible to begin GAM implementation using a simple sequential entry (e.g., 1, 2, 3) for each asset, but this system is not preferred because it may be difficult to integrate into other agency databases. Asset identification can be modified during later stages of implementation.

Asset Age (Estimated or Actual)

The age of an asset, either actual (if available) or estimated, should be included in the asset inventory. Even though estimates of asset age contain uncertainties, the data can be useful for certain assets and in future modeling. If the level of uncertainty is judged to be unacceptable, this data input can be left blank in the GAM Planner.

Input Models Based on Asset Type

In the GAM Planner, each asset type has a unique model for predicting treatment costs and future conditions. The spreadsheet tool is populated with several default models, as shown in Table 2.1. For each geotechnical asset in the inventory, the user must select the model that will be applied. The default models enable the inventory and assessment process to start based on generalized performance assumptions, but the models and assumptions can be revised later

Table 2.1. Default models based on asset type as used in the GAM Planner.

Model	Description	Asset Type
Cut	Soil, rock, or mixed cut slopes with a minimum height of 10 feet within the ROW. In general, cut-slope assets will have a higher deterioration rate when compared to natural slopes.	Slope Asset
Natural Hazard – Rock and Debris	Natural hazard sites that contribute rockfall, debris flows, or other rapid slope movements that may pose a safety threat in addition to mobility and maintenance impacts. The deterioration rate associated with this model is assumed to be slower than that for a cut-slope asset or based on recurrence intervals.	Slope Asset (Beyond-the-ROW Feature*)
Natural Hazard Landslide	Landslide hazard sites that may be included in a GAM inventory. Typically, these assets will consist of natural slides that originate beyond the ROW but impact the agency's performance objectives.	Slope Asset (Beyond-the-ROW Feature*)
Embankment	Used for constructed earthwork fills with a minimum height of 10 feet that contribute to the support of a roadway or other transportation assets.	Embankment Asset
Subgrade	Engineered subgrades that have been improved through ground modification/improvement works and support a roadway asset. The subgrade model can also apply to unimproved subgrades with geologic or other subsurface hazards, such as expansive or collapsible materials, frost-susceptible soil, or karst and underground mining activity.	Subgrade Asset
Retaining Wall Above Roadway	Applicable to retaining walls where the consequences of deterioration or a failure would be confined to locations at or above the roadway elevation.	Retaining-Wall Asset
Retaining Wall Below Roadway	Applicable if a wall supports traffic directly or if the deterioration or failure of the wall would impact the roadway integrity or mobility.	Retaining-Wall Asset

*Discussion of beyond-the-ROW features in GAM is presented Chapter 5 and considerations for their inclusion are detailed in Chapter 8 of this *GAM Implementation Manual.*

based on the judgment and experience of the asset manager. If desired, the GAM Planner can be expanded to incorporate up to 50 distinct asset-type models.

Locate Assets

Each geotechnical asset specified in the GAM Planner inventory will have a unique location and a defined length. Although location inventory can be a complicated process using various free and proprietary software systems, the inventory process described in this manual is intended to be simple, thus removing a potential barrier to implementation that could result from needing to learn and understand complex and dynamic geo-referencing processes before progressing in GAM.

Location

The location references assigned to transportation assets can have differing levels of complexity depending on agency data resources, capabilities, technology, and the level of accuracy needed for the task at hand. Location precision is valuable for certain applications, but a simple GAM implementation can use existing agency location referencing (e.g., mile point, mile marker, or reference point), as these systems generally satisfy a desired level of sophistication. The asset manager is cautioned against investing time and resources to use a highly precise location method for the asset inventory because the offsetting benefits will likely be minimal.

Geotechnical asset types often overlap. The photograph in Figure 2.5 shows one example, in which a road traverses sloping terrain. A slope asset can be seen on the uphill side of the road, and both an embankment asset and a wall asset are visible on the downhill side. In this situation, the slope, the wall asset, and the embankment should be inventoried as separate assets.

GAM Segment Length

For purposes of the implementation process embedded in the GAM Planner, the recorded lengths of geotechnical assets are considered independent of an agency's referencing system, and each asset is inventoried based on a pre-defined length, defined as a *segment*. As users' experience with GAM planning matures, the defaults established in the GAM Planner can be customized as desired to reflect the agency's specific referencing system and measurements.

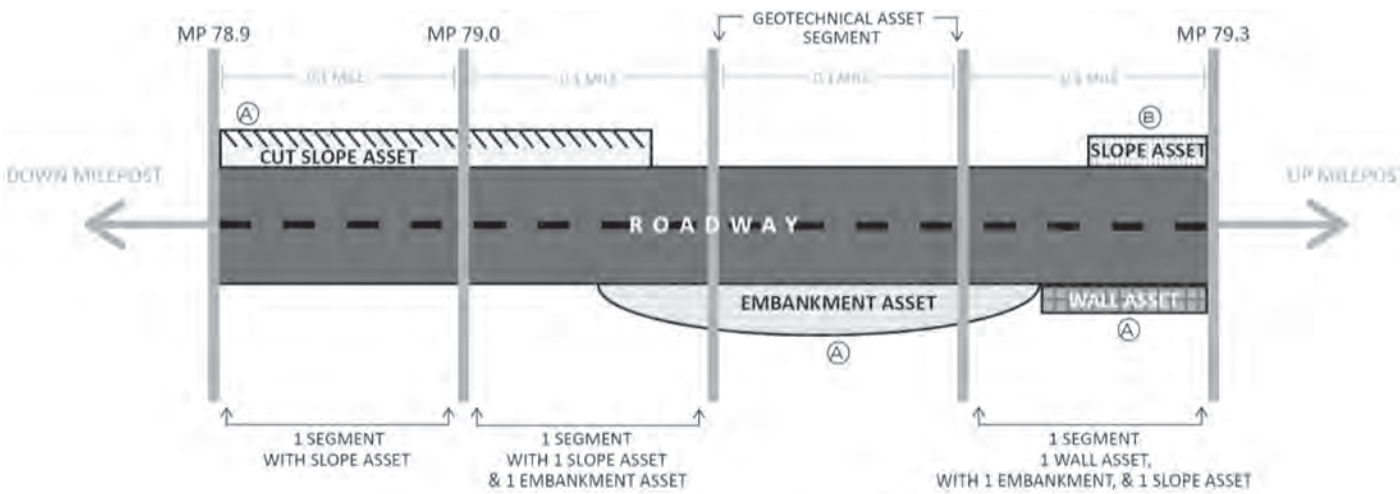
For example, when developing the initial geotechnical asset inventory, the accompanying model is based on a default segment length of 500 feet (approximately 0.1 mile), which is similar to the measurements used for pavement condition assessment practices. Users of the GAM Planner have the option to change this value if desired. Shorter lengths will result in more assets and complexity, whereas greater lengths can result in a more granular inventory relative to other asset groups.

The use of segments is a proven GAM practice that has demonstrated value in established programs in Alaska, Montana, Colorado, and internationally with Network Rail and UK Highways.

Each geotechnical asset will be entered in the GAM Planner inventory on the basis of a segment. For individual assets that are longer than one segment, additional segments are added and the user can assess the total asset length along the roadway by adding segments together if needed. The recommended procedures for establishing geotechnical asset segment references in a traditional DOT linear referencing system are:

- Point (also called one-dimensional, or 1-D) asset locations are assigned to the nearest mile point (MP) by *rounding down* (e.g., an asset falling between MP 92.6 and MP 92.7 would be assigned to a segment designated as MP 92.6); and
- Laterally extensive assets are assigned to each of the roadway segments intersected by the asset (e.g., an embankment that intersects two roadway segments would be assigned to *both* the roadway segments).

Figure 2.7 provides a conceptual view of the geotechnical asset inventory with segments.



GAM Inventory Example

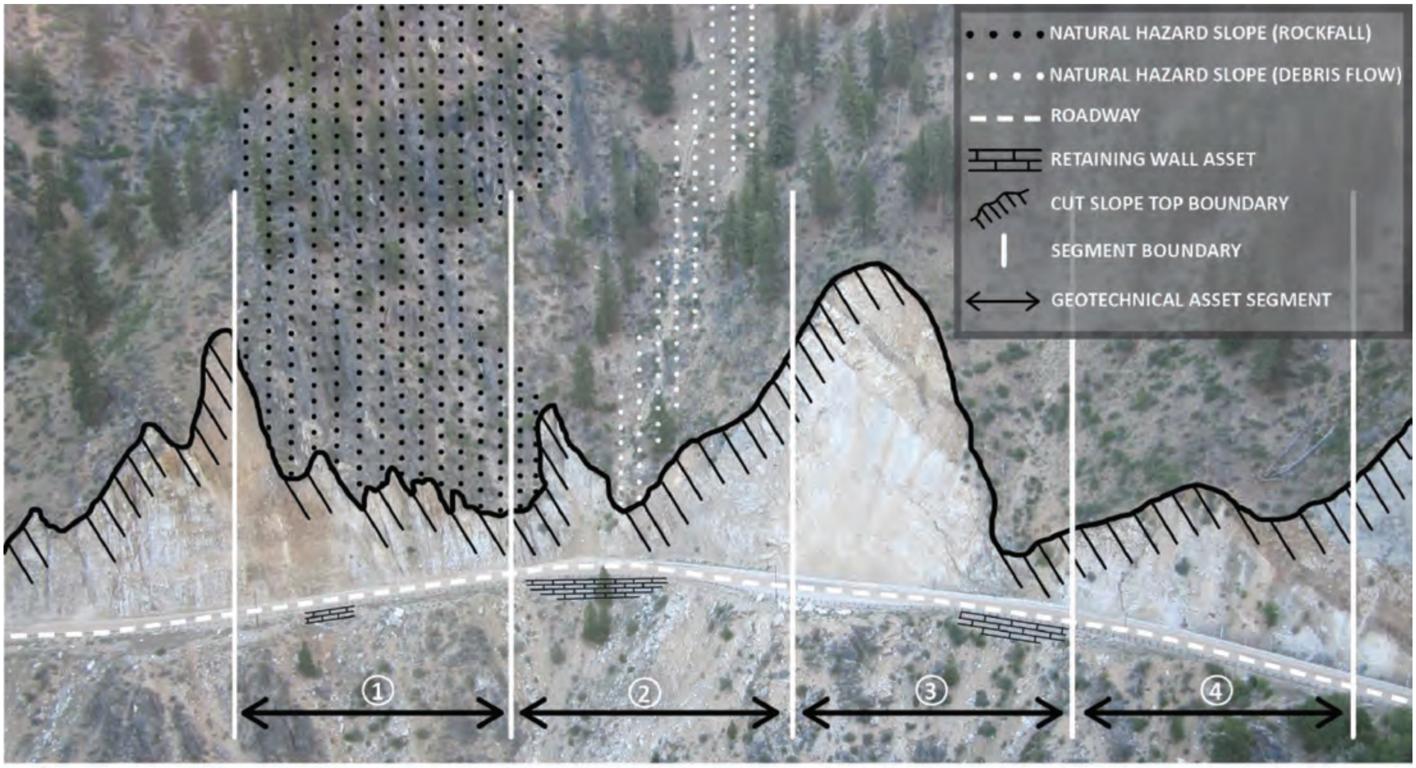
ASSET ID	ASSET TYPE	TOTAL LENGTH IN SEGMENT
Highway MP 78.9	Cut Slope (A)	400 feet
Highway MP 79.0	Cut Slope (A)	400 feet
	Embankment (A)	250 feet
Highway MP 79.1	Embankment (A)	500 feet
Highway MP 79.2	Embankment (A)	200 feet
	Wall (A)	300 feet
	Slope (B)	100 feet

Figure 2.7. Geotechnical asset segment and location process.

The purpose of using the segment concept during input of the inventory will become apparent later in the implementation process, particularly in the steps related to communicating results and performance, and those related to investment planning. The segment approach also allows the asset manager to consider the aggregated risk from various geotechnical asset types that have differing geographic characteristics. Figure 2.8 illustrates this concept using a view of a hypothetical corridor with multiple asset types.

Step 2: Record Asset Operations and Maintenance (O&M) Conditions

The next step in creating a GAM plan is to record the available information about the current condition of each asset. In the GAM Planner, the template for this step aggregates the methods used to estimate asset condition into a five-level assessment that quantifies asset condition in terms of (1) visual condition and/or (2) the level of effort needed to operate and maintain the asset. Each asset is assigned to one of the five levels using the Asset Operations and Maintenance (O&M) Condition decision tree. Presented in Figure 2.9, this decision tree is structured to enable use by a wide range of personnel, including geotechnical staff, bridge inspectors, and planning staff (who may have experience with visual condition assessment) or maintenance personnel (who may identify more closely with operational and maintenance needs). Geotechnical



① Geotechnical asset segment with cut slope asset, retaining wall asset, & natural hazard slope asset (rockfall)
② Geotechnical asset segment with cut slope asset, retaining wall asset, & two natural hazard slope assets (rockfall & debris flow)
③ Geotechnical asset segment with cut slope asset & retaining wall asset
④ Geotechnical asset segment with cut slope asset

Figure 2.8. Hypothetical view of a geotechnical asset inventory in complex terrain.

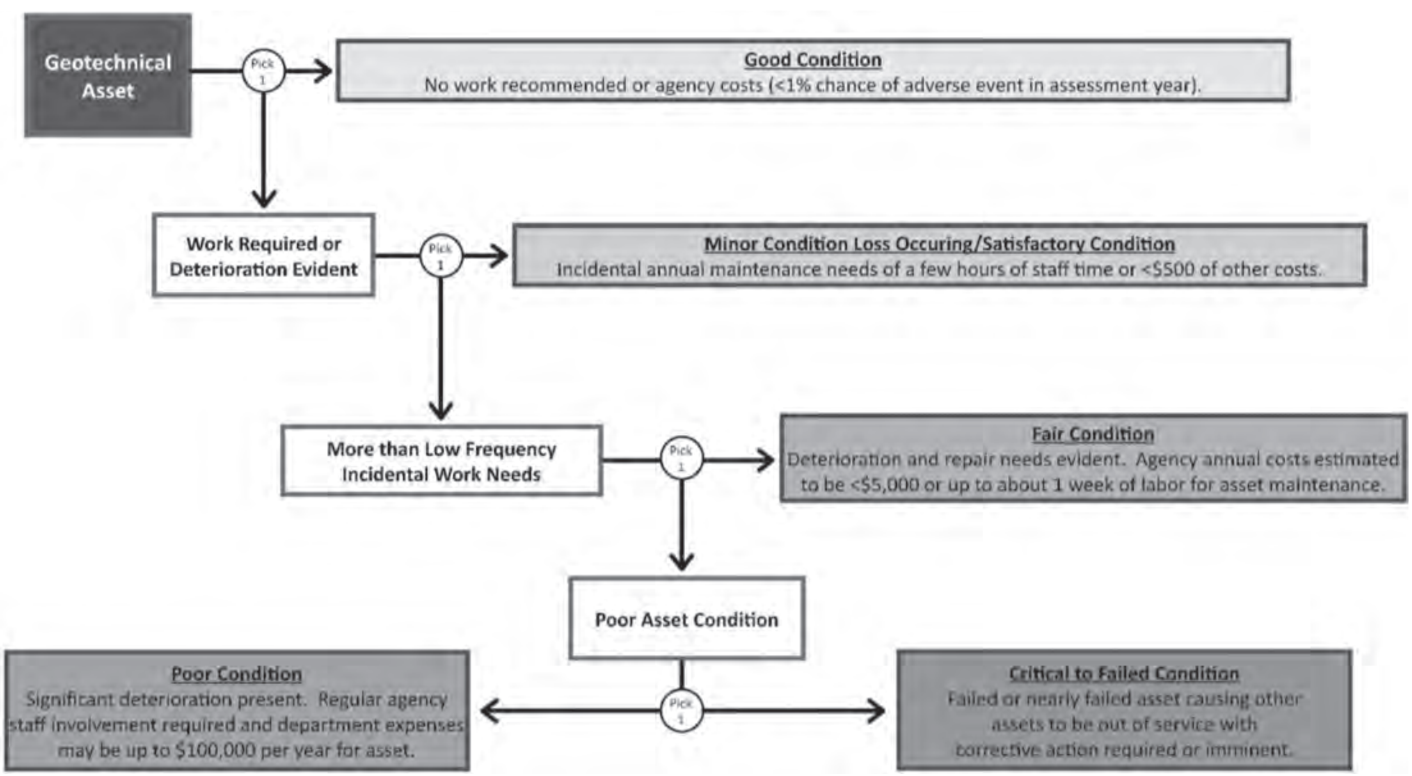


Figure 2.9. Asset O&M condition decision tree.

asset assessment photographs have been provided in Appendix D (available online) to help with understanding how individual assets can be classified using the decision tree. As background information, decision trees such as the one shown in Figure 2.9 are commonly used to guide the standardization of inputs in risk assessment practices.

Step 3: Assess Asset Performance Consequences

Safety Consequences

Part of a risk-based asset management plan is the evaluation of how the asset affects various performance objectives of an agency. As safety is a common objective for transportation departments regardless of asset management maturity levels, the GAM Planner assesses the risk to safety performance objectives from geotechnical assets. The inputs to this process are selected using the consequence tree shown in Figure 2.10. The photographic examples in Appendix D again provide examples of inputs for each safety consequence category.

Mobility and Economic Vitality Consequences

The GAM Planner enables management of geotechnical assets with respect to mobility objectives and the economic consequences from delays and closures that result from adverse asset performance. The mobility and economic consequences are assigned in the GAM Planner following the decision tree shown in Figure 2.11.

A key input to mobility consequences is the volume of traffic at the asset location. Inclusion of actual traffic volumes can increase the accuracy of mobility consequence assessment, but a quick GAM implementation can be impeded by the challenges of capturing data at each asset, including distributions in traffic type, divided roadway effects, detour options, or perceptions of traffic volume scales (e.g., roadways in areas that are more rural compared to areas with dense populations). Thus, the GAM Planner relies on user judgment to assess the relationship

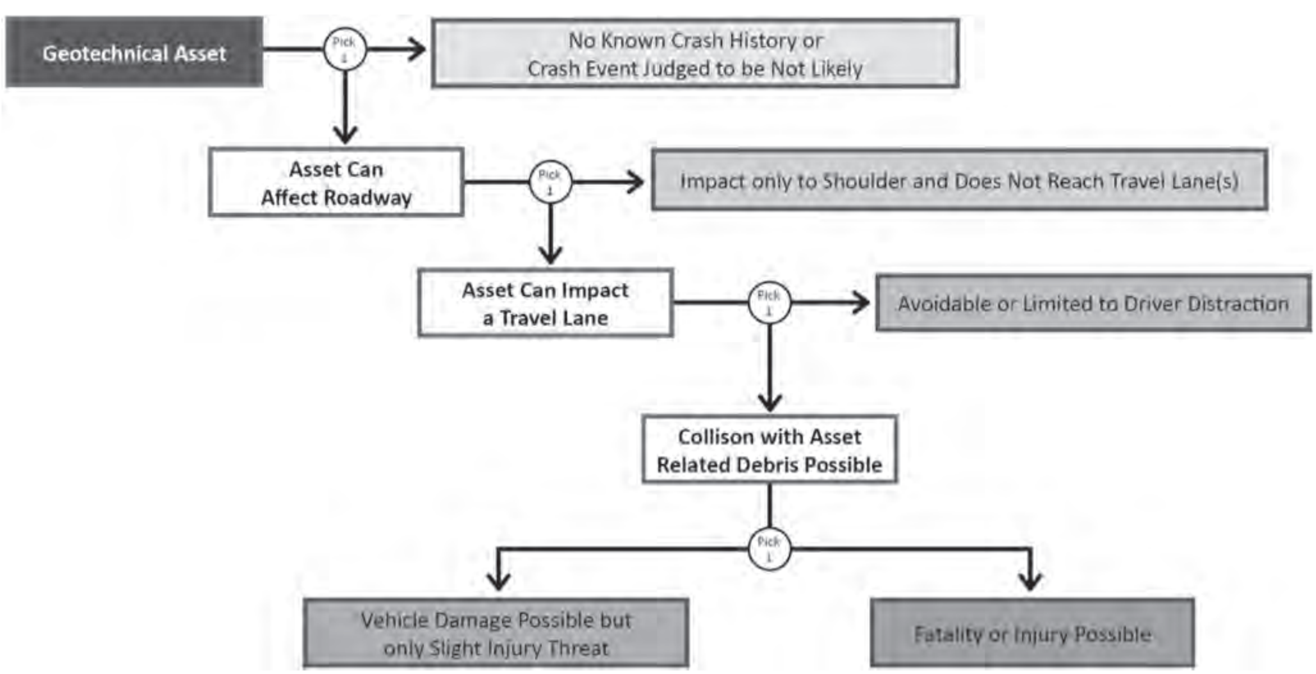


Figure 2.10. Safety consequence decision tree for the GAM Planner.

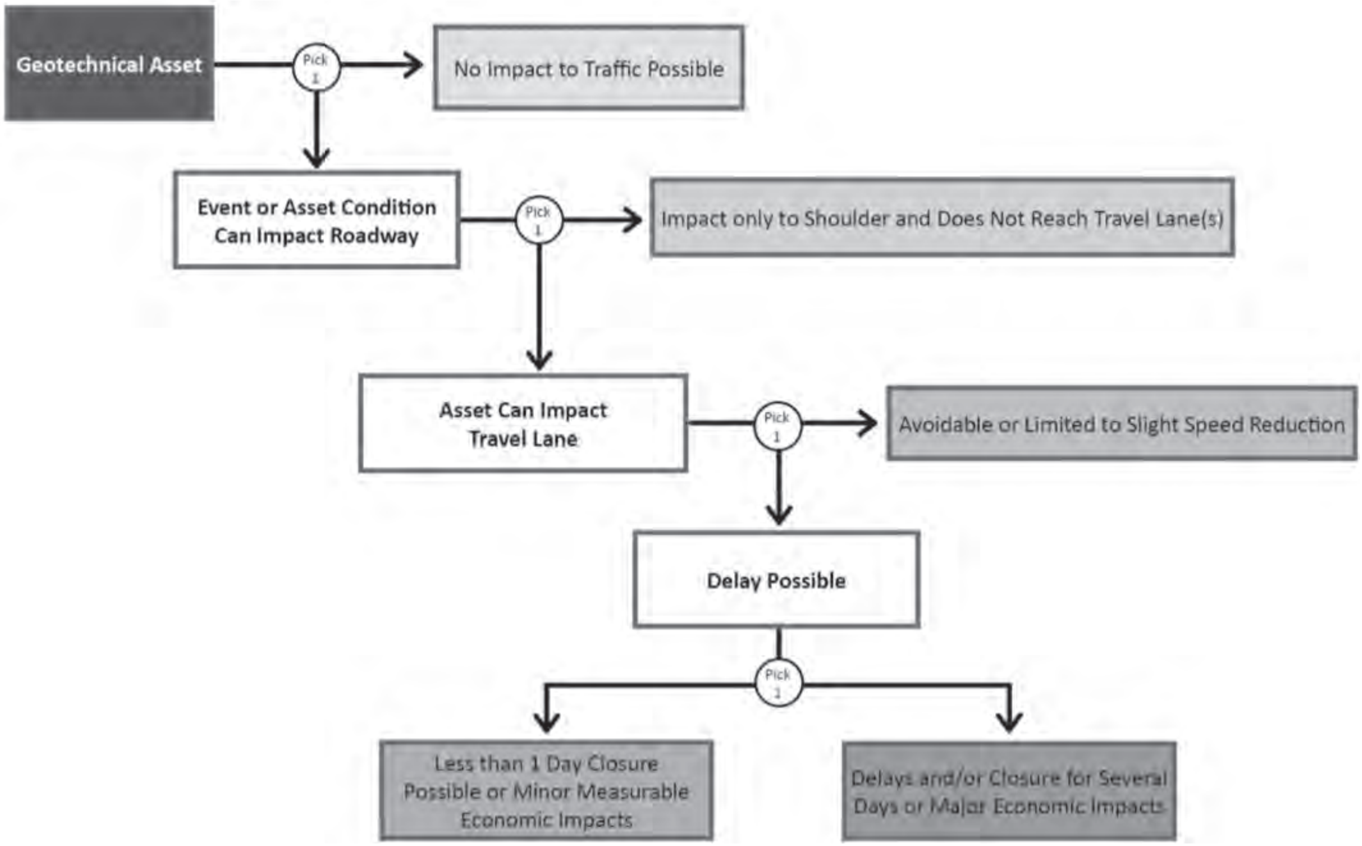


Figure 2.11. Mobility and economic consequence decision tree for the GAM Planner.

between traffic volume and magnitude of consequence. As an example, for an asset that has potential for a long closure but is located on a low-volume road and/or in an area with detour routes or other options that minimize economic and traffic disruption, the asset manager can select the inventory input option that includes "minor economic impacts." Conversely, if the asset could influence a significant volume of traffic such that even a short closure would cause significant economic and congestion impacts, the asset manager can select the consequence input option with "major economic impacts."

Step 4: Review Treatment Recommendations

For any asset, various life-cycle treatment options exist. These options can range from a "no action" alternative to robust, engineered treatments that are considered a permanent improvement that improves the reliability of the asset and extends its service life. This section of the *GAM Implementation Manual* describes the treatment outcomes from the GAM Planner. As the asset manager gains experience with GAM, the manager can edit these preset asset-type models to revise treatment feasibility, cost, or effects as desired. Appendixes A and C to this manual (available online) provide instructions for revising or creating new models in the GAM Planner.

The GAM Planner shows the treatment recommended for each asset based on its initial condition. The model can be adjusted or calibrated to the judgment of the user when future inventory adjustments or improvements are made. For example, if actual treatment costs for a given asset are greater or less than those suggested by the model, the user can edit the Cost

Scale Factor to multiply the predicted treatment cost by a specified factor. It is recommended that these types of adjustments take place as part of later process improvements after GAM implementation has started.

Do Minimum

The **"Do Minimum"** option consists of performing only the minimum level of work needed to keep the asset in a condition that allows for traffic conveyance without performing actions that add or preserve life-cycle value. The Do Minimum option does *not* correspond to no cost to the asset owner. It can be considered a "hands off" management approach that will result in accelerated deterioration and/or service interruptions. Do Minimum actions could involve removing rock and soil from the travel lanes below a slope asset or applying leveling pavement layers to the roadway on an actively moving landslide within an embankment asset. Do Minimum actions typically occur only when a mobility interruption or safety impact has occurred and requires immediate action.

Maintain

The **"Maintain"** treatment category assumes the asset will be maintained in nearly continuous O&M state through planned actions such as:

- Cleaning the roadside ditch below a slope asset that generates rockfall;
- Managing the vegetation on an embankment or slope asset;
- Minor earthwork activities to repair an erosion scar in an embankment or slope asset;
- Cleaning of drainage features on a wall or embankment asset to ensure that drainage flow is as designed;
- Light slope asset scaling activities to reduce specific hazards exposed through erosion;
- Patching of pavement or other structure cracking associated with geotechnical asset performance; or
- Occasional element replacement (e.g., precast blocks) or preservation tasks such as crack sealing or rinsing of accumulated salts on a retaining wall.

In general, these treatments are regular, frequent, but short work activities that often may be considered routine maintenance on an approximate annual basis. These treatments also can be considered preservation work that is conducted needed to help the asset fulfill the originally intended service life. In other words, a Maintain treatment will be performed to enable an asset to deteriorate at a rate that is equal to or better than the originally intended or assumed deterioration rate.

Particularly in relation to geotechnical assets, the concepts of Do Minimum and Maintain may be unfamiliar in some organizations because these assets have not previously been incorporated into defined preservation programs.

Rehabilitate (Rehab)

In the GAM Planner, the "**Rehabilitate (Rehab)**" treatment category refers to rehabilitation activities that will improve the asset condition to at least the next higher condition level. Rehab work can include:

- Installing groundwater drains or other drainage features into a geotechnical asset with the design intent of reducing likelihood of disruptive movement of the asset;
- Installing anchored or draped mesh on a slope asset to reduce the amount of debris reaching the road or catchment ditches;

- Modifying the geometry of an asset or placing buttress fill on a slope to create a more stable condition;
- Excavating larger catchment ditches, heavy scaling and slope modifications, and/or installing barriers below a slope asset to reduce the potential for rock reaching the roadway travel lane;
- Over-excavating and re-compacting a subgrade asset as part of a pavement rehabilitation project; or
- Replacing or improving a significant quantity of deteriorated retaining wall facing elements.

Typically, rehabilitation treatments extend the asset's service life through an improved condition.

Reconstruct (or Renew)

Treatments in the "**Reconstruct (or Renew)**" category will consist of actions that result in a significant O&M asset performance improvement to a new or nearly new condition, effectively resetting the asset's service life. Reconstruction also can refer to treatment processes designed to reduce safety and/or mobility consequences in addition to extending the asset's service life. Examples of reconstruction treatments include:

- Reconstructing a retaining wall to meet the design standard for a "current" service life;
- Realigning a roadway to add reliable wall systems and reduce the deterioration rate of assets and/or the quantities of slope assets;
- Reconstructing a distressed embankment or subgrade asset with a reliable engineered fill; and
- Placing ground reinforcements with long service lives (e.g., ground anchors) to stabilize an embankment or slope asset to a high-performance reliability.

Restore

In the GAM Planner, the model triggers a treatment action called "**Restore"** if an asset fails (reaches an O&M Condition level of 5). The user sets parameters to define what constitutes failure for the given asset type, specifies the agency and user costs of this treatment, and defines the resulting condition on completion of the treatment. As defined in the GAM Planner, restoration differs from reconstruction or renewal in that the Restore treatment is undertaken only upon failure of the asset. By contrast, Reconstruct (or Renew) treatments are used to improve asset performance and/or extend the asset's service life before it reaches operational failure.

Step 5: Analyze the Impacts of Differing Investment Levels

Once a collection of assets has been entered in the inventory, the GAM Planner allows an asset manager to evaluate the impact of alternative investment levels. It is important to note that the asset management process will enable better decisions and derive benefits for an organization even if GAM is applied only to a small portion of inventory. Having a limited or small inventory should not be a barrier to implementing GAM; rather, beginning with a small inventory may facilitate broader adoption because it allows the asset manager to demonstrate the utility and benefits of GAM.

To complete the investment analysis using the GAM Planner, the user will need to input the expected or proposed budgets by year for the set of geotechnical assets that have been included in the inventory. Given the budgets and initial conditions, the GAM Planner then calculates what costs are expected to be incurred each year, and projects the resulting conditions for a 10-year planning cycle. The detailed **"Summary Results"** view in the spreadsheet tool predicts what will happen over time to a selected asset. The Summary Results can then be used as a starting point for prioritizing or modifying asset-specific treatment plans. These concepts are expanded in Chapter 8 of this manual, which presents recommended processes for improving the success potential of GAM implementation, enabling an agency to realize the benefits.

Analyzing investment levels is an important step toward the realization of GAM benefits. Using the GAM Planner, the outcomes shown in the Summary Results enable an asset manager to demonstrate favorable investment scenarios that can help deliver on agency objectives and performance areas. Simply put, the outcomes of the investment analysis can help a geotechnical asset manager "earn a seat at the table" with other asset managers and executives. The GAM Planner analysis provides the opportunity to propose investment strategies for a program of assets and to demonstrate that life-cycle costs will likely increase if sufficient funds are not applied. Consider a hypothetical asset management program that spends $1 million per year on Do Minimum and Maintain treatments. Should this investment level continue, longer-term needs will likely increase to $2 million each year after 5 years. Using the risk-based GAM Planner assessment, it might be shown that increasing the agency's investments to $1.5 million for the next 3 years (Year 2 through Year 4) would reduce the annual funding needs to $0.5 million each year after Year 5, and that the additional investment of $1.5 million over those 3 years could result in a net savings to the agency of $6 million by the end of 10 years. The workflow example provided in Appendix B shows a similar outcome.

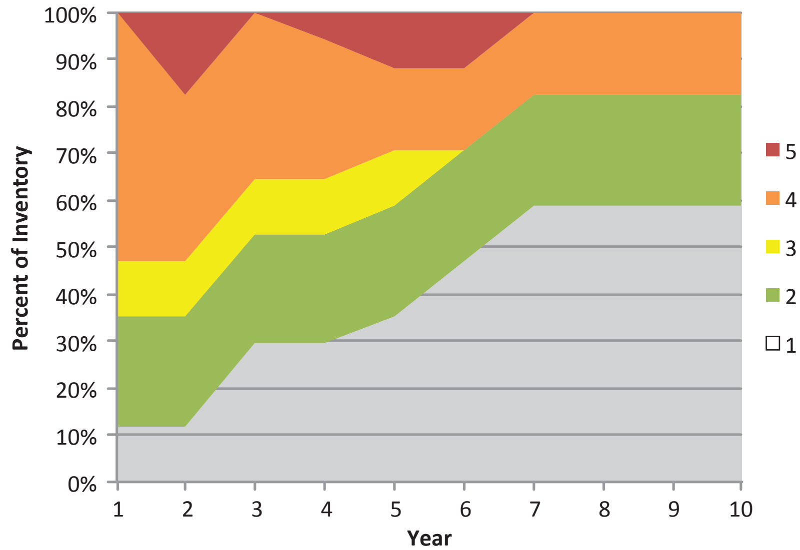
Step 6: Communicate Results

Steps 1 to 5 yield a great deal of valuable information for documenting the existing conditions of an organization's geotechnical assets, quantifying the assets' LOR, and predicting what work should be performed and what conditions will result from a given investment (budget) level. The GAM Planner includes various tables and charts that can be used to help communicate results. Key measures and relationships the asset manager may wish to use to make the case for needed investments include:

- **Profile of the Existing Inventory:** In the GAM Planner, the O&M condition and safety/mobility consequence levels for a given asset are combined into an overall score for the LOR, which is given a letter grade from A to F for use in summarizing conditions. A more detailed discussion of the performance measures for geotechnical assets is presented in Chapter 4 of this manual.
- **Predicted Investment Needs Over Time for Differing Budget Levels:** When considering future needs, it can be helpful to show a variety of scenarios based on differing budget levels. The default model easily demonstrates that it is simply not feasible to invest no money in geotechnical assets, as the Do Minimum costs and costs to Restore an asset following a failure cannot be avoided. Moreover, the long-term (reactionary) financial needs over time are typically minimized if the asset manager budgets sufficient funds to Maintain and, as needed, to Rehab the assets.
- **Predicted Distribution of Conditions Over Time:** Often it is helpful to supplement estimates of investment needs with additional information on asset condition. Figure 2.12 is an example generated using the GAM Planner that shows the predicted distribution of asset conditions over time using the O&M condition level.

Next Steps

The discussion of Steps 1 through 6 has been provided to enable a geo-professional, asset manager, or other engaged agency representative to move a group of geotechnical assets through the process of risk-based GAM. This workflow process can be repeated and modified as the



Note: Higher number and red (darkest) color indicate less favorable conditions.

Figure 2.12. Example distribution of O&M condition over time.

inventory expands, and as GAM becomes easier and more familiar, thus enabling an agency to increase its GAM maturity level. Chapters 3 through 7 in this *GAM Implementation Manual* present information on the supporting processes and data that align GAM with the existing practice of TAM and that form the foundation of the implementation approach.

Simply having an inventory and models that produce investment plans will probably not be enough to enable successful GAM implementation. The assessment process will likely reveal investment needs that are well above practical or feasible amounts, which is a common occurrence across even established asset categories such as bridge and pavements. Chapter 8 contains information about additional processes and concepts that can help asset managers prioritize the GAM implementation for success in differing organizational cultures (i.e., a variety of agencies).

These processes are offered as suggested next steps, to be taken in no particular order, for continuing the asset management journey:

- Expanding inventory;
- Calibrating the default asset models;
- Developing new asset models, if needed;
- Including other agency staff in inventory development;
- Developing a data management program to enable visual graphics of asset characteristics and performance;
- Authoring a GAM plan document;
- Adding objectives and measures based on stakeholder feedback; and
- Evaluating the use of other agency-supported software that may offer additional analysis capabilities or compatibility with other TAM databases.

Presented near the end of Chapter 3, Figure 3.4 summarizes an expanded workflow that incorporates these steps and other optional process improvements that can improve the benefits an agency receives from GAM.

PART C

Understanding the GAM Process

CHAPTER 3

Purpose and Need for GAM

Introduction to Asset Management

This chapter provides an introduction to the basic concepts of TAM, definitions and examples of geotechnical assets, and fundamentals of the implementation process.

TAM for the Geotechnical Professional

Bridges and pavements garner the majority of the attention, legislation, and budgeted expenditures for many U.S.-based owners of transportation infrastructure, but the condition and reliability of other assets, such as walls and embankments, often are no less critical to the continuous operation of the transportation network. A program that helps manage the performance of the network may therefore be well served by including more asset types than just bridges and pavements, which are the obligatory requirements of risk-based plans under federal authorization. According to the FHWA (2018), "[TAM] plans are an essential management tool which bring together all related business processes and stakeholders, internal and external, to achieve a common understanding and commitment to improve performance."

The performance of an agency hinges on the performance of the "weak links" in its management plan. Even the most robust bridge and pavement asset program will have diminished value if other assets are ignored simply because of lack of federal authorization requirements.

To truly drive performance, transportation agencies will need to look beyond the two legacy asset categories named in federal authorization and better understand the impact of *all* assets—including geotechnical assets—on the system that they must manage as responsibly and cost-effectively as they are able. As can be seen in Figure 3.1, adverse performance from a geotechnical embankment asset can threaten the performance of other assets, and thus impact higher-level agency performance objectives.

Understanding the management of any type of asset begins with an understanding of key asset management concepts such as *inventory, condition, life-cycle costs, risk, performance,* and *prioritization.* Practicing sound asset management requires knowledge of the assets owned, including both the current condition of those assets "today," how they are likely to deteriorate over their useful life, and the risks their failure or underperformance will pose to the costs and objectives of the organization. Agencies that embrace asset management commonly shift away from reacting to failures as they occur to proactively and systematically prioritizing work, keeping valuable assets in good condition, and finding cost-effective treatments that allow them to prolong the assets' useful life. The International Organization for Standardization (ISO) established standards for asset management in 2014 based on these principles together with the Publicly Available Specification (PAS) 55 that had been developed by the British Standards Institution (BSI). The ISO 55000 standard for asset management (2018) provides an overview of the subject of

Figure 3.1. Example of an embankment in poor condition.

asset management and the standard terms and definitions relevant to the geotechnical asset owner, including:

- **Asset:** "[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;
- **Asset Management:** "[A] coordinated activity of an organization to realize value from assets";
- **Critical Asset:** "[An] asset having potential to significantly impact the achievement of the organization's objectives"; assets can be safety-critical, environment-critical, or performance-critical, and can relate to legal, regulatory, or statutory requirements;
- **Incident:** "[An] unplanned event or occurrence resulting in damage or another kind of loss";
- **Level of Service (LOS):** Parameters, or a combination of parameters, that "reflect social, political, environmental, and economic outcomes that the organization delivers"; these parameters can include "safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost, and availability";
- **Life-Cycle:** "[The] stages involved in the management of an asset";
- **Objective:** "[A] result to be achieved; an objective can be strategic, tactical, or operational"; and
- **Risk:** "[T]he effect (good or bad) of uncertainty on objectives."

Asset Management Maturity: A measure of how advanced an organization is with respect to asset management (e.g., basic to advanced).

Incorporating these concepts into the business practices of an organization often entails introducing skills and methodologies less familiar to agencies that were formed to design and construct rather than maintain the assets. As the agency transitions its emphasis from building to preserving, the staff must realize that asset management is a journey of continual improvement and not simply another fixed task in a project schedule. ISO 55000 notes that "asset management capabilities include processes, resources, competences and technologies to enable the effective and efficient development and delivery of asset management plans and asset life activities, and their continual improvement." To chart an agency's progress along the continuum of improvement, this manual offers support in developing asset management maturity.

The GAM implementation process recognizes that agencies vary greatly in their need for GAM and in their levels of process and technology complexity. Figure 3.2 presents a conceptual "maturity assessment" framework for considering the people, systems, and processes

Figure 3.2. Maturity assessment example.

that support asset management in a given organization. For the example, the agency shown has experienced geo-professionals, but has limited executive engagement with inventory and knowledge of the current condition of the assets is based on simple systems and data. In this agency, the maturity of the asset management could be advanced based on the ability of the geo-professionals to perform detailed risk and cost calculations for treatment options, then by vetting the conclusions with maintenance workers and management. As a result, the agency could be considered to be "mature" in advanced processes for fundamental asset management decision-making despite its use of simple systems and data.

Some users of this manual may have already conducted a self-assessment of asset management (geotechnical or otherwise) maturity using a capability maturity model such as the Asset Institute's *Asset Management Capability Maturity Model* (2015). Additionally, the 2011 AASHTO *Transportation Asset Management Guide: A Focus on Implementation* (the *TAM Guide*) provides a survey that agencies can use in assessing asset management maturity. The users of this guide may opt to complete the survey strictly within the context of GAM. TRB also provides a TAM Gap Analysis Tool (Zimmerman 2015) that consists of eight topic areas for maturity assessment:

- Policy goals and objectives;
- Asset management practices;
- Planning, programming, and project delivery;
- Data management;
- Information systems;
- Transparency and outreach;
- Results; and
- Workforce capacity and development.

Geotechnical engineers or other geo-professionals may use this guide to justify investment and work prioritization, and asset managers may apply it to include additional assets in an enterprise-wide asset management plan. In either situation, it is critically important to first understand the organization's current capabilities. Attempting asset management using a framework that is incompatible with the agency capabilities can limit or significantly delay the realization of benefits. Having dissimilarities in capabilities is not a reason to delay implementation; rather, it is expected to be a common situation among agencies implementing GAM. The implementation process described in this manual is constructed around the basis of relatively simple levels of GAM capabilities and maturity. It is expected that geotechnical asset managers will make themselves aware of best practices that can be applied to agency-specific GAM implementation efforts, and will determine how to close any maturity gaps that are prioritized for the later stages of process improvement.

Asset management best practices offer those pursuing GAM useful roadmaps for identifying, prioritizing, and determining how to close performance gaps. Best practices have been developed for a wide range of asset types and are well established within the greater discipline of asset management. Although they focus on roads, bridges, dams, levees, or any number of non-geotechnical assets and disciplines, the overarching tenets of existing asset management best practices can be applied directly to GAM. For example, in 2013 the USACE's Institute for Water Resources (IWR) set out to develop an asset management roadmap with a best practices study. The agency methodically reviewed multidisciplinary asset management practices, identified relevant best practices, reconciled agency program management approaches with those offered by existing best practices, and developed asset management recommendations that were documented in a *Best Practices in Asset Management* document (USACE 2013). The effort was successful in developing a hierarchy to define the criticality of each asset so that decisions could be optimized in accordance with the agency's management priorities. This USACE example illustrates how agencies can better support the goals of asset management by aligning steps the agency will take with the management priorities and goals.

The Goals of TAM

Like other disciplines that benefit from the use of asset management practices, transportation-focused asset management has goals to methodically align transportation asset O&M and to upgrade decisions in ways that embody an agency's larger goals and objectives. Furthermore, TAM seeks to make such systematic decision-making consistent and entrenched as time goes on. In meeting the goals of TAM, the agency realizes the following benefits:

- Decisions supporting agency and executive objectives are informed by data, consistent processes, and optimization;
- Transparency and accountability are improved;
- Life-cycle costs for managing and maintaining transportation assets are minimized;
- Performance disruptions are reduced;
- Consistency in tracking performance is improved;
- Adverse economic impacts to users, private enterprise, and communities are reduced; and
- TAM also may enable safety improvements.

First published in 2004, the BSI work on standardization of asset management reflected contributions from more than 50 public and private entities spanning 10 countries and 15 sectors. This work was later adopted by ISO, and has become instrumental in current international asset management practice.

In its 2008 update to the PAS 55 specification, BSI posits that "[t]he adoption of [asset management] standards enables an organization to achieve its objectives through the effective and efficient management of its assets. The application of an asset management system provides assurance that those objectives can be achieved consistently and sustainably over time." The benefits of such alignment between agency objectives and decision-making processes through the adoption of asset management standards have been borne out in real-world examples from across the globe (e.g., Network Rail and Highways England) and across multiple disciplines. These examples illustrate that extending asset management practices to less traditional asset management disciplines (e.g., geotechnical engineering) has yielded the same mission-critical benefits obtained by traditional, infrastructure-focused asset management.

The linkages between TAM and GAM are clear. Poor management of geotechnical assets can delay timely application of necessary maintenance, thereby increasing maintenance costs or leading to premature replacement. Poor management of geotechnical assets also can have catastrophic impacts on other transportation assets, such as the preventable collapse of an earth-retaining structure that forces the closure of a critical roadway. For these reasons, it is possible to demonstrate the need for including GAM in overarching TAM programs.

This trend is demonstrated in an ASCE study, titled Managing Ancillary Transportation Assets: The State of Practice, which reviewed 64 agencies through literature review and interviews regarding their use of "ancillary" assets such as earth-retaining structures in their TAM programs. This review of less traditionally managed ancillary assets concluded that "interest in managing ancillary transportation assets has grown with agencies in transition toward more mature asset management programming" (Akofio-Sowah et al. 2014).

The ASCE study highlights the Oregon DOT experience with having asset management systems in place. For example, by using asset management systems, asset inventories (including some ancillary assets) could be performed with greater reliability and approximately five times faster than before. Data were more easily accessible, and data from one primary source could be obtained in 5 minutes or less, as compared with previous time allowances of up to 8 weeks that were tied to the need to make numerous requests of multiple points of contact. At the time of the ASCE study, the Oregon DOT was actively developing a prioritization framework for considering the criticality of an asset to mobility, operations, safety, stewardship, and other measures.

Whether the assets be highways, bridges, and walls or power plants, factories, and buildings, the goals of asset management revolve around optimizing performance and levels of service. In its guidance document, the UK Roads Liaison Group (2013) listed the following objectives of an asset management policy and strategy:

- Demonstrate the commitment to adopting the principles of highway infrastructure asset management by senior decision-makers.
- Document the principles, concepts, and approach adopted in delivering highway infrastructure asset management at a high level.
- Link with the local authority's policies and strategic objectives and demonstrate the contribution of the highway service in meeting these.
- Set out the desired levels of service from implementing asset management.
- Facilitate communication with stakeholders of the approach adopted to managing highway infrastructure assets.

With regard to these and similar objectives, public agencies around the globe have developed guidance for their member organizations. The next section of this chapter examines guidance for transportation organizations.

Guidance for TAM

From the FHWA, TRB, and AASHTO in the United States, to the Institute of Public Works Engineering Australasia (IPWEA), governing and research bodies offer guidance to asset owners and practitioners to help further the practice of TAM. Table 3.1 provides summary descriptions and background for several such guides. The summaries are provided to illustrate the depth of well-established, and in many cases, internationally specified guidelines for implementation of asset management across industries and infrastructure sectors. Thus, asset management should not be considered only as a federally authorized practice for bridges and pavements, but rather as an internationally accepted means of managing performance and investment for many types of assets.

Introduction to Geotechnical Assets

Geotechnical Assets

As introduced in Chapter 2 of this manual, a geotechnical asset is an embankment, slope, retaining wall, or constructed subgrade that contributes to the continuous operation of a transportation

Table 3.1. Example guidance documents for management of transportation assets.

Source	Use	Description	Background
FHWA (MAP-21)	To understand the purpose of, and the minimum requirements for, performance management.	FHWA provides the legislative underpinning for TAM and the resources requiring performance management and guidance on some minimum performance requirements.	FHWA provides stewardship, oversight, and guidance regarding the Moving Ahead for Progress in the 21st Century Act (MAP-21). MAP-21 was signed into law by President Barack Obama on July 6, 2012. Funding surface transportation programs at over $105 billion for fiscal year (FY) 2013 and FY 2014, MAP-21 was the first long-term highway authorization enacted since 2005.
FHWA (FAST Act)	To understand the purpose of, and the minimum requirements for, performance management.	FHWA builds upon MAP-21's legislative underpinning for TAM and the resources requiring performance management and provides guidance on some minimum performance requirements.	FHWA provides stewardship, oversight, and guidance regarding the FAST Act (Pub. L. No. 114-94). Signed into law on December 4, 2015, the FAST Act authorizes $305 billion over FY 2016 through FY 2020.
AASHTO	To find TAM resources, including research, best practices, project case studies, processes, lessons learned, and evaluation methods, such as those published in the AASHTO *TAM Guide.*	AASHTO is a source of TAM thought leadership, guidance, tools, and best practices.	AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments. AASHTO works to educate the public and key decision-makers about the critical role that transportation plays in securing a good quality of life and sound economy for our nation.
TRB	To find state-of-the-practice examples of TAM research, best practices, project case studies, processes, lessons learned, and other relevant resources, such as those published in *NCHRP Research Report 866: Return on Investment in Transportation Asset Management Systems and Practices*.	TRB is a source of and gateway to relevant guidance and best practices for planning, implementing, managing, and improving asset management programs and strategies, among countless other transportation-related topics.	TRB is a division of the National Research Council, which serves as an independent adviser on scientific and technical questions of national importance in the United States. TRB facilitates the sharing of information on transportation practice and policy by researchers and practitioners, stimulates research, and offers research management services that promote technical excellence. TRB also provides expert advice on transportation policy and programs, disseminates research results broadly, and encourages their implementation.

IPWEA	To find TAM resources including research, best practices, project case studies, processes, lessons learned, and evaluation methods.	Offers TAM-related resources including education, case studies, research, publications, and discussion communities.	The IPWEA is the leading association for the professionals who deliver public works and engineering services to communities in Australia and New Zealand. IPWEA provides services to its members and advocacy on their behalf. The association was formed as a result of the Local Government (Shires) Act of 1905, which transferred works of a local government nature from the Roads and Bridges Section of the Public Works Department to Councils.
Asset Management Council	To find asset management guidance, training, resources, and models to help define and develop asset management practices.	The Asset Management Council provides professional development opportunities, asset management training, maturity assessment, guidance, technical reports, training, and knowledge exchange.	A membership-based, not-for-profit organization, the Asset Management Council is a Technical Society of Engineers Australia, a founding member of the Global Forum on Maintenance and Asset Management (GFMAM), and a founding member of the World Partners in Asset Management (WPiAM).
ISO 55000	To find an overview of asset management concepts and terminology as needed to develop a long-term plan that incorporates an organization's mission, values, objectives, business policies, and stakeholder requirements.	ISO 55000 provides an overview of the subject of asset management and establishes the standard terms and definitions.	The ISO is a worldwide federation of national standards bodies. The work of preparing ISO's International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. Governmental and non-governmental international organizations also take part in the work in liaison with ISO. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.
ISO 55001	To identify specified requirements for the establishment, implementation, maintenance, and improvement of an asset management system. ISO 55001 can be used by any organization to determine to which of its assets this International Standard applies.	ISO 55001 is a requirements specification for an integrated, effective management system for asset management.	
ISO 55002	To find interpretation and guidance for an asset management system to be implemented in accordance with the requirements of ISO 55001.	ISO 55002 provides guidance for the implementation of a management system that complies with the International Standard.	

network. Assuming these assets to be static, constructed features with minimal life-cycle needs—or an unplanned "liability" once a failure has occurred—reflects an incorrect "legacy" approach, particularly when examining the ISO 55000 definition of an asset. Per ISO 55000, a geotechnical asset can easily be shown to have both tangible and intangible value to an organization that has both financial and non-financial aspects. In addition, geotechnical assets are known to contribute risk to several organizational objectives and measures. An expanded discussion about geotechnical asset types and the associated value is presented in this section.

Embankments

An embankment asset is constructed earth fill, composed of soil or mixtures of rock and soil, which 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 in this manual, the recommended threshold height for an embankment is a minimum of 10 feet (about 3 meters) above the adjacent grade (see Chapter 2, Figure 2.2 for embankment schematics). This suggested threshold is based on similar criteria applied by Network Rail in the United Kingdom, which has developed knowledge and experience based on an inventory of more than 190,000 geotechnical assets. At heights below this threshold, an agency could define embankment-like assets as *minor earthworks.* Alternatively, an agency could establish its own criteria for defining an embankment. Table 3.2 presents additional examples of embankment assets.

Slopes

For the purpose of creating an initial inventory, slope geotechnical assets may involve either:

- A permanently excavated slope (a cut slope) that is incorporated into the roadway template and within the ROW, easement, or other property boundary; or
- 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 slope geotechnical asset 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 precipitated by or related to adverse performance from cut slopes and beyond-the-ROW geologic hazards may have similar operational consequences to an agency, the geotechnical asset manager is encouraged to differentiate in the inventory between slope assets that originate as constructed assets and those that originate as natural hazards beyond the ROW. Through this differentiation in the inventory, the GAM Planner affords the asset manager the option to develop differing treatment planning, investment strategies, and risk management plans as the agency gains increasing asset management maturity.

Within this manual, the term *cut slope* applies to a geotechnical asset created through the excavation of a roadway or associated assets. The term *natural hazard slope* applies to geologic hazards beyond the ROW that may be incorporated into a GAM plan.

Cut slopes differ from embankments in that the slopes are excavated into the terrain rather than being a constructed fill feature. Similar to embankment assets, however, a 10-foot minimum 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.

Slopes can consist of soil, rock, and mixtures of soil and rock. Table 3.3 illustrates examples of cut-slope assets and Table 3.4 illustrates examples of beyond-the-ROW natural hazard

Table 3.2. Examples of embankment assets.

Embankment Example	Example Asset Values
	<u>Tangible Financial Values:</u> Initial construction cost Annual vegetation and erosion maintenance <u>Functional Values:</u> Companion asset to bridge asset Flood mitigation for roadway <u>Intangible Values:</u> Environmental protection Aesthetic characteristics and agency reputation
	<u>Tangible Financial Values:</u> Initial construction cost Annual vegetation maintenance Ongoing and future instability repair work <u>Functional Values:</u> Pavement support Enables divided regional highway performance Separation from private property <u>Intangible Values:</u> Active threat to private property Agency reputation
	<u>Tangible Financial Values:</u> Initial construction cost Annual vegetation maintenance <u>Functional Values:</u> Pavement support Separation from private property <u>Intangible Values:</u> Buffer between roadway and private property Aesthetic reputation

sites. For agencies that have an existing rockfall hazard management program, this manual could be considered an initial form of slope management for GAM segments that generate rockfall.

Retaining Walls

Retaining walls are a common geotechnical asset that can be understood by many. Retaining-wall asset inventories represent an increasing asset inventory for many DOTs because of the

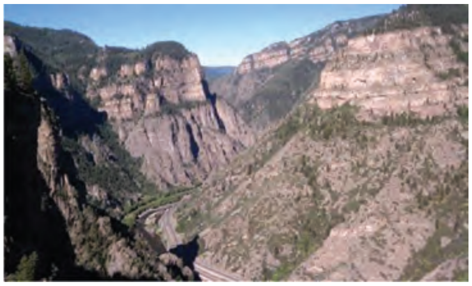
Table 3.3. Examples of cut-slope assets.

Slope Asset Examples (Cut Slopes)	Example Asset Values
	Tangible Financial Values: Initial construction cost Erosion maintenance Rockfall debris removal Functional Values: Highway design Intangible Values: Safety Environmental resources Aesthetic characteristics and agency reputation
	Tangible Financial Values: Initial construction cost Erosion maintenance Rockfall debris removal Functional Values: Highway design and minimizing ROW Intangible Values: Safety Environmental resources Aesthetic characteristics and agency reputation
	Tangible Financial Values: Initial construction cost Erosion maintenance Rockfall debris removal Functional Values: Highway design in hilly terrain Intangible Values: Safety Environmental resources Aesthetic characteristics Agency reputation

increased complexity of transportation infrastructure in urban areas and the need to minimize environmental disturbance or impacts beyond the ROW.

Retaining walls are constructed structures that hold back natural soil, rock, or engineered materials to prevent sliding of material onto a roadway or other structure, or support a roadway. Retaining walls are also referred to as *earth-retaining structures* in some organizations. Retaining-wall types include gravity walls, soil nail walls, concrete cantilever structures, and MSE walls.

Table 3.4. Examples of natural hazards originating beyond the ROW.

Natural Hazard Slope Examples	Example Asset Values
 Interstate through mountain canyon	Tangible Financial Values: Response and recovery from natural hazard events beyond the ROW Potential hazard mitigation and monitoring expenses Functional Values: Travel through corridor Intangible Values: Safety Agency reputation Broader economic impacts
 Natural debris flow reaching and blocking roadway	Tangible Financial Values: Recovery costs from natural hazards beyond the ROW Functional Values: Travel through mountain corridor Intangible Values: Safety Agency reputation Broader economic impacts
 Subgrade and embankment damage from regional flooding	Tangible Financial Values: Post-event maintenance Hazard mitigation works Functional Values: Travel through flood plain Intangible Values: Agency reputation Broader economic impacts

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

Many retaining walls are associated with bridge structures or approaches to a bridge. For the purposes of this implementation manual, if a wall is also a bridge abutment that is integral with the bridge structure, the wall should be considered to be part of the agency's bridge inspection and asset management program. It is encouraged that all other walls associated with bridge approaches be incorporated into the GAM plan inventory if they are not already managed in an asset management program. Examples of retaining walls are presented in Table 3.5.

Subgrades

Subgrade assets are made up of an earth material below the engineered pavement layers. Subgrade assets create a life-cycle management need that is independent of the engineered pavement.

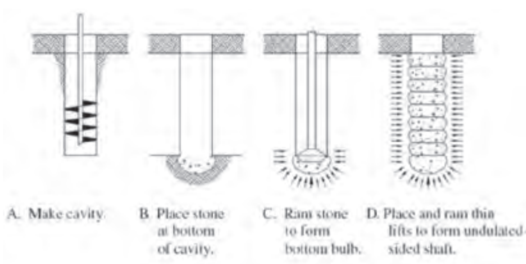
Table 3.5. Examples of retaining-wall assets.

Wall Asset Examples	Example Asset Values
	<u>Tangible Financial Values:</u> Initial construction cost Inspection, maintenance, and repair of elements <u>Functional Values:</u> Limits disturbance area into steep slopes above highway <u>Intangible Values:</u> Safety Environmental resource protection Aesthetic
	<u>Tangible Financial Values:</u> Initial construction cost Inspection and maintenance <u>Functional Values:</u> Elevated roadway section (above) sloping ground <u>Intangible Values:</u> Safety Environmental resource protection Reduced ROW needs
	<u>Tangible Financial Values:</u> Initial construction cost Inspection and maintenance <u>Functional Values:</u> Separation of bridge approach and roadway from river <u>Intangible Values:</u> Safety Environmental disturbance Projection of adjacent aquatic resources

Examples of subgrade assets include constructed earthworks and ground improvements to address swelling, compressible, or collapsible soil or bedrock, or threats from karst (sinkholes) and underground mining. A subgrade asset also can consist of an unimproved (or natural hazard) subgrade that generates performance risk to the roadway. Table 3.6 presents conceptual views of constructed subgrades in construction.

In some conditions, a geo-construction technology such as geofoam or geopiers will be part of a wall or slope repair. In those situations, the recommended approach is for the wall or slope to be considered the asset and the geotechnology to be considered a modification to the asset. By emphasizing the direct connection of this subgrade asset to pavement performance,

Table 3.6. Examples of subgrade assets.

Subgrade Asset Examples	Example Asset Values
 *Image source:* NCHRP 24-46 project team Lightweight foam fill	<u>Tangible Financial Values:</u> Initial construction cost <u>Functional Values:</u> Reduction of settlement over soft ground <u>Intangible Values:</u> Pavement management benefits Agency reputation
 *Image source:* Collin et al. (2008) Construction of aggregate pier subgrade asset	<u>Tangible Financial Values:</u> Initial construction cost <u>Functional Values:</u> Improvement of soft ground <u>Intangible Values:</u> Agency reputation Performance of other assets
 *Image Source:* Photograph courtesy of Carmeuse Lime & Stone (www.carmeusena.com) Construction of chemical stabilized subgrade	<u>Tangible Financial Values:</u> Initial construction cost <u>Functional Values:</u> Pavement performance over expansive soil <u>Intangible Values:</u> Agency reputation Pavement management

any potential confusion with other geotechnical assets should be reduced; however, this topic could be addressed with process improvements, if necessary, as geotechnical asset inventories are developed.

Setting the Context and Enabling GAM

Scaling the GAM Implementation

Striving for an advanced level of maturity at the start of the GAM process can add challenges to the implementation process because a higher level of investment is required before benefits are evident.

Asset management, and thus GAM, is an ongoing process; it relies on process improvements to direct advancement where the greatest value can occur. This approach can be unfamiliar to geotechnical engineers, who often are adept at following design procedures to complete discrete tasks for a design project but may have limited involvement in the later stages of life-cycle performance. When implementing asset management, each agency will need to adapt the fundamental concepts to the needs and objectives of the agency. As noted in the executive summary to the AASHTO *TAM Guide,* "[t]here is no 'one-size-fits-all' TAM solution for an agency" (AASHTO 2011).

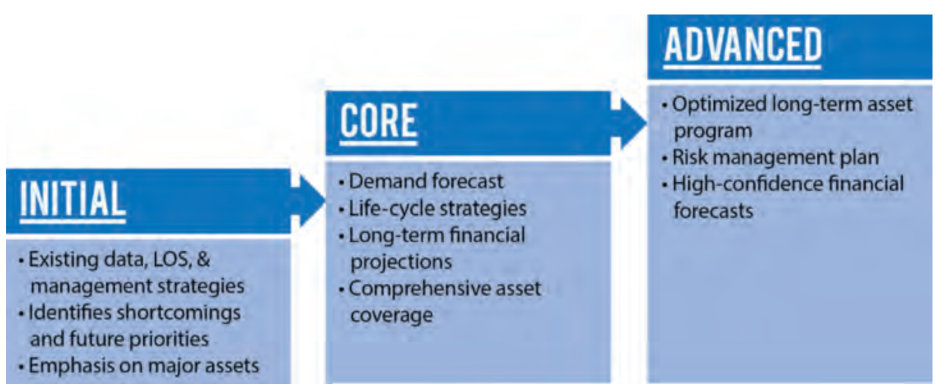
It is suggested that GAM implementation start in a simple manner and advance with time as the accumulated data and measured results help the agency advance its level of asset management maturity. In the absence of an existing GAM plan, the geo-professional and TAM staff are encouraged to start at a simple (low) level of asset management maturity (e.g., by creating a simple inventory) and develop the plan over time in conjunction with process improvements.

Various asset management publications offer guidance on how to assess the maturity of an organization's asset management efforts in terms of up to five levels. When discussing TAM maturity and the scaling of an agency's GAM plan, the *GAM Implementation Manual* references the three levels of maturity presented in the National Highway Institute (NHI) course, "Developing a Transportation Asset Management Plan" (FHWA–NHI-136106B): initial, core, and advanced. Figure 3.3 briefly characterizes the three maturity levels.

Initial Maturity

The initial level of asset management maturity allows the geo- or TAM professional to start at a relatively simple level in regards to the staff, processes, and data needed to begin implementing GAM. Examining the specific criteria for an initial level of maturity, GAM implementation can be started using:

- **Existing Data:** Most agencies have some type of data that can be used to support GAM. These data can include formal or informal inventories compiled by subject matter experts



Source: FHWA-NHI Course 136106B (2017)

Figure 3.3. Asset management maturity levels.

(SMEs), event records, maintenance work orders, and traffic delay and closure information. Even incomplete data can be enough to start a GAM plan.

- **Performance Measures of Other Assets:** Existing measures in use for other assets or performance areas typically will connect to existing department objectives. These measures or other similar measures also can be found in a transportation department's existing TAM plans or pavement and bridge management plans. This manual provides recommendations for performance measures that could be adapted for use when implementing GAM. Any of these sources can be used to understand agency objectives and develop the GAM performance measures for the agency without having to undertake a separate formulation step.
- **Management Strategies:** Every transportation agency manages geotechnical assets, whether or not a plan exists. For an initial level of maturity, development of a management strategy can be as simple as documenting how management currently occurs, such as minimum response actions, routing maintenance, or urgent rehabilitation and reconstruction projects when needed to address disruptions in service.
- **Shortcomings and Future Priorities:** Identifying shortcomings and future priorities involves a straightforward process of comparing current performance (or lack of performance) to desired performance. This comparison—sometimes called a *gap analysis*—provides the focus needed to identify and rank future work. The GAM Planner that accompanies this manual can enable the GAM implementation leader to develop the gap analysis as the inventory is being built. Moreover, documenting the incompleteness of the initial inventory is an acceptable and encouraged portion of the gap analysis.
- **Emphasis on Major Assets:** The GAM implementation may start with inventory and assessment of just a few critical, known assets, even if the initial assessment is based only on the judgment of the geotechnical SMEs. Evidence from existing programs suggests that the completion of a GAM inventory can be expected to take several years. Delaying the full spectrum of GAM implementation until the inventory is complete only delays the creation of value that is the desired outcome of asset management. If an agency addresses certain geotechnical assets at the outset, those assets could very well demonstrate the need (and benefits) of investing in a comprehensive inventory. Thus, known, critical geotechnical assets are good candidate assets for the initial inventory and action plans.

Core Maturity

An agency that has reached the core maturity level has begun GAM implementation, and performance data and executive input feedback loops are in progress. Core maturity can be considered to be the stage at which an agency is customizing its initial GAM program based on process and data constraints and to reflect the agency's requirements and objectives. The agency may modify the processes and data obtained during the initial maturity phase based on lessons learned and internal stakeholder input. For example, an agency may revise asset management objectives as executives gain specific understanding of how asset performance is impacting performance objectives and recognize the opportunities that may exist. Core maturity is often the level at which asset management workflow process improvements are selected. This also is the stage at which an agency develops longer-term investment and life-cycle plans, in addition to expanding the GAM inventory.

Advanced Maturity

An advanced level of GAM maturity is expected to be an eventual outcome, after several years of implementation experience. At this level of maturity, the agency's GAM planning is in concert with its TAM planning. An advanced level of maturity is a desired goal for any asset management plan, but it is unrealistic to expect that an agency's GAM implementation efforts will reach this level of maturity quickly. At an advanced maturity level, an organization's GAM planning will have the following characteristics:

- A complete asset inventory that is aligned with agency data management standards;
- Analysis methods that align with executive objectives;
- Annual and long-term financial plans for assets;
- A culture of risk management and asset management across programs and processes;
- Execution of an optimized cross-asset program; and
- Internal and external asset performance communication plans.

Addressing the Hurdle of Constrained Funds in Starting GAM Implementation

At most agencies, the perception that new or increased funding will be needed to start a GAM program will be a barrier to implementation. Any asset management implementation, geotechnical or otherwise, should be considered and communicated as a **sound business practice with measurable and targeted outcomes** rather than as a new procedural process for SMEs that will require new resources in an already resource-limited agency.

A GAM program is a business process improvement that enables an agency to improve the performance and life-cycle cost-effectiveness of geotechnical assets. Any public agency that values effective stewardship of taxpayer funds will recognize that GAM helps the agency fulfill this role, particularly over time as comparisons are made between the benefits accrued to agencies practicing GAM versus those without.

To counter the perception that funds are not available to start GAM even at an initial maturity level, the following suggestions are provided:

- GAM can result in life-cycle savings when the O&M phase is considered in the whole-life cost of an asset. Guidance from agencies with asset management programs indicates that life-cycle savings range from 3 percent to greater than 38 percent (Taggart et al. 2014; USACE 2013). Anecdotal evidence suggests even higher savings potential, but it was not possible to establish this quantitatively because baseline life-cycle costs had not been measured previously at the agencies consulted.
- When implementing risk-based GAM, an agency can:
  - Improve the reliability or performance of the system without increasing costs (e.g., do more for the same cost); or
  - Reduce costs without significantly reducing strategic performance (e.g., maintain current performance, but at a lower cost).
- The benefits of GAM can be realized early, even before inventory is complete, as evidenced by several years of implementation experience at both Network Rail and Highways England in the United Kingdom. Striving for a complete inventory while delaying decision-making for the assets with data can result in a challenging GAM implementation environment because a higher development investment is necessary before results have been observed. Because both geo-professionals and agency executives must make decisions based on incomplete data and information as part of the normal execution of their work, this judgment-based approach is acceptable and encouraged for initial GAM implementation.
- In discussions with agency executives and TAM staff, communicating potential "quick wins" for a few geotechnical assets at the individual project level may be more effective than advocating for the investment required to complete a system-wide inventory or showing a multimillion-dollar program-level investment gap.

Even at the initial maturity level, the GAM investment plan can present defensible management options for communicating with executives because it can be based on a variety of funding levels.

Developing Support and Communicating the Need for GAM

Asset management implementation will involve individuals beyond the SMEs charged with developing the program. This process includes executives making investment decisions, engineering and project delivery staff, maintenance departments, and even input from system users. Through the risk-based GAM implementation process, an agency can measure and manage direct and indirect consequences to multiple performance objectives as an outcome from GAM.

When developing support for GAM implementation, it is helpful to discuss outcomes relative to the perspective of the stakeholder. This does not need to be a complex or difficult conversation. The potential outcomes from GAM generally can be categorized in terms of performance characteristics that relate to three stakeholder perspectives:

- **Customer-Related Asset Performance Characteristics:** Customer-related performance characteristics relate to how the user of the system is impacted by the asset. Basically, support for GAM from a customer perspective will relate to performance details such as safety, delay, regional economic impacts, or property damage.
- **Outward (or *Outward-Facing*) Asset Performance Characteristics:** Outward-facing asset performance characteristics (i.e., those that relate to the asset's impact on customers or the public) likely will be preferred and more easily understood by executives and by the non-engineering management staff who will help facilitate GAM implementation throughout the agency. The communication of outward-facing objectives involves answering the question, "What does the asset do for us as an organization?" The resulting answers will relate to risk tolerance and acceptance, financial measures, impacts on the agency's highest-level objectives, on other assets, or on issues such as agency reputation and environmental damage.
- **Inward (or *Inward-Facing*) Asset Performance Characteristics:** These characteristics are most easily recognized by the engineering SMEs and will relate to asset performance in geotechnical terms. Examples include embankment distress, deteriorating retaining walls or structure elements, or adverse slope movements. Inward-facing asset performance objectives can be beneficial when developing support from the engineering and operations staff who are involved in the design and maintenance of geotechnical assets.

Evidence from successful GAM implementations and other TAM plans suggests that support is more likely to occur when the asset performance is connected to outward-facing and/or customer-related performance characteristics. Chapter 4 provides a more detailed discussion about how these perspectives influence the establishment of performance objectives for a GAM plan.

Enabling Support and Funding for GAM

Prepare Quick Selling Points for GAM

Often the geo-professional or asset manager has limited opportunity to communicate the importance of GAM to executives, whose support is often important toward the long-term stability of a program. The enabling communication to potential stakeholders and supporters should be both concise and direct, and presented in a context that is easily understood.

Key points to communicate when advocating for GAM can include:

- Better achievement of agency performance measures;
- Reduction of direct financial impact to the agency through:
  - Lower life-cycle costs for assets, and
  - Reduced costs for incident management and recovery actions;
- Reduction of financial and economic impact due to reduced mobility and access;

- Reduction of broader economic impacts from:
  - Injury or loss of life,
  - Property damage,
  - Business interruptions, or
  - Other governmental needs; and
- Improvements to environmental, community, public perception, and social performance areas.

Emphasize the Business Case

Although it also was needed on the basis of good business and safety practices, nationwide implementation of bridge and pavement asset management programs has been made possible in part because of regulatory requirements and dedicated federal funding. Recent federal authorization has encouraged asset management for additional non-bridge-and-pavement assets in the ROW; however, there is no explicit requirement for GAM. Therefore, the anticipated federal legislative environment is such that for the foreseeable future, GAM implementation should be expected to function on the basis of economic and performance improvement benefits rather than on the basis of regulatory requirements. The absence of federal rules and funding oversight allows agencies the flexibility to develop GAM plans that are specific to their goals and missions, which will vary. Rather than focus on federal compliance issues in the implementation process, agencies can direct efforts solely toward their objectives.

When the federal authorization guidance is combined with the obligation for sound investment of public funds, the benefits of GAM will need to be communicated by agency geo-professionals to executives and TAM staff, who may not recognize the benefits on their own. When advocating for GAM, it is important to emphasize the economic and performance benefits that can result, regardless of the status of regulatory catalysts. For example, on the subject of risk-based dam safety management—which can be considered an established form of GAM for critical safety and economic assets in the United States—a senior executive with the USACE indicated that the USACE has avoided $7 billion of expenses, and commented, “We couldn’t afford not to do it” (Russell 2017). Regardless of regulatory requirements, the USACE values its GAM program on the basis of economic benefit and other performance benefits, such as safety and risk management.

In the absence of federal or state requirements for GAM, the GAM program should demonstrate a value or other benefit proposition for obtaining funds based on a sound business case and a favorable ROI. The guidance and tools provided with this manual are intended to assist geo-professionals and TAM professionals in demonstrating the economic and social benefits of GAM at both the individual project level and the program levels.

Discuss Measuring and Managing Risk

To resonate with agency executives, GAM must support and help deliver agency objectives and performance areas.

Regardless of the presence or absence of regulatory requirements, DOT executives and managers have a strong interest in managing risks to the performance and viability of their agencies. This interest has been evidenced by the adoption of risk-based concepts into numerous agency functions, ranging from implementation of insurance programs, contracting and purchasing procedures, and probabilistic design of multiple structure types. Incorporating risk into GAM enables the plan to align with executive-level risk management interests, thus gaining stakeholder support and increasing the potential for implementation success.

By incorporating risk-based practices into GAM, an agency can measure and direct actions toward objectives and performance criteria that exist at all levels of the organization, including executive staff, maintenance management, TAM professionals, and the geotechnical programs. As indicated by several executives and supported by the literature reviewed in the development of this manual, this connection to all organizational levels and objectives is a key step in enabling asset management without a regulatory mandate. Without it, the geo-professional is essentially competing for project priorities within and among a grouping of only geotechnical assets. Following a risk-based approach, decision-makers can better understand the benefits of proactive investment and preventative maintenance in terms of reduced likelihood of disruptions or losses. If the agency asset manager can compare risks posed by deteriorating or failing assets across categories, including geotechnical, that individual can help senior management allocate resources to mitigate the risks and the adverse conditions that result from misallocation of investments. Thus, incorporating formal risk-based processes into the GAM program better facilitates the connection of geotechnical asset performance to the priorities of agency executives.

At a minimum, by measuring the risks associated with geotechnical assets, an agency can become more aware of the LOR that is being accepted at the current investment levels, which should be of interest to executives regardless of any federal or state legislative requirements. Further, the asset management literature across infrastructure sectors indicates that risk-based network-level decision-making can be directed toward the following two key approaches:

- Improving reliability/performance of the system without increasing costs, or
- Reducing costs without adversely reducing system reliability.

Alternatively, an organization can choose to improve system performance through increased funding. Through the use of risk-based GAM practices, the agency will be able to demonstrate that the increased funds are being optimized across the life-cycle of the system, rather than following the legacy practices that are responsible for the current conditions.

When advocating for the initiation of GAM in an agency, a risk-based plan can be proposed (1) as a budget/cost-neutral process that will improve performance, or (2) as a process to work toward cost savings should the existing performance be deemed acceptable. As the organization's level of asset management maturity increases, the agency may have the opportunity to increase GAM investment, knowing that the funds are being allocated with favorable cost-benefit ratios that also support improved system performance when compared with investments in other asset classes.

Draw from Successful Examples

To provide evidence of the business case and potential investment and risk reduction benefits, examples of successful programs are valuable illustrations of the aspirational outcomes that can result from committing to GAM. **GAM does not need to be invented or started from scratch,** and by considering the experience of successful programs, an agency can efficiently implement asset management practices that have already been tested and proven elsewhere. The "lessons learned" that are noted in this section have been considered in the formulation of the risk-based framework and analysis concepts presented in this implementation manual. The same approach can be used by agencies at an advanced level of GAM maturity when incorporating value-added, agency-specific process improvements into their plans.

- The 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 is completed by staff using conventional spreadsheet programs (Connelly et al. 2016).

- 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 the 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 embankment 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 Swiss francs.

Risk-based GAM provides cost savings and performance benefits.

A key component of these examples is that risk-based GAM is providing life-cycle cost savings and performance benefits through a sustained process that has existed for about 15 to 20 years, depending on the program. This sustained GAM practice is similar to bridge and pavement asset management programs in the United States. All of these program examples started in response to regulation; however, after several years of implementation, each of these examples has evolved from a startup program to a more complex maturity level that demonstrates measurable benefits. In the case of bridge and pavement asset management programs in the United States, many municipal agencies have adopted the practices without being required to do so because of the obvious benefits that result. Further, if the legislative requirements for pavement and bridge asset management ceased to exist, it is unlikely that agencies would stop their asset management practices. Doing so could be viewed as a negligent step away from a well-established professional standard of care and stewardship of public funds.

Workflow for GAM

Just as transportation agency decision-makers must prioritize budgets through projects and programs, staff resources are equally limited and often consumed with the daily activities of responding to road and bridge repair work and needs. Dedicating time for strategic and proactive

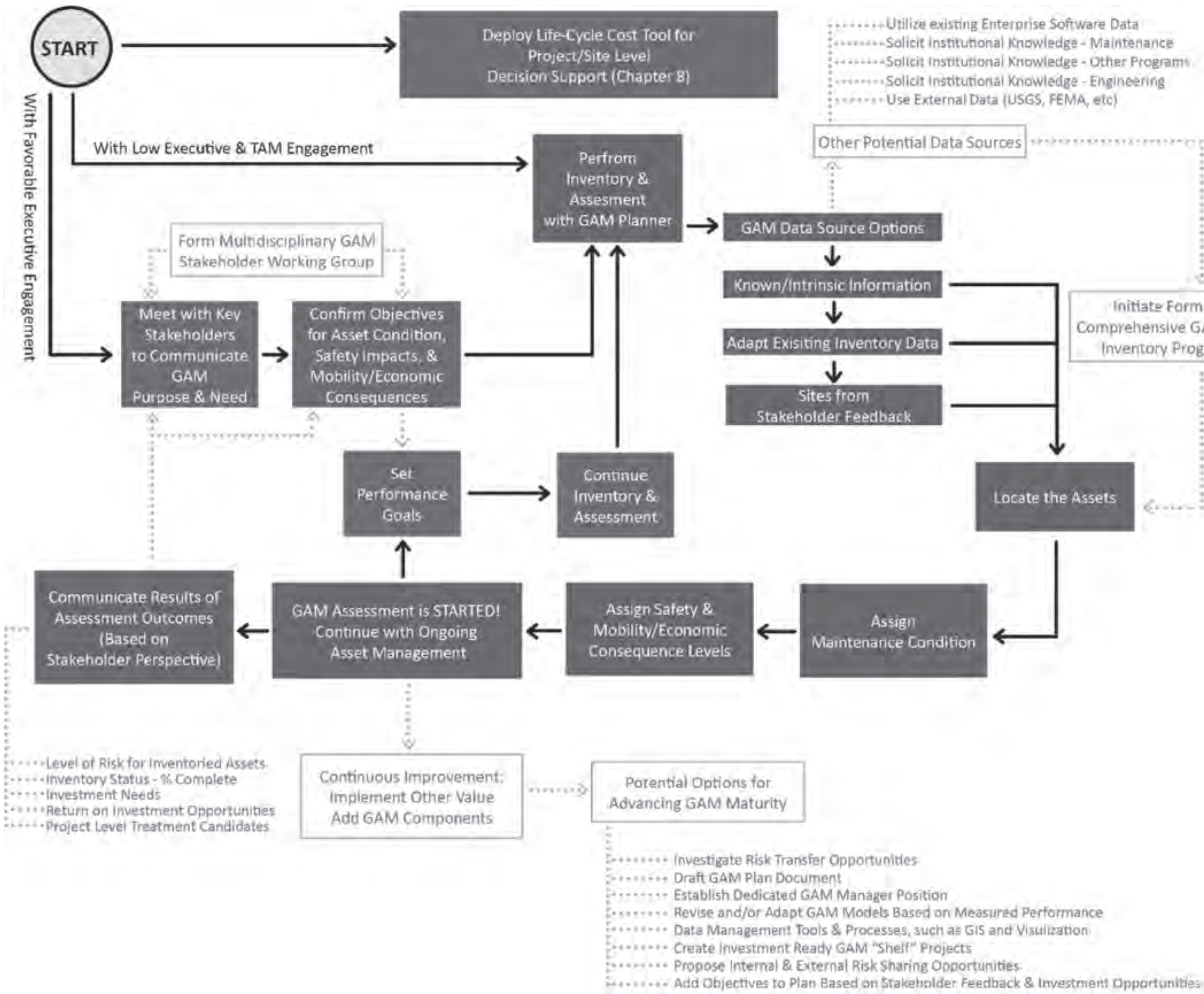


Figure 3.4. Proposed workflow for GAM.

planning for asset management requires setting aside activities that are seemingly more urgent. This manual recognizes the opportunity costs that managers must consider when choosing how to deploy their staff and resources every day, and offers both an abbreviated workflow for quick GAM implementation (in Part B) and a more comprehensive level of planning guidance. Figure 3.4 modifies the "quick start" workflow from Part B to include additional details. The more comprehensive approach, which can be developed over time, includes several process improvements steps that are not reflected in the abbreviated workflow, such as establishing a dedicated GAM manager position and investigating opportunities to transfer risk. The more comprehensive workflow (as described in the chapters in Part C of this manual) can assist the agency's asset management lead and GAM professionals to consider process improvements that improve maturity in management of ancillary assets such as slopes and walls.

Implementing a Successful Workflow Within an Agency

How many steps an agency will implement from the suggested workflow—and how many staff will participate—will depend not only on the level of the agency's asset management maturity and sophistication, but also on the LOR posed by the agency's geotechnical assets relative to the risks posed by other preservation challenges and priorities. For example, a state DOT in a region of the United States with gentle topography that has no significant operational risk from slopes or embankments may assign GAM to the agency's asset manager and allow the manager to prioritize GAM actions against other preservation needs for bridges and culverts. That asset manager may find the abbreviated workflow outlined in Part B adequate to meet the agency's GAM needs. Conversely, a state DOT in a region with varied terrain or with complex, interacting geologic and urban regions may already have in place a GAM manager and dedicated GAM budget. The latter agency could use this manual to create investment-ready GAM "shelf" projects or to introduce a GAM steering committee that includes co-workers from the field, O&M and finance staff, as well as members from local and other partner agencies.

Start Lean

Even at an agency with a sophisticated asset management program and many geo-professionals, the most difficult challenge may still be initiating GAM implementation. The agency's asset management lead should recognize the benefits of starting a lean plan at a simple level of maturity even if several geo-professionals are available, and then making incremental improvements over time rather than delaying implementation to invest in development of a comprehensive, complex plan. This chapter of the *GAM Implementation Manual* has presented an abbreviated workflow for implementing a lean GAM program in six steps:

Step 1: Identify and locate geotechnical assets;
Step 2: Record asset O&M conditions;
Step 3: Assess asset performance consequences;
Step 4: Review treatment recommendations;
Step 5: Analyze the impacts of differing investment levels; and
Step 6: Communicate results.

Shortcuts are available to an agency that is launching a lean GAM program. Rather than locating and creating an inventory of *all* GAM assets in Step 2, the agency can start with key corridors. It is advisable to locate GAM assets in heavily trafficked highways or corridors whose closure would result in significant freight detours. This choice essentially allows the agency to make prioritized risk assessments as it would for other critical assets, and to apply resources accordingly. Rather than developing a full life-cycle analysis for each asset, the abbreviated Step 6 (as presented in Part B) helps the agency use the GAM Planner to determine appropriate budget levels by year for the geotechnical assets selected in Steps 1 and 2. The GAM Planner also shows, given the assigned budget and initial conditions, annual costs and projected conditions. The spreadsheet tool includes a "Results" view that forecasts what will happen over time to a selected asset.

Increase Complexity/Maturity

If an agency sometimes allows "the perfect" to become the enemy of "the good," an incremental improvement approach that starts lean and adds complexity over time may work best. Some of the largest potential impediments to launching a comprehensive asset management program—data, financial justification, or field implementation of proactive treatment strategies—also offer the best areas to look to advance an agency's emerging GAM program.

At first, data that can help build models to accurately prioritize maintenance, rehabilitation, and reconstruction of geotechnical assets may seem to be non-existent or, at best, difficult to find, interpret, and analyze. Actually, practitioners forming a new program may leverage the experience and judgment of experienced geotechnical professionals and use available data to begin to build asset-level decision trees. For example, analyzing maintenance work orders or interviewing maintenance staff following heavy rains on highways with embankments can begin to provide insights into the level of effort required to react to events that impact geotechnical assets. Comparing that data to practices from industry-wide or neighboring agencies, the practitioner can then determine how to better collect maintenance information in the field to track labor and material costs going forward.

Justifying investments in slopes and embankments against the backdrop of federal authorization and all of its focus on highways and bridges may also appear to be an insurmountable challenge. Bridge and pavement leads for the agency likely already have dedicated deterioration models, proven communication tools, and long-standing approaches for garnering comparatively large budget requests. The agency's asset management lead can, however, enable the geotechnical assets to compete on a more level playing field by standardizing the annual processes for measuring and reporting performance, by demonstrating the benefits of investment in the context of executive-level objectives, and by actively seeking funding.

By pairing clear communication about the risks of underfunding with the development of a 10-year forecast of condition (see Chapter 2, Figure 2.12), a geo-professional can better articulate the need for agency funding at a program level. By comparing the geotechnical forecast to similar 10-year bridge and pavement forecasts developed for federal authorization, the asset management lead now allows decision-makers to see how funding GAM can help achieve the agency's outcome-based safety and mobility goals. Despite these communication steps, however, realization of funding can be difficult to achieve, particularly because the agency's needs will more than likely exceed its practical investment capabilities when balancing all needs. Additional prioritization steps will be needed to guide the agency and the asset manager to the optimum use of funds that will be encumbered. In this manual, the necessary steps for this prioritization are discussed in detail in Chapter 8.

Asset managers who are starting GAM implementation from the ground up should plan to start lean and need to be willing to make assumptions and make mistakes, all the while considering future areas for improvement. The agency's eventual GAM plan may even include a section for "Next Steps," ways the agency wants to mature the program over 1-year, 5-year, and 10-year time periods. The agency also can identify "champions" for each improvement area and define success for each step so that the agency knows when to celebrate victories. It is not realistic to expect to launch a GAM program that will reach full maturity in Year 1. Successful GAM implementation includes acknowledgment that this new process will improve over time and will continue to support planning efforts as veteran staff retire and new staff join, providing fresh perspectives. Further discussion about the steps an organization can take to enable GAM within agency-specific processes and programs is provided in Chapter 8.

CHAPTER 4

Linking to TAM

Integrating GAM with TAM

GAM implementation should occur such that the eventual plan can be incorporated into an agency-wide TAM plan. The success of GAM integration is dependent on the program's alignment with established TAM practices. This chapter provides an introduction to TAM processes that should be considered to enable the connection between a GAM program and the agency's broader asset management program.

The guidance provided in this manual is intended to be consistent with AASHTO TAM practices, which prescribe the following features for a TAM plan:

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

This chapter is intended to help the reader understand how these characteristics of TAM influence GAM implementation.

Objectives: *Strategic, tactical, or operational results that are desired outcomes from asset management.*

Performance Measures: *Values that indicate how the asset is performing relative to technical, system performance, and customer perspectives.*

Objectives and Measures

Transportation agencies are not created to manage assets. Their primary mission is to help transport people, goods, and services safely and efficiently. To that end, agencies develop goals at the highest level that seek to achieve safety, mobility, and economic development. An agency asset management plan will therefore be formulated to support these and other high-level goals.

A TAM plan and the supporting asset-specific management programs, such as a GAM program, will specify objectives and measures that the agency will use to track and manage asset performance. In an asset management plan, the objectives should align with the higher-level, agency-wide mission or purpose. The measures in the asset management plan then relate the performance of each managed asset to those established agency objectives. Put another way, *objectives* support the highest-level goals of the agency and *measures* indicate how progress toward those objectives will be tracked and forecasted.

In bridge and pavement programs, minimum performance measures for use in federal reporting are established by federal regulations (23 CFR 490), and agencies also have freedom to establish additional measures should that be desired. For geotechnical assets, performance measures should relate to TAM objectives just as they would for any other transportation asset. In the absence of federal requirements to specify GAM measures, the geotechnical asset manager has an opportunity to establish measures specific to their agency objectives and mission presented in the TAM plan. This same opportunity exists for those implementing GAM in the absence of a TAM or executive support as most agencies will at a minimum have a mission or high-level purpose that is communicated to public and government stakeholders.

Lessons learned from mature GAM programs and input from agency executives indicates that successfully adopted performance measures have been those that relate how the asset's performance affects customers or executive decision-making. For example, 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.

These measures are related to high-level, outward-facing agency objectives that involve safety and system performance.

Network Rail collects and tracks additional internal measures that relate to geotechnical performance criteria as understood by geotechnical professionals in the asset management process, but it is the comparison to agency and customer service performance objective areas that has allowed Network Rail to demonstrate earthwork performance improvements since planning was started in 2000. Similarly, the UK Highways Agency GAM program focuses on providing assets that provide the required service level for the user. Examining these long-standing programs, it is clear that ***demonstration of success in performance terms understood by public stakeholders and executives is critical for enabling continued asset management for geotechnical assets.***

If the GAM implementation will take place in a culture with limited engagement from executives and/or planning staff, the plan should still be structured to connect performance measures with objectives at the highest levels of the agency. Doing this will increase the chances for implementation success and will set the stage to invite eventual executive engagement and support.

Considering the Perspective of Objectives and Measures

In the management of transportation assets and system performance, individual asset management program objectives should use measures that connect with *outward-facing* (primary) objectives. These outward-facing objectives can be considered in terms of public-facing asset characteristics. Outward (or primary) objectives align with overarching agency performance areas or goals, such as safety, mobility, and promoting economic vitality (see Figure 4.1).

An asset management plan also uses *inward-facing* (or secondary) objectives to further guide the operations of programs that are responsible for the asset or performance area. If the data needed to measure progress toward outward-facing objectives are limited, inward-facing objectives also may be used as a proxy for achieving the primary (outward) objectives. Inward-facing objectives and measures can be considered as related to engineering-based asset characteristics and/or performance-driving asset characteristics.

Agency executives who are able to authorize a GAM plan are more likely to understand asset measures that indicate what the asset can do in terms of system performance.

An example outward-facing objective and measure for many DOTs is to reduce traffic fatalities to zero. In a DOT that has this safety objective, the various operational programs will have objectives and measures that support this goal, such as traffic safety design policies to reduce crashes, construction procedures for reducing traveler delays, or maintenance standards that set expectations for roadway operational performance in adverse weather. Figure 4.1 illustrates the conceptual relationship between outward, public-facing objectives and internal measures.

Outward-facing objectives like safety are achieved as an outcome of measuring and tracking progress toward internal measures that align with objective performance areas. Thus, asset-specific measures should purposely overlap with the outward measures and objectives. This overlap of the measures for a GAM program with the outward-facing objectives of the agency can be a key enabler for successful GAM implementation while also supporting the overall TAM performance planning and communication process.

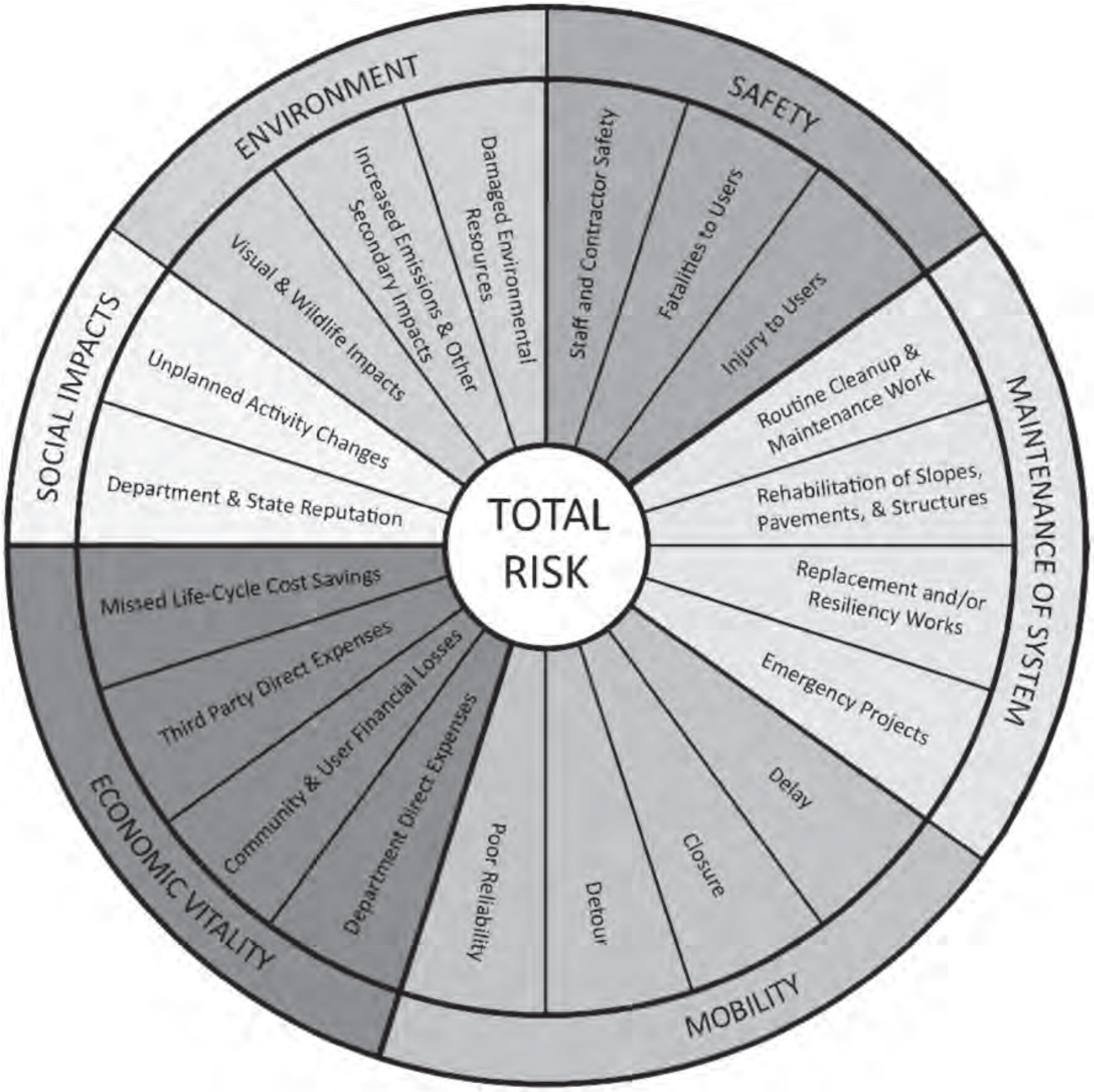


Figure 4.1. Outward-facing objectives (rim of wheel) with internal measures (spokes) that inform a performance metric (hub).

Outward-facing, outcome-based objectives such as safety, mobility, and economic vitality help communicate to the public—the agency's "investors"—how the agency achieves these desirable goals. The seven national performance areas authorized in 23 CFR 150 help U.S. transportation agencies speak to the public in terms of both outward-facing measures such as fatalities and travel reliability, and internal measures such as lane-miles repaired or deck area preserved. The internal measures help the agency measure progress in its achievement of the outward objectives.

One way to measure and manage the advancement of an asset management program is through the use of *lead and lag metrics.* Now required through federal authorization, lag metrics such as percent of bridges by deck area or National Highway System (NHS) lane-miles in good/fair condition. Using only lag metrics, which rely on annual or biennial data collection and often are reported a full year after their collection, does not help guide the agency in making short-term course corrections. Lead metrics will serve this purpose once a program of projects has been developed through a Statewide Transportation Improvement Program (STIP) and incorporated into an annual budget. Who measures the progress of those programmed projects? Who checks to see if the projects recommended by the asset manager or GAM professional are implemented in the field? And who is responsible for ensuring that the predicted outcomes are actually achieved once the projects are completed? Building a lead-lag program and assigning the responsibility of focusing on the lead metrics to a few key individuals will help to refine models, improve scoping, and enhance life-cycle cost analysis (LCCA) as the GAM implementation matures.

Relying only on the achievement of outward-facing measures might lead an agency to believe, falsely, that its asset management mission is complete. A balance of emphasis between inward and outward measures is important in the continual advancement of TAM and GAM, which is a continuous journey without a final outcome or finish line.

Background for GAM Measurement in Support of Executive Communication

In a GAM program, the geotechnical performance measures should be tailored to connect with familiar objectives related to federal authorization and other common executive benchmarks found in the agency's mission and vision statements. The purpose of this measurement and communication process is to convey levels of risk, preservation need, or other factors that will enable decision-makers to attain agency-specific goals.

To communicate implementation success simply, the geotechnical asset performance measures should be generalized and high level while still being effective at informing decisions and measuring performance relative to outward objectives. The simplest performance measures can be as basic as whether the asset status is "functioning" versus "non-functioning." Even such a simple performance measure as this can serve as a meaningful gauge of an agency's operational needs, cost-effectiveness, and forecast of asset performance. Because scrutiny of federal authorization and other executive-related performance measures has grown in importance for decision-making processes, including simple geotechnical performance measures offers a more complete picture of a transportation system's performance and provides greater insight to decision-makers.

The communications aspects of geotechnical performance measures can be crafted just as they would be for other measures. This begins with connecting an agency's goals and objectives with an asset's impact on performance (e.g., safety, mobility, and preservation). Understanding the nature of executive communication in terms of policy objectives, programs, management styles, and reporting needs informs this process, and can help set a minimum baseline for communication in service of keeping things simple.

Crossett and Schneweis (2012) documented the importance of improving agencies' ability to communicate performance effectively in *NCHRP Report 742: Communicating the Value of Preservation: A Playbook.* This guidance document provides state DOTs and other transportation agencies tools to develop and implement strategies for communicating the role and importance of maintenance and asset-preservation in sustaining highway system performance. The report guides the development of effective communication skills by focusing on four simple and connected building blocks: (1) audience identification, (2) message design, (3) message delivery, and (4) market research. It also provides creative ideas for mitigating the unique factors that will shape communications such as infrastructure conditions, transportation funding levels, and political considerations. The playbook offers tips, templates, and techniques that can be used for effective branding and messaging to stakeholders. Further, the ISO 55000 asset management series focuses on goals for implementation of an asset management system that considers the roles, needs, and expectations of stakeholders and how to communicate effectively. The strategies contained in these guidance documents, together with examples from successful GAM programs, strongly support the need for GAM measurement to connect with executive measures.

Introduction of GAM LOR Measures in Support of Executive-Level Communication

The measurement and reporting of an asset status to executive and planning professionals should be communicated in a simple format that conveys the asset performance to high-level executive or TAM planning objectives. The purpose of this communication step is to quickly communicate the outward geotechnical asset performance to non-geotechnical decision-makers, rather than delving into the technical condition or performance aspects of the asset that are best understood by the geo-professional. The data collected in the GAM inventory or at the asset level will enable the communication of more technical details of asset performance information on request, but initial performance communication will be best received by non-geo-professionals if it can be understood in simple terms, ultimately improving the likelihood for successful GAM implementation.

When developing or selecting outward-facing or executive-level performance measures for any asset, several criteria should be considered; specifically, do the selected metrics:

- Provide a means to efficiently or simply assess and communicate baseline asset conditions;
- Address performance across the range of impacted agency objectives;
- Allow for modeling of future asset performance based on investment and treatment scenarios; and
- Allow the asset manager to establish and gain consensus toward a target performance level?

The LOS standards used in many TAM and maintenance planning programs are an established form of communicating the service quality of an asset to executives and non-technical stakeholders.

Level of Risk (LOR): A recommended executive-level communication metric for a GAM plan.

The implementation approach proposed in this manual defines LOR as the suggested performance metric. For a GAM program, the LOR can be a grade-based categorical measure for asset performance communication to executives and other non-geotechnical stakeholders. The LOR is 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. A visual representation of LOR for different geotechnical assets is presented in Appendix D.

The LOR measure functions similarly to the LOS measure; however, the concept of LOR as applied in this manual is based in part on the early GAM implementation experience at the Colorado DOT, where challenges arose with communicating 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, such as understanding what are "good," "fair," or "poor" conditions for slopes, walls, embankments, and subgrades and how this translates to the agency's performance.

Thus, the LOR measure can be an effective tool in communicating the magnitude of performance risk from geotechnical assets to TAM and executive stakeholders that do not have geotechnical training. Illustrating the aggregation of these performance risks relative to the range of measures and objectives, Figure 4.2 presents a geotechnical asset-specific adaptation of the concepts presented in Figure 4.1.

The LOR framework presented in this implementation manual allows the TAM or geo-professional to communicate, at the start of GAM implementation, the magnitude of asset risk acceptance that currently exists based on a connection to common TAM objectives. The LOR is intended to function as a simple magnitude grade scale that is based on the aggregate of

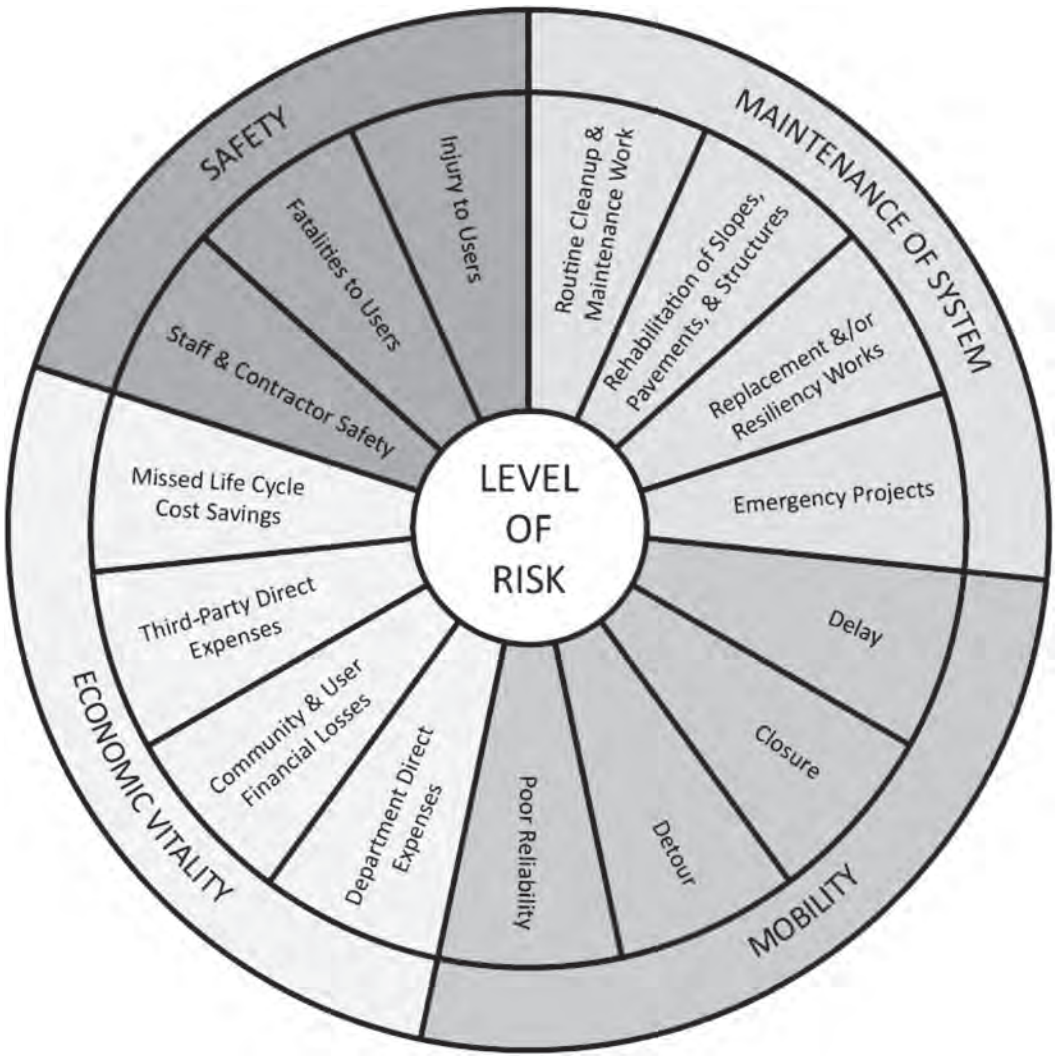


Figure 4.2. LOR performance metric for communicating risk from geotechnical assets.

the performance risk to objectives. Over time and with increasing program maturity, the LOR grades can be used to track performance of the GAM program and communicate potential performance improvements or risk reduction that would result from investment scenarios. The changes in LOR distribution based on different investment approaches also can be modeled in a GAM implementation.

Using the GAM Planner provided with this manual, the LOR will communicate performance risk magnitude for objectives of asset condition, safety impacts, and mobility and economic consequences. The LOR grade category default framework established in the GAM Planner is as follows:

A = GAM risk score less than 10,
B = GAM risk score of 10 to 20,
C = GAM risk score of 20 to 30,
D = GAM risk score of 30 to 40, and
F = GAM risk score greater than 40,

where the GAM risk score is the sum of the safety and mobility risk scores calculated within the GAM Planner processes.

Appendix D provides examples of geotechnical assets using these default grade categories. The LOR metric distinguishes *asset condition* in relation to risk and objectives. In the GAM process recommended by this manual, asset condition functions as a surrogate for "likelihood" in the estimation of risk. Asset condition also can be used as a separate measure (a topic that is discussed in more detail in another section of this chapter). Appendix D provides visual examples to illustrate both asset condition and differences in LOR to represent what the asset condition can do to the safety and mobility and economic performance objectives of the agency.

To address potential questions regarding what should influence GAM when measuring and reporting asset condition and LOR, each agency has flexibility in pursuing its implementation depending on executive input (a topic further explored in Chapter 8). Asset condition is only one component in the risk analysis, and relying only on asset condition information will not fully examine or convey the risks to agency objectives. For risk-based GAM, the LOR performance measure is designed to communicate the combination of *condition* (likelihood) and *consequence* (i.e., the impact to objective performance areas).

The use of a fixed inventory segment length (e.g., 500 feet in the GAM Planner) reduces the potential scale effects that can distort information when comparing very large (e.g., long) assets in fair condition with less significant assets in poor or critical condition. By using segmentation of assets, each asset segment is more comparable and less influenced by length.

If desired, the default grade categories in the GAM Planner can be adjusted after review and input from executive and TAM planning staff in the agency. The use of the A through F grade scale is important; executives and other non-geotechnical stakeholders will recognize the context of a grade more quickly and with less explanation than a raw score or some other numerical value that requires interpretation.

For an agency with increased maturity and GAM planning experience, the LOR scale can be modified to be more specific to the agency's objectives, data, and processes. What is important is that the eventual thresholds for the LOR categories are determined with executive and TAM input such that the categories reflect the agency's risk tolerance. Similar to LOS for maintenance planning, each agency can have different expectations for traffic service levels on roadways; however, in general a grade of A will be understood to indicate a favorable condition when compared with grades such as C, D, or F.

As an example of a more advanced LOR categorization process, both the Alaska Department of Transportation and Public Facilities (Alaska DOT&PF) and the Colorado DOT have started including LOR categories as a means of reporting performance risk from geotechnical assets. At these agencies, the LOR categories are based on risk scores that are determined from an estimate of risk exposure magnitude that incorporates a monetized risk cost. At these agencies, the grades assigned to the LOR categories are:

A = less than $1,000 annual asset risk exposure,
B = $1,000 to $5,000 annual asset risk exposure,
C = $5,000 to $50,000 annual asset risk exposure,
D = $50,000 to $100,000 annual asset risk exposure, and
F = greater than $100,000 annual asset risk exposure.

The estimation of a monetized risk exposure requires more input data than what has been incorporated into the GAM Planner provided with this manual. These additional data include traffic volumes and estimated costs for safety impact, which could be incorporated into a maturing GAM program and inventory if stakeholder feedback indicates there would be benefit in doing so. Thus, incorporating a monetized risk exposure could be a process improvement step considered by agencies implementing GAM.

Regardless of the underlying numerical values used to create the grading scale, the intent of the LOR categories is to indicate a magnitude estimate of the risk exposure for an agency that owns and manages geotechnical assets whether or not a formal GAM plan has been created. The LOR category values can be selected based on the agency's tolerance for various risk consequence levels. For example, an agency could decide to increase the LOR category thresholds presented in the examples above based on a higher tolerance for risk from geotechnical assets. Alternatively, the agency could establish performance objectives that "accept" or work toward grades of A through C but do not accept grades of D through F, or could even accept grades of A through D, but not F.

Through this process, an agency executive or TAM manager can contribute to geotechnical asset performance goal-setting based on their perspective of tolerable risks from a geotechnical asset class and their measurable impacts on TAM objectives. Using the LOR matrix examples in Appendix D, or developing a similar matrix for the agency, the geotechnical asset manager can quickly and simply communicate magnitudes of risk to performance objectives. This enabling step is preferred by non-geo-professionals to having to communicate and educate stakeholders on the separate technical performance measures that exist for each asset type.

LOR can have value in an overall TAM program that focuses on risk-based processes across all asset types and can support separate risk management plans, should those exist. For example, the LOR measure could be applied to other asset classes that measure risk to TAM performance objectives, and this would facilitate cross-asset management planning. Such an application is beyond the scope of this implementation plan, but the geo-professional is encouraged to pursue this approach with TAM staff who may see the value in cross-asset performance analysis and management of other ancillary assets. For example, a transportation asset manager could compare LOR scores for differing asset classes to evaluate performance risks on similar scales. Additionally, the geographic distribution in LOR could be compared across all assets to identify concentrations of performance risk and opportunities to examine the potential for a combined investment strategy that may demonstrate improvement to several asset groups while resulting in a more favorable investment scenario. This approach is discussed in more detail in Chapter 8.

As GAM implementation occurs across the country, use of the LOR metric also could enable states to report on current performance to FHWA and other external stakeholders using a comparable metric.

Measures for Customers and Users

In addition to the proposed executive LOR performance measure, asset management implementation can include other outward- or inward-facing performance measures deemed valuable to technical staff, other asset owners, internal stakeholders, and external customers or users. As discussed previously, criteria used to craft asset performance measures include metrics that can be understood by both technical and non-technical audiences, can be implemented with current resources (e.g., use currently available data and established information systems), and should reflect characteristics that the agency can influence.

Whether tracking the impacts of program investments or O&M improvements, monitoring system performance, or gauging an agency's effectiveness, selecting measures that connect to customers and users is recommended as a best-practice process improvement that can increase the maturity level of the asset management process. Performance goals that can align agency interests with those of transportation stakeholders and users include:

- More effectively achieving the agency's long-range and policy goals and objectives;
- Greater accountability to customers and users;
- Demonstrating increased organizational efficiency;

- Keeping agency staff focused on priorities that mean something to customers and users;
- Demonstrating tangible results of program investments; and
- Demonstrating improvements to business processes by conveying a better understanding of management's goals and actions.

Based on these interests, a recommended performance measure that can connect geotechnical assets to stakeholders and users would be annual delay and closure time resulting from geotechnical asset–related disruptions. This performance measure is similar to the measurement of train delay times in the Network Rail GAM program. Although reducing delay and closure times to zero may be an aspirational measure that is difficult to capture in some agencies, establishing and monitoring the measure communicates an easily understandable performance aspect to users. The measure also can be demonstrably influenced by investment levels. Currently, including this performance measure may not be feasible at some agencies, but the potential of including it should be continually reevaluated as technological advancements improve the accuracy of continuous traffic volume measurement.

Further, the presence alone of thoroughly developed and meaningful performance measures may not be enough to connect the agency to stakeholders, including customers and users. The clear and convincing presentation of this information is paramount to the acceptance of the data and meaning by customers and users. The Washington State DOT's successful performance management program has adopted a "performance journalism" approach to communicating performance on its "Gray Notebook" webpage (Washington State DOT 2017). The approach combines quantitative reporting and narrative storytelling, and is based on seven principles: good stories, writing, data, graphics, presentation, quality control, and timing.

Additional discussion and consideration of approaches to developing agency-specific performance criteria in concert with TAM planning is provided in Chapter 8.

Introduction to Technical Measurement

In addition to executive- and customer-oriented performance measures, an agency's GAM implementation can include internal, technical measures that relate to the various geotechnical performance characteristics of an asset. These technical measures should be considered as secondary measures that support the efforts of the geotechnical program and/or asset manager to align the primary measures, such as LOR, with the agency's overarching TAM and performance plans. These technical measures also can improve informed decision-making as changes with time and trend analyses contribute toward life-cycle investment plans.

Although technical measures can be beneficial to the asset management processes and data, the collection and reporting of a wide range of technical measures is not essential at the start of GAM implementation. Rather, technical measures can be incorporated into process improvement steps as GAM matures within the agency and the relevancy of the measures to business performance becomes evident. The early adoption of several technical measures actually could result in an over-allocation (or even a misallocation) of resources, should those measures prove redundant or irrelevant to the support of the primary objective and measurements.

The input criteria developed for the GAM Planner prescribe simple technical measures that could be used at initiation of implementation. These measures are:

- 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.

Once implementation has started, feedback from stakeholders can guide selection of internal technical measures that are relevant to agency performance objectives and support the internal asset management process.

Inventory and Condition

Inventory and condition data can be managed successfully using commonly available spreadsheet software, and the need for proprietary software should not be viewed as a barrier to GAM implementation.

The inventory and condition step of the TAM process involves the collection and maintenance of asset data or knowledge that enable the other steps in the asset management process. The asset data will consist of both inventory characteristics and measures of condition. In general, inventory data consist of fixed or static information about the asset (e.g., location, size, age, or material type). The inventory also may incorporate other data that are associated with the asset (e.g., a carried traffic volume or a replacement cost). Condition data describe how the asset or components of the asset are performing (including poor performance) at a given time. Condition data will typically change with time.

Data collection to support the ongoing process of building inventory and monitoring condition can be time and cost intensive. As stated in the *International Infrastructure Management Manual* (IIMM), "a rule of thumb is often 80% of the data can be collected for half the cost of 100%. Seeking 100% coverage and accuracy may not be justified, except for the most critical assets" (IPWEA 2015). Accordingly, the investment in data collection and management should be compared against the level of detail required for decision support and any other benefits.

As with asset management maturity levels, GAM implementation can benefit from an approach that relies on varied levels of detail in the collection of inventory and condition data. This flexibility allows a DOT to collect only the data required for the level and complexity of decision-making. The DOT thus sidesteps two barriers to implementation: significant upfront investment and the burden of collecting a quantity of data that may or may not be used in the future. At the most basic level, inventory and condition data can be collected and maintained in simple spreadsheet registers that enable modeling, similar to the GAM Planner provided with this manual. As the level of GAM matures (and the benefits are justified), the DOT may eventually progress to using custom or proprietary software systems that include geo-reference visualization frameworks and integrate into other enterprise software systems.

One purpose of the objectives and measures step in TAM is to help an asset manager identify what level of data is needed to support measurement and decision-making that supports achievement of objectives. Decisions can be made at many different levels, including:

- Strategic decisions, which carry the greatest potential business impact, but also require the kinds of objective data that are most likely to be difficult to obtain and analyze;
- Management decisions, such as those relating to the replacement or upgrading of assets to better meet business objectives; and
- Operational decisions regarding actions involved with short-term control of maintenance and operational activities.

The data needed to support these decisions can come from both within and outside the organization. Data from within the organization may come from corporate information systems, active and archive project records, enterprise accounting systems, operational technology systems (such as traffic data), or anecdotal staff sources. External data can consist in various forms, ranging from proprietary, vendor-provided systems, outside stakeholder sources, and free, web-based programs, such as Google Earth.

Per the well-developed practices in the IIMM, a staged approach is the most practical process for data collection. Figure 4.3 presents the concept of staged data collection. This staged approach 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. As discussed in Power et al. (2012), a similar progression to data collection occurred with GAM implementation for Highways England (then called the UK Highways Agency). Within this staged data workflow, not all assets will necessary go to the final data-collection level, and reaching the most detailed data state occurs only where justified.

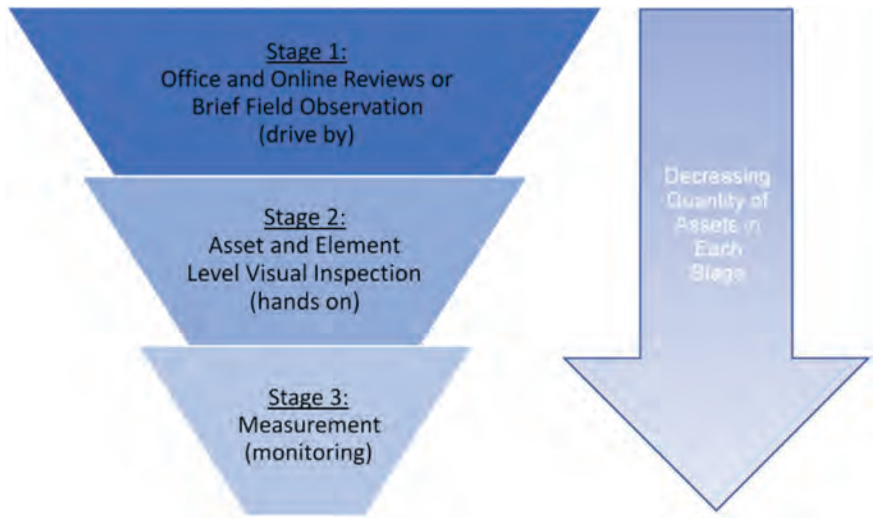


Figure 4.3. Staged approach for data collection in asset management.

For the experienced geo-professional adapting to asset management, this process is analogous to performing a desk review or brief field reconnaissance during the pre-environmental decision phase of a highway improvement project and then progressing to detailed subsurface investigations once final design needs are known and additional costs for data collection can be justified. Within an asset management framework, the geo-professional or asset manager may use online and existing records (Stage 1) to build the inventory that supports the GAM Planner, as discussed in Part B of this manual. As the GAM program matures and gains support, additional (Stage 2) data collection may occur for assets with lower LOR grades (e.g., LOR grade of C or below), with only a few of the most critical assets advancing to intensive (Stage 3) data collection and monitoring.

Performance Gaps

Performance Gaps: In relation to objectives, the differences between how an asset currently functions and the desired performance level.

In asset management, performance gaps are the difference between current and desired or planned performance. For an agency starting GAM at a simple level of maturity, performance gaps may evolve as knowledge is gained about the current asset performance. Thus, a reasonable performance gap to communicate to executives would involve recommended approaches to address the performance gap associated with a developing inventory. As the GAM program's maturity level increases, an analysis of performance gaps (i.e., a *gap analysis*) can be performed to define the performance measure targets for assets, project and model future conditions, and compare investment scenarios for closing performance gaps.

Investment Concepts and Life-Cycle Planning for Geotechnical Assets

A key component of TAM is the consideration of the asset life-cycle through the phases of design, construction, O&M, and decommissioning. Asset management processes that include evaluation of the asset life-cycle include:

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

Figure 4.4 illustrates the phases of a transportation asset life-cycle. By adopting a life-cycle approach for geotechnical assets, geo-professionals and decision-makers will need to consider all the costs of the asset and not just the initial design and construction costs, which is the current, legacy-based approach at many agencies. The final life-cycle phase of disposal or decommissioning is not illustrated in Figure 4.4 because this phase is not common for geotechnical assets. Instead, geotechnical assets typically are managed as an "ongoing concern" that the agency will continue to manage for the foreseeable future. That said, situations can occur in which asset disposal could be a necessary consideration at the planning stage.

As components of life-cycle planning, risk and risk management are discussed in expanded detail in Chapter 7. Figure 4.4 is an introduction to the life-cycle planning and financial aspects of asset management that traditionally are not incorporated into the design phase of geotechnical engineering.

Life-Cycle Planning

In recently adopted asset management requirements (23 CFR 515), 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." Thus, the life-cycle cost of an asset is the total cost of ownership throughout the life of the asset, including planning and design, construction and project delivery, and O&M. Life-cycle cost also is sometimes termed the *whole-life cost.* When considering life-cycle topics in asset management, it is important that the life-cycle analysis period for individual assets align with expected life-cycle durations of the system. Figure 4.5 illustrates the concept of life-cycle cost. The figure illustrates the calculation of hypothetical life-cycle costs for four distinct geotechnical assets, each plotted as a different series. It shows time on the horizontal axis and the accumulated cost for the asset on the vertical axis. In these examples, the life-cycle cost is largely driven by costs incurred during planning, design, and construction, but costs continue to rise following these phases as a result of preservation actions.

Ideally a GAM program would include development of a life-cycle plan for each type of geotechnical asset. The process of developing such a plan is termed *life-cycle planning.* This term has been defined by FHWA as "a process to estimate the cost of managing an asset class,

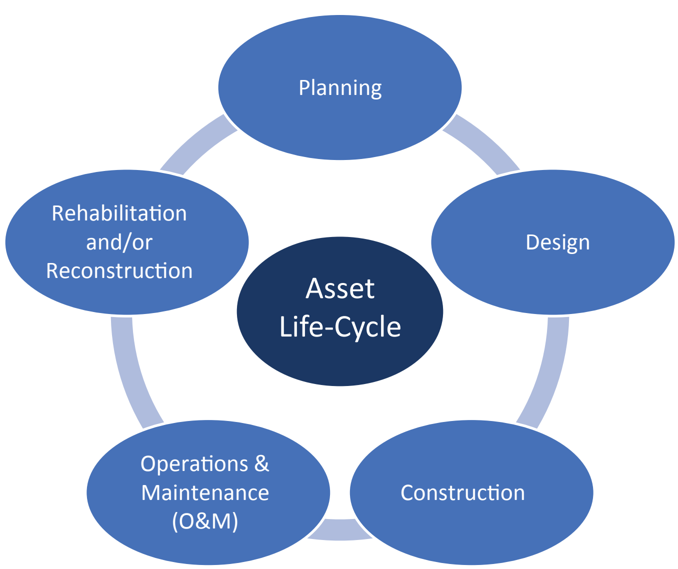


Figure 4.4. The asset life-cycle.

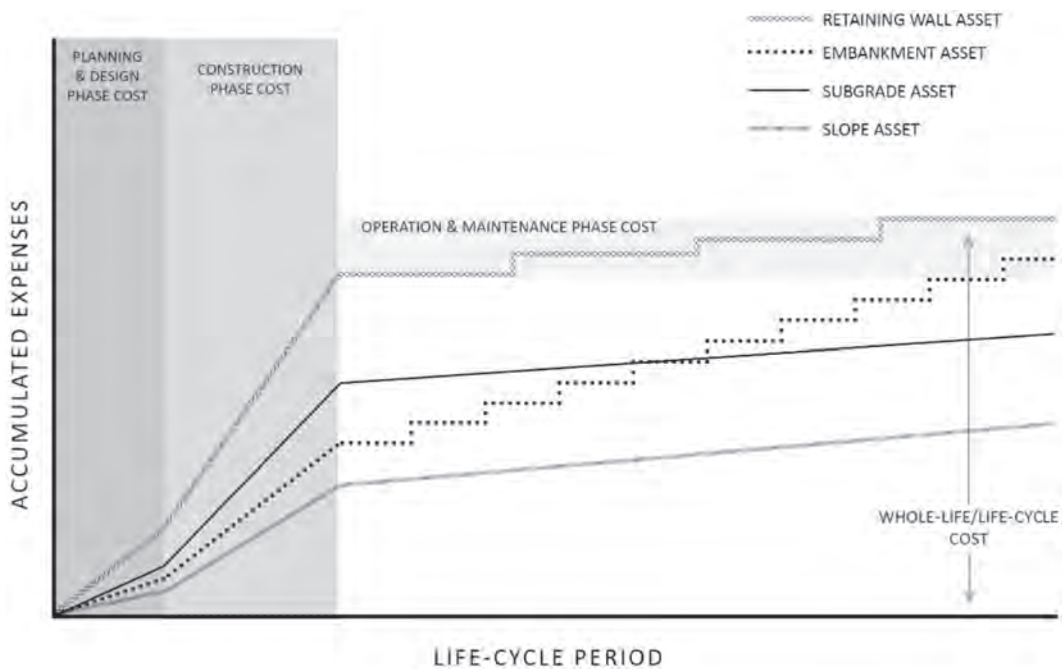


Figure 4.5. Conceptual life-cycle cost graph for geotechnical assets.

or asset sub-group over its whole life with consideration for minimizing cost while preserving or improving the condition." Typically, a life-cycle plan estimates the cost of constructing and maintaining an asset over time, and defines the treatments typically performed on the asset, when they are triggered, and their costs.

Here it is important to distinguish between life-cycle planning and the related process of *life-cycle cost analysis* (LCCA). LCCA is the process of evaluating the life-cycle costs of different project alternatives, and is often performed in the design phase of a project. Further discussion of LCCA is presented in Chapter 8.

An important step in developing a life-cycle plan is to define what treatments can be performed on an asset following its initial construction, the cost of each treatment, when the treatment may be performed, and what effect performing the treatment has on the asset. Basic treatment options for geotechnical assets, as defined in the GAM Planner, are:

- **Do Minimum:** The Do Minimum option essentially consists of performing only the minimum level of work to keep the asset in a condition that allows for traffic conveyance without performing actions that add or preserve life-cycle O&M value. To return to the car maintenance analogy, Do Minimum is equivalent to deferring replacement of worn tires and only replacing individual tires when they have deteriorated to the point that they can no longer function. The Do Minimum option defers actions until there is no choice but to do something to maintain a minimum level of operation.

  Do Minimum actions could involve removing rock and soil from the travel lanes below a slope asset after a rockfall event or applying leveling pavement layers to the roadway on an actively moving landslide within an embankment asset. Do Minimum actions typically are taken only when a mobility interruption or safety impact has occurred and immediate action is required. As such, the Do Minimum option does not equate to a "no-cost" option for the asset owner; rather, it is best considered a "hands off" management approach that typically will result in accelerated deterioration and/or service interruptions.

The GAM Planner, which is detailed in Appendix A, can be used to support development of the life-cycle plan for a geotechnical asset. This spreadsheet tool models a program of assets using a Markov Decision Process that is similar to the approach used in many other asset management systems. To minimize life-cycle costs using the four treatment options, the model solves for the optimal life-cycle policy, or the optimal set of treatments to perform as a function of the asset's O&M condition and risk level.

- **Maintain:** The Maintain option focuses on keeping the asset in a state of near-continuous operation and involves actions that enable the asset to continue functioning as intended in design. This option is analogous to changing the oil and tires on a car on the required schedule. The Maintain option thus differs from the Do Minimum approach by (1) involving a routine, or schedule, of planned actions, and (2) seeking to maintain the asset at the highest possible functional level for the longest amount of time. With respect to geotechnical assets, planned maintenance actions may include:
  - Cleaning the roadside ditch to maintain the design condition below a slope asset that generates rockfall;
  - Managing the vegetation on an embankment or slope asset to arrest or prevent erosion that will lead to accelerated deterioration and drainage problems;
  - Conducting minor earthwork activities to repair an erosion scar in an embankment or slope asset;
  - Cleaning of drainage features on a wall or embankment asset to ensure drainage flow is as designed;
  - Conducting limited slope asset scaling activities to reduce a specific rockfall threat exposed through erosion;
  - Patching of pavement or other structural cracking associated with geotechnical asset performance;
  - Mitigating rodent damage on an embankment to prevent surface erosion and undermining below a roadway; and/or
  - Occasionally, element replacement (e.g., precast blocks) or preservation actions such as crack sealing, removal of vegetation, or rinsing of accumulated salts on a retaining wall.
  - Generally, these treatments are frequent, short, and lower-cost activities that may be considered routine maintenance on an approximate annual basis.

  As part of the GAM implementation process, the geo- or TAM professionals are encouraged to meet with the agency staff in charge of maintenance programs to understand what activities may or may not be completed in the routine maintenance of geotechnical assets.
- **Rehabilitate:** Rehabilitation treatments consist of any actions taken to improve the operational and maintenance reliability of an asset to a higher performance level. Work performed under the Rehabilitate treatment option can include:
  - Installing groundwater drains or other drainage features into a geotechnical asset with the design intent of increasing reliability and reducing movement of the asset;
  - Installing anchored or draped mesh on a slope asset to reduce the quantity of debris reaching road or catchment ditches, resulting in lower risk of operational disruptions;
  - Re-grading an embankment asset or placing buttress fill on a slope to create a more stable condition;
  - Excavating larger catchment ditches, conducting heavy scaling and slope modifications, and/or installing barriers below a slope asset to reduce the quantity of rock reaching the roadway over a period of several years;
  - Over-excavating and re-compacting of a subgrade asset as part of a pavement rehabilitation project with the intent of creating improved pavement reliability in the future; and
  - Replacing or improving a significant quantity of retaining-wall facing elements to improve the overall condition and expected life of the wall.

In addition to improving the annual operation and maintenance performance for a geotechnical asset (i.e., providing improved reliability), rehabilitation activities typically will extend the performance improvements over a portion of the life-cycle, ideally for a duration greater than 10 years.

- **Reconstruct (or Renew):** The Reconstruct (or Renew) treatment option consists of actions that result in a significant asset performance improvement to a new or nearly new condition, effectively resetting the asset service life to a minimum of 50 to 75 years. Examples of actions taken for the Reconstruct option include:
  - Rebuilding a retaining wall to meet a current design standard with a long service life;
  - Realigning a roadway to add long-term functioning retaining-wall assets that improve mobility and safety for the traveling public while minimizing operational and maintenance impacts;
  - Reconstructing a distressed embankment or subgrade asset with a reliable engineered fill that is intended to function over a longer or specified service life; and
  - Placing ground reinforcements with a long service life, such as ground anchors, to stabilize an embankment or slope asset to a greater reliability or factor of safety.
- **Restore:** The Restore treatment option is triggered by the model in the GAM Planner if an asset reaches an O&M Condition level of 5, indicating asset failure. The user specifies the resulting state in the event this treatment is triggered, as well as the agency and user costs of the treatment. Examples of actions taken for the Restore treatment option may include:
  - Constructing a new (replacement) asset of the same type as the failed asset;
  - Constructing a new asset that changes or improves upon the design or function of the failed asset;
  - Using or developing an alternative route or bypass that can safely or more efficiently move traffic without rebuilding at the site of the failed asset.

Financial Plans and Investment Strategies

In asset management, a *financial plan* is a **long-term projection** (i.e., covering several years) of both expected and desired funding to achieve the plan objectives. The *investment strategies* consider the allocation of resources within the plan, such as where funding will be directed. The financial plan should not be discounted during GAM implementation because it provides decision-makers an easily understood status of the current and future impacts and needs of geotechnical assets. Even with a small investment commitment to GAM, investment strategies can be executed that, at minimum, will describe which assets are treated and when within the planning cycle.

The *investment strategy* portion of an asset management plan describes strategies necessary to sustain, maintain, and make necessary improvements to assets. The investment strategies can be considered as the tactical inputs that make up the long-term financial plan.

A key input in developing investment strategies is a life-cycle plan for each asset type that describes what investments ideally should be made over an asset's life-cycle. If projected funds support performing the treatments described in the life-cycle plan, then the agency proceeds with creating a program of work based on those recommendations. However, it may be the case that projected resources are less than what is required to support the life-cycle plan. In this case, developing the financial plan requires consideration of what investments will be made and what will be deferred.

Asset management investments, like business or personal financial investments, should be evaluated based on the relative benefits that result from the available alternatives. This evaluation of alternatives will guide the geo- and TAM professionals through an informed process.

Although it can be time-consuming to develop asset financial plans and investment strategies, there are many benefits to their development. One benefit is that the financial plan and investment strategy can help demonstrate to executives and other stakeholders that the correct decisions are being made from an economic standpoint. Without an investment analysis, the potential exists for the wrong choices to be made in the asset management plan, or for treatment of newly constructed assets to be unintentionally overlooked. For an agency that is reliant on public funds, analysis of the benefits and ROI for the investment options that make up the financial plan is essential in showing good financial stewardship of the public dollar.

Consideration of Life-Cycle Costs in Design

Considering life-cycle cost is a key issue in the design phase. The life-cycle concept illustrated in Figure 4.5 can help better quantify future asset cost when performing a detailed LCCA during project design. In manufacturing industries, a well-documented observation is that up to 80 percent of the life-cycle cost is "locked in" by design decisions (Hurst 1999). A similar condition has been acknowledged in the life-cycle management of wastewater facilities (WERF 2018). With respect to geotechnical assets, this trend may be similar and will become evident with time as more agencies implement GAM.

The consequence of fixing life-cycle costs through design decisions can be conceptually illustrated for geotechnical assets through the following example: An agency is widening a road that will require cutting into a slope. For each potential slope angle, there will be a corresponding maintenance need and potential safety impact. A steeper slope inclination, although typically cheaper to construct, will also erode more quickly and may generate rockfall or other debris events that require frequent responses from maintenance staff to remove accumulated debris. Conversely, a shallower slope inclination may have a greater initial cost but also may be built in a way that has little to no maintenance needs. In this scenario, the agency can evaluate the whole-life cost of each option over the life-cycle of the asset to determine which option is preferred from an economic perspective.

Demonstrating the ROI of GAM

Having established how to apply asset management concepts to determine how best to manage geotechnical assets over their life-cycle to minimize costs and maximize benefits, a basic challenge remains: namely, that to achieve the benefits of an asset management approach, it is necessary to make investments in staff time, data collection, and systems to support an asset management approach. Further investments are needed to perform the recommended treatments to put asset management concepts into practice. For agencies in the early stages of implementing GAM and attempting to justify the required investment to do so, this can create a chicken-or-egg problem. The premise of GAM is that it will help an agency reduce life-cycle costs over time, but one cannot demonstrate these savings without some level of initial investment.

Determining the return on GAM investment requires calculation of benefits over time in comparison to upfront and ongoing costs. At the very least, a breakeven analysis can demonstrate the amount of benefits that would be needed to cover the costs of including GAM in a TAM program. A breakeven analysis may provide the justification needed to validate investment in GAM when more exact quantification methods are not possible. *NCHRP Research Report 866: Return on Investment in Transportation Asset Management Systems and Practices* (Spy Pond Partners, HDR, and Cohen 2018) offers detailed guidance on demonstrating ROI for implementing a new system or upgrading an existing system. *NCHRP Research Report 866* does not specifically address GAM implementation, but the concepts can be applied to adding a GAM program to a TAM system. The report describes that, for public agencies, ROI is best understood as a form of benefit-cost analysis. Thus, the measures for communicating ROI include those common to benefit-cost analysis, such as net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR).

NCHRP Research Report 866 includes several case studies that profile examples of the costs and benefits realized by agencies implementing pavement, bridge, and maintenance management systems, concluding that the returns for these systems are quite high, particularly when implementation of a new system or process results in changes in capital investments. The report is accompanied by a spreadsheet-based tool for calculating the ROI of an asset management system or process investment. One of the report appendices describes the pilot application of the ROI framework for evaluating an agency's investment in improving its data on culverts. This example analysis is illustrative of how an agency might evaluate investing in GAM. In this pilot, investing in a new asset management system was predicted to have a BCR of approximately 1.8, with the major benefit of investment being a reduction in unplanned closures due to culvert collapse. Figure 4.6 shows an example of the results generated by the ROI calculation tool for this pilot.

Overall Benefits of GAM

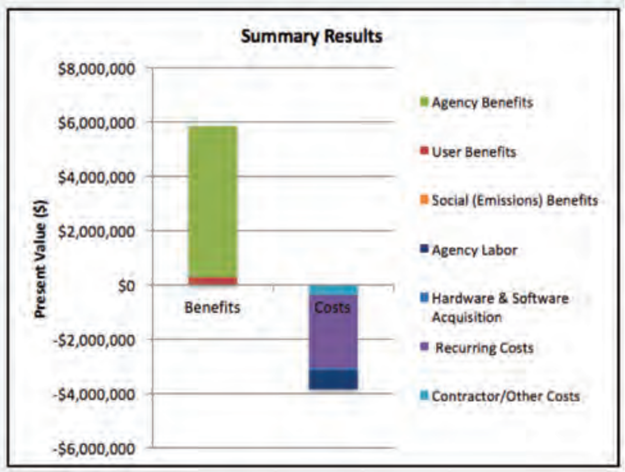
The ROI of including GAM in a TAM program might hinge on the wide-ranging GAM benefits and agency-specific implementation approaches presented in Chapter 8 of this manual. The majority of the existing research on TAM discusses agency benefits in terms of changes in

NCHRP Project 20-100 ROI Calculator
Summary Results last modified: 3/16

Summary Measures

Description		Undiscounted	Present Value
Total Benefits ($)	Agency Benefits	$7,000,000	$5,584,808
	User Benefits	$322,778	$257,522
	Social (Emissions) Benefits	$5,823	$4,646
	Total	$7,328,602	$5,846,976
Total Costs ($)	Agency Labor	$719,958	$615,400
	Hardware & Software Acquisition	$100,000	$91,096
	Recurring Costs	$2,700,000	$2,277,540
	Contractor Costs	$350,000	$295,237
	Other Costs	$0	$0
	Total	$3,869,958	$3,279,272

	Value
Net Present Value ($)	$2,567,704
Benefit/Cost Ratio	1.78
Internal Rate of Return	40.05%
Payback Period (years)	4

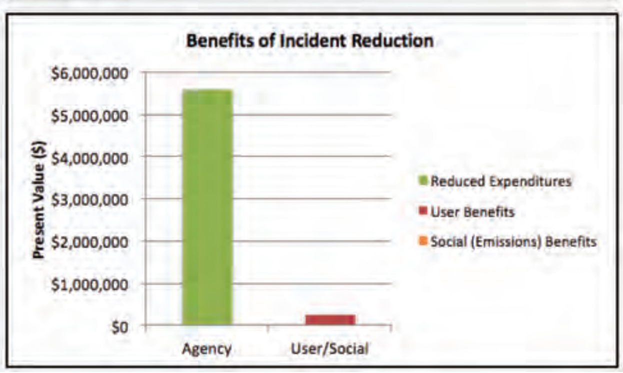


Agency, User and Social Benefits of Incident Reduction ($)

Description	Undiscounted	Present Value
Reduced Agency Expenditures	$7,000,000	$5,584,808
User Benefits	$322,778	$257,522
Emissions Benefits	$5,823	$4,646

Agency, User and Social Benefits Predicted Using HERS-ST ($)

Description	Undiscounted	Present Value
Reduced Agency Expenditures	$0	$0
User Benefits	$0	$0
Reduced Maintenance Expenditures	$0	$0
Emissions Benefits	$0	$0



Source: NCHRP Research Report 866, Figure F-7

Figure 4.6. Example ROI calculation for an asset management system investment.

O&M cost or changes in data collection, processing cost, and analysis cost. Through this lens, TAM ROI estimation typically considers benefits and costs in relation to specific benefits for the implementing transportation agency itself, to asset users, and to the general public. These categories are useful for grouping benefits when comparing TAM programs with, and without, GAM. When making comparisons between a non-GAM TAM program base case versus a GAM-inclusive TAM program investment case, the common TAM benefits summarized in Table 4.1 are useful factors from which to evaluate ROI. Similarly, typical TAM costs are noted in Table 4.2.

Documenting the Risk of Not Implementing GAM

A carefully crafted benefit-cost analysis will account for the risk-mitigating benefits of GAM to other (non-geotechnical) transportation assets. This consideration is necessary to account for the opportunity costs of not implementing a GAM program. Not implementing GAM means that the risks of damage from unmanaged geotechnical assets is passed along to other transportation assets. For example, the Colorado DOT estimates that the annualized average economic impact of closures to Hanging Lake Tunnel due to rockfalls is $7.1 million.

For a similar analysis, a transportation agency could review the impacts of major geotechnical asset–related events in the agency or could extrapolate an estimate of the cost for routine maintenance work activities to begin to communicate the economic impacts from the current management approaches. Alternatively, the GAM Planner can provide baseline estimates of the current LOR and financial impacts associated with assets in the inventory. If it is not possible to

Table 4.1. Potential benefits of TAM investments by stakeholder group.

Direct and Indirect Agency Cost Savings
• Staff time savings from improved data collection and accessibility; • Cost savings from the optimization of investment strategies; • Lower costs from reductions in failure risks for critical assets (e.g., bridges); • Avoided outlays for legacy systems, including hardware maintenance and software updates; • Enhanced reputation and level of public trust gained through information-sharing; • Delayed capital expenditures due to increased asset life (residual value of assets); • Worker safety (due to bundling of projects); and • Residual value (remaining asset value at end of analysis period).
User Cost Savings
• Vehicle operating cost savings (e.g., reduced wear and tear, and reduced fuel consumption) from smoother pavements or more direct routing (e.g., with bridge availability); • Travel time savings; • Accelerated improvements from timely asset management decisions or increased capacity to program maintenance and rehabilitation projects due to cost efficiency; • Reduced work zone delays; and • Safety benefits.
Benefits to the General Public (Social Benefits)
• Emission cost savings from smoother pavements or more direct routing; and • Reduced noise generation.

Source: NCHRP Research Report 866

Table 4.2. Life-cycle costs of TAM investments.

Non-Recurring Costs
• Hardware and software acquisition; • Installation; • Training; • Decommissioning; and • Shifts in investments (e.g., delays in some investments to perform additional preservation or other work).
Recurring Costs
• Maintenance and repair; • Operating expenses; • Software maintenance costs; • Software updates; and • Data collection and data analysis costs.

Source: NCHRP Research Report 866

capture specific maintenance and/or event data costs, agencies could use estimates generated in the GAM Planner as pro-forma estimates.

If geotechnical assets are managed, agencies can reduce the risk of unpredictable events associated with those assets impacting other transportation assets. For unmanaged geotechnical assets, however, catastrophic events may appear as unpredictable or unpreventable asset impacts even if a TAM system is in use. Absent a GAM system, the latter situation sets agencies up to respond to these events on a case-by-case basis rather than by managing geotechnical asset needs. The presence of a GAM system works in concert with the TAM system, allowing agencies to proactively direct maintenance and other resources in accordance with well-established agency objectives and strategies, thereby reducing or eliminating surprise events and potentially catastrophic impacts.

Cross-Asset Analysis

In many agencies, a motivating factor for implementing GAM is the increasing interest in determining how best to allocate resources among various assets and using structured processes to make such cross-asset investment decisions. Various approaches have been developed for supporting cross-asset investment decisions, and this area is rapidly evolving. As agencies shift toward placing increasing emphasis on performance-based approaches, the costs continue to decline for obtaining, storing and analyzing the requisite data to support a cross-asset approach.

NCHRP Report 806: Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance (Maggiore et al. 2015) presents a framework for making cross-asset decisions. Research is currently underway to implement the results of presented in *NCHRP Report 806* and further develop cross-asset decision-making approaches. Key considerations for geotechnical asset managers who are considering or involved in efforts to support cross-asset data include:

- **Data Quality:** Good data is essential for obtaining the best results in a cross-asset analysis. Ideally, the analysis should use projections of life-cycle costs generated by tools such as the GAM Planner rather than subjective scores assigned by decision-makers.

- **Risk:** Incorporation of risk can help best make the case for investing in geotechnical assets. The LOR grade and other measures in the GAM Planner consider the consequences of asset risks, and can help best make the case for needed GAM investment by informing stakeholders of the magnitude of exposure and acceptance.
- **Assumptions in Prioritization:** Approaches to cross-asset prioritization often make simplifying assumptions that may understate the importance of GAM investments. A frequent, major assumption is that if no investment is made, then no cost is incurred. In the case of geotechnical assets, however, significant costs can be associated with the Do Minimum treatment option of keeping an asset in service regardless of whether additional investments are programmed for the asset. It is important to consider these costs in any analysis. Instead of a no-cost option, it may be more accurate to view the Do Minimum option as a deferred-cost option.

CHAPTER 5

Adapting TAM Practices for GAM

Introduction

Chapter 4 introduced the steps and high-level TAM processes that are critical to implementing GAM in a framework that connects with the broader practice of asset management. This connection to TAM increases the potential of both successful GAM and acceptance by executive and planning professionals, who likely understand asset management practices more than the technical aspects of geotechnical assets.

In addition to connecting GAM to processes, the potential for GAM implementation success can be improved by adapting enabling TAM practices that give further credibility among non-technical stakeholders. These practices include consistent use of asset terminology in communication and data and data management techniques. The discussion in this chapter expands on these topics.

Taxonomy of Geotechnical Assets

A taxonomy is a means for classifying and describing the hierarchical order or relationships for the components of a system. Commonly used in subjects like biology, with its classification of plant and animal kingdoms, *taxonomy* also is a term used in business and other fields (Oxford University Press 2014). Within the practice of geotechnical engineering, the AASHTO soil classification system is another use of a taxonomy.

The practice of TAM also uses a taxonomy to help enable common understanding among professionals and maintain consistency in and across asset management processes and data. The chances of a successful GAM implementation improve when it uses a taxonomy that is consistent with and can integrate into the broader TAM program and taxonomy. This point is of particular importance for geotechnical assets because, even though definitions for specific geotechnical assets have been discussed for more than 10 years, the practice of GAM is starting at a simple level of maturity and has limited examples of established taxonomies (or classification systems). As the GAM program matures, benefits will accrue to integrating GAM with a broader TAM program, and the integration will be much easier to achieve if the taxonomy adopted at the outset of the GAM program has been chosen and kept consistent with this integration in mind.

Regardless of the asset type, consistent classification, definitions, and hierarchical order are necessary to enable effective asset management and the development of best practices that are shared across DOTs. Maintaining such a taxonomy will help communicate GAM inputs and outcomes to both internal and external stakeholders. Further, the successful engagement of executive-level stakeholders and decision-makers throughout the asset management process relies on the ability of these individuals to quickly understand complex details. Use of a common taxonomy for assets can enable this to occur.

The taxonomy presented in this manual is based on guidance from Anderson et al. (2016), who researched and presented a geotechnical taxonomy for transportation infrastructure assets with the goal to facilitate communication and advancement in GAM and TAM. This taxonomy is based on practical definitions and distinctions based on the state of practice with TAM and the requirements of the MAP-21 legislation. The proposed taxonomy also resembles the general GAM taxonomy used for several years by Highways England and Network Rail, which means there are opportunities for GAM implementation in the United States to connect with international practice as well. As noted by Anderson et al. (2016), the purpose of the proposed taxonomy was to clarify language and ideas so that geotechnical engineers, other disciplines, and asset managers can communicate effectively both within and across organizations.

Introduction of a GAM Taxonomy

Institutional geotechnical knowledge, geotechnical data, and various geotechnical infrastructure components all have importance in geotechnical engineering and contribute value to a highway agency. Each of these geotechnical items could be considered "geotechnical assets" in a broad sense, but they have differing functions in the practices of geotechnical engineering and TAM.

The principles and terminology of the recommended GAM taxonomy discussed in this section are presented in Figure 5.1. With regard to communication, the taxonomy is intended to

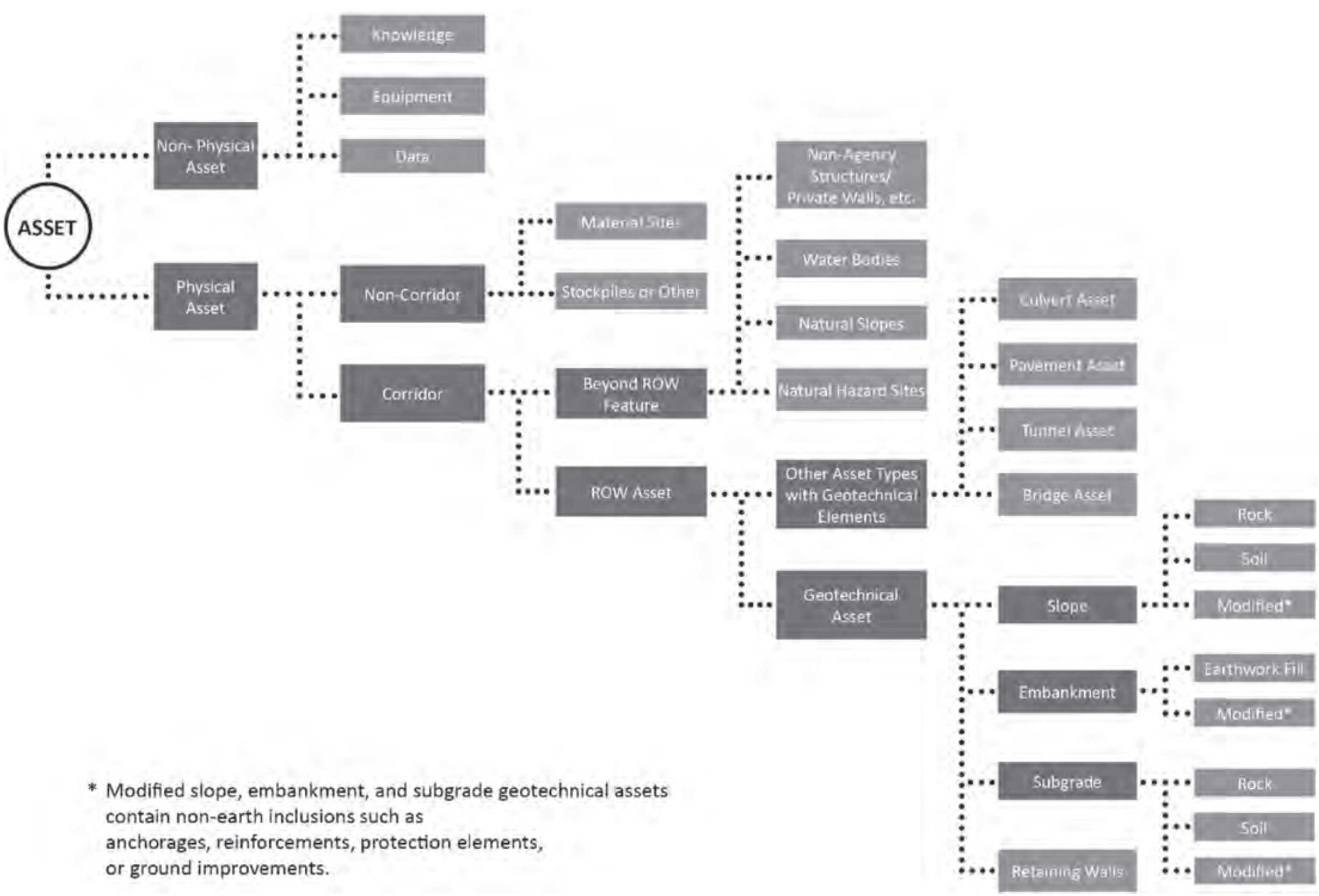


Figure 5.1. ***Proposed geotechnical asset taxonomy (modified from Anderson et al. 2016).***

function similarly to the AASHTO soil classifications, which enable consistent communication and engineering practices in geotechnical design and construction both within single agencies and between domestic and international agencies and stakeholders.

Adopting the taxonomy presented by Anderson et al. (2016), this manual defines geotechnical assets as *physical assets within the ROW that are an integral part of a transportation corridor or system.* As introduced in Chapter 2 and briefly discussed in Chapter 4, geotechnical assets are considered as having four types: embankments, slopes, retaining walls, and subgrades. Within TAM, other assets (e.g., bridges and pavements) make up other managed asset classes. The balance of this chapter further discusses the formulation and concepts of the taxonomy presented in Figure 5.1.

Aligning with Other Assets in TAM

A key process for enabling GAM implementation is the alignment of definitions within the GAM taxonomy with definitions used in other asset management taxonomies. Without this alignment, communication from the geo-professional in the TAM process may be misunderstood or, worse, ignored. Thus, a successful implementation process is one that will connect with existing systems versus attempting to redefine and persuade the managers of existing asset management systems to change.

Consistency in Asset Definition

The AASHTO *TAM Guide* (2011) glossary entry for *asset* reads as follows:

> Asset—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 surface, streetlight.

The first and third parts of the three-part AASHTO definition apply to physical infrastructure assets to which the TAM steps discussed in this manual can be applied. The second part of this definition includes other kinds of assets such as knowledge, data, and equipment. This distinction is shown by the proposed taxonomy's first split in hierarchical relationships: physical and non-physical assets (see Figure 5.1).

A similar distinction can be seen when using the ISO 55000 asset definition (first presented in Chapter 3) of an asset as an "item, thing or entity that has potential or actual value to an organization" and for which "value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities."

A *physical* asset typically will have *tangible* value, as provided for in the ISO definition. The physical assets of a transportation system are distinguishable from the non-physical assets such as digital data, property easements, institutional knowledge, and even the outward reputation of an agency. The latter assets are not components of the physical transportation infrastructure, and their value is *intangible*. A similar distinction can be made for material items such as drilling or laboratory equipment; although these items are physical assets, they are not specifically components of the physical transportation infrastructure system that is evident to the user, so their value can be considered intangible. Although such equipment assets are not considered as candidates for GAM in this implementation manual, there is value in managing both intangible physical (non-infrastructure) and non-physical assets through equipment maintenance and replacement plans and data management systems.

The most visible physical assets are those that form a part of the highway infrastructure. As presented by Anderson et al. (2016), the adjective "geotechnical" means the asset is composed of earth (soil and rock), pertains to earth, or its performance is achieved through the earth's interaction with a structure or inclusion. The geotechnical assets that can and should be part of a TAM plan are part of this grouping, and the discussion of taxonomy follows this branch in the taxonomy (see Figure 5.1).

Some geotechnical assets, as well as assets such as bridges and tunnels, can involve non-earth modifications, improvements, or inclusions (e.g., steel anchorages and reinforcement, geosynthetic grids and fabrics, and concrete or other ground improvements) that are a distinguishing trait. This distinction appears later in the hierarchical GAM taxonomy under the term *modified* (see Figure 5.1). Among geotechnical assets in the Network Rail system, these inclusions are identified as local support to the geotechnical asset; thus, the basis for the distinction in the taxonomy is supported by several years of applied GAM in the United Kingdom.

Aligning Definitions to TAM Taxonomy

The practice of TAM has matured through several decades of applied management for critical assets such as bridges and pavements. Within each existing program, the definitions that comprise the respective taxonomies have become commonly accepted with well-understood meanings within and among agencies. Where applicable, these terms are defined and incorporated into this implementation manual and summarized in the glossary. The following additional terms also are introduced based on the potential for confusion among asset managers when defining the GAM taxonomy. The geo-professional is therefore encouraged to become familiar with and use the following terms in a consistent context when communicating with other asset managers:

- **Element:** The term *element* has a usage within the taxonomy for bridge asset management. For example, the FHWA Specification for the National Bridge Inventory (FHWA 2014c) provides the framework for the inventory and assessment of common bridge elements to enable consistency for element identification, quantity measurement, and condition state assessment. Within the practice of bridge inspection, elements are items that can be visually observed, measured, and evaluated on the basis of condition. For geotechnical assets following this taxonomy, elements could include retaining-wall facing systems, permanent erosion controls on embankments, or draped rockfall mesh on slope assets.
- **Component:** Another commonly used term in bridge asset management, a *component* is typically considered a sub-category of the overall structure or asset. For example, in bridge asset management, components consist of items such as the bridge deck, superstructure, and substructure. For retaining-wall assets, a similar substructure component and superstructure component definition could be adopted within GAM implementation.
- **Segments/Management Sections:** In pavement management, data collection intervals often are standardized at intervals (or segments) of one-tenth (1/10) of a mile. The pavement management system then aggregates the segment data into management sections and performs analysis at this level.

Classifying Assets that Contribute to Performance

For a transportation agency with physical assets, most of these assets will be located within transportation corridors bounded by ROW or easement boundaries. The performance of these ROW corridors is critical to the agency's ability to satisfy executive-level objectives related to safety, mobility, and economic vitality. Thus, the assets within these corridors can be managed with a connection to the same executive-level performance objectives.

The earliest work in classifying geotechnical assets used the ROW corridor as a means for classifying assets. Sanford Bernhardt et al. (2003) identified geotechnical assets only as those that would be part of a corridor. They described geotechnical assets based on the interaction of the geotechnical assets with other types of assets and indicated that the boundaries often are blurred. In the period since the Sanford Bernhardt publication, TAM planning has clarified some of these boundaries by defining specific asset types, such as culverts. However, other assets of a geotechnical nature may need to be clarified for the GAM taxonomy applied within a transportation agency. The *location* of the asset relative to the corridor ROW and its connection to TAM performance objectives offers a means for making a further distinction in the taxonomy. For example, material sites, quarries, and earth material stockpiles are types of physical assets that may be owned by some agencies. These physical assets can be managed using similar GAM principles, as has been demonstrated by the GAM plan of the Alaska DOT&PF (Thompson 2017). For the purpose of the taxonomy presented in this manual, these physical assets are identified in a separate, non-ROW but owned asset category based on a function that has a less direct connection to GAM/TAM performance objectives in a transportation ROW corridor.

ROW Boundary Considerations

Assets in the ROW

Under existing asset management plans, most physical transportation assets are easily recognized as being within the ROW or easement boundaries of the agency. For example, pavement and bridge assets generally are understood to be contained within the ROW, and often occur with ample buffer space from boundaries. For assets that fall within the ROW boundary, the agency has control over how they are built, maintained, and managed, in addition to full access rights. Moreover, assets that stakeholders can clearly identify as being within the ROW involve little doubt about ownership and O&M responsibility.

Conversely, many geotechnical assets will extend right to the ROW boundary, or beyond. In some areas, it is not uncommon that the limits of the disturbed area associated with a slope or embankment asset will define the ROW or easement boundary for the agency. Additionally, retaining walls often have the function of minimizing ROW disturbance, so they may be constructed at or very near to a boundary. In each situation, potential exists for adverse performance consequences beyond the ROW from an agency-owned and agency-maintained asset. Figure 5.2 illustrates this concept by showing a DOT addressing an undermined retaining-wall asset at one edge of the ROW boundary with a slope asset in the background that constrains the other side of the ROW boundary. In this situation, both the wall asset and the slope asset were designed

Figure 5.2. Geotechnical assets forming the ROW boundary.

and constructed on or near ROW boundaries, and are now the maintenance responsibility of the agency.

An important consideration for geotechnical assets at the ROW boundary is that these assets can affect non-agency property, assets, and safety beyond the ROW.

Situations also can arise in which a retaining-wall asset exists on or near the ROW boundary and the ownership (and thus, asset management responsibility) is not known. Input from DOTs with operations in older urban areas suggests this is a common occurrence when the age of the infrastructure exceeds 100 years and uncertainties exist in property-ownership boundaries. In this situation, the DOT has assumed responsibility for the asset because of the potential for operational and safety impacts and the likelihood that a private owner may not have the resources for asset management of a complex infrastructure asset.

Given these complicating factors, the location of an asset relative to the ROW or other agency boundary creates another distinction in the taxonomy for GAM, as shown in Figure 5.1. In many cases, this distinction may be considered secondary, or even "not relevant," as the consequences to agency objectives often are similar regardless of asset location. However, the geotechnical asset manager is encouraged to make this distinction in GAM planning because the management options may differ depending on the asset's location relative to the agency boundaries.

Assets Beyond the ROW

Geotechnical assets located outside of the ROW or other boundary are not owned by the agency. These assets often consist of natural geologic slope hazards or other natural hazard features that may threaten other transportation assets or the agency's transportation objectives. As discussed in Chapter 3, the hazards associated with these features may include natural rockfalls from geologic outcrops, landslides that originate beyond the ROW or in natural ground, or debris flows that enter into the ROW. Assets beyond the ROW also can include private retaining walls, which are common in urban areas and can impact the performance of an agency roadway or other asset. Historically, many agencies have assumed the responsibility for mitigating and responding to events originating beyond the ROW boundary.

As these features are likely related to natural hazard sites, versus designed and constructed transportation assets, the deterioration and event details can differ from those of inside-the-ROW constructed assets. Moreover, access and ownership constraints may limit the agency's ability to manage these sites using the same design, maintenance, rehabilitation, or replacement treatment concepts applied to geotechnical assets in the ROW. Thus, the agency generally has limited control over the factors that contribute to deterioration or events from a beyond-the-ROW feature, but can address the consequences once they occur and affect operations and other assets within the ROW.

The Swiss PLANAT program demonstrates an innovative approach to managing natural hazard sites and risk outside of agency boundaries through shared treatment costs and benefit-cost modeling among multiple risk owners.

For example, a naturally occurring rock slide or debris flow that originates well beyond the agency boundary during a wet weather cycle but reaches the roadway would be considered a natural hazard event from a beyond-the-ROW geotechnical feature. In this situation, the agency did not design, construct, or maintain the geotechnical feature, but it is assuming responsibility for the consequences to the agency objectives when they are impacted. Conversely, a shoulder embankment slump, or a rockfall that originates from an agency-constructed and maintained embankment or slope during the same wet weather cycle, can be considered as an event originating from an agency geotechnical asset. In this latter case, the event or associated deterioration rate can be directly influenced by agency decisions during design, construction, and/or maintenance management activities. Thus, the agency has a greater ability to control both the likelihood of adverse events and to respond to consequences from the within-the-ROW geotechnical assets.

Given this ownership distinction, the GAM taxonomy presented in Figure 5.1 includes a separate category for geotechnical features or natural hazard sites that are beyond the ROW.

Even though these features or hazard sites are distinguished in the GAM taxonomy, an agency can choose whether to include them in the GAM inventory. The decision to include or not include such features may relate to the potential impacts from those beyond-the-ROW assets, the agency's options management, or the possibility of deferring those assets to other management programs. For example, geotechnical features beyond the ROW boundary also can be candidates for larger-scope risk and resilience strategies that address other external agency hazards, such as flooding, earthquake, or terror events. In this case, having an inventory of beyond-the-ROW geotechnical features or assets can be beneficial to others.

The management approaches for assets beyond the ROW can be expected to mature as GAM implementation occurs in each agency. Drawing from the experience of well-established GAM programs in the United Kingdom, this topic has been identified as an area for future improvement after several years of implementation experience for assets within the ROW (Network Rail 2017).

Geotechnical Elements Within Other Assets

Once the asset location is established relative to the ROW or other boundary types, the taxonomy can be further divided on the basis of the asset's function and whether a system exists already (e.g., the National Bridge Inventory System [NBIS] for bridges, the National Tunnel Inventory System [NTIS] for tunnels, or an existing pavement management system). The asset groups associated with bridges, tunnels, and pavements include geotechnical items, but these asset groups already have asset management plans that comply with federal authorization.

For the geotechnical items within other assets or structures, the function of the geotechnical item is to enable the function of that specific asset, versus the function of the corridor in terms of executive-level objectives. As indicated by Anderson et al. (2016), it is important to recognize the contribution of the geotechnical element(s) to these other assets and manage them through the existing platforms, and not to create something new.

For the geotechnical components of these other structure assets (e.g., bridges and tunnels), those items can be identified in the GAM taxonomy as *geotechnical elements* or *components of other structures,* or using the exact terms already used within the asset-specific asset taxonomy. For example, the geotechnical foundations of a bridge compose a portion of the bridge substructure component. Thus, the term *geotechnical element* is defined herein to capture geotechnical items within an already-managed asset.

Anderson et al. (2016) indicate that existing management systems for bridges, tunnels, and pavements may not be fully effective at capturing the ways in which geotechnical element performance contributes to the root causes of adverse performance of the observable structure components. This may occur because many practitioners, including the engineers of bridges, pavements, and the fabricated parts of tunnels, consider the geotechnical elements as being static in terms of deterioration; consequently, the service life of the geotechnical elements are not considered except in a rare circumstance where a geotechnical failure occurs and requires a response. Following this approach, asset management practices may direct efforts to the fabricated or visible structural components of a pavement section, a bridge superstructure, or a tunnel lining or portal, where deterioration can be readily observed. A future improvement of these existing asset management systems could be the incorporation of geotechnical performance if and when appropriate geotechnical performance indicators, measurement tools, and models of performance are established. It is anticipated that GAM implementation can enable these improvements to occur in the future.

Geotechnical Assets

As presented in Figure 5.1 and elsewhere in this manual, the next level for the GAM taxonomy is the identification of the four geotechnical asset types discussed in this manual: embankments, slopes, retaining walls, and subgrades. Each of these geotechnical asset types has a geotechnical composition and contributes measurably to the ability of an agency to reach its goals and objectives. In some agencies, existing inventory and/or management systems may address one or a few of these geotechnical asset types. For example, a rockfall hazard rating system (RHRS) was developed in the 1980s by the Oregon DOT with support from FHWA and other states (Pierson 1991). The RHRS has since been adopted or modified by several states, with some agencies including other slope types as well. Although some of these assets share characteristics with asset management systems, the GAM implementation process proposed in this manual can be used to integrate these asset-focused systems into the broader geotechnical asset category shown in Figure 5.1 and to incorporate the assets into a risk-based TAM approach that enables all geotechnical assets to compete with other assets on the basis of favorable investment cases and similar objectives.

The final level in the GAM taxonomy shown in Figure 5.1 relates to the distinction of a geotechnical asset that consists entirely of soil and rock (earth materials) from one that includes earth material that also is modified by inclusions or ground improvement. An example of a modified geotechnical asset is presented in Figure 5.3. As indicated by Anderson et al. (2016), further refinement of a nationally consistent terminology below this level of geotechnical asset types is less important, because communication at this level will generally occur among other SMEs in the same discipline, and there could be other agency preferences.

Examples of Geotechnical Assets Within the Asset Management Framework

NCHRP Report 632: An Asset Management Framework for the Interstate Highway System presents a practical framework for applying asset management principles and practices to managing Interstate highway system investments (Cambridge Systematics et al. 2009). The taxonomy in this report identifies asset categories of roads, structures, safety features, and facilities, of

Figure 5.3. Geotechnical embankment asset modified with soil nail and mesh inclusions.

which retaining walls are identified as a type of asset within the structure asset category. Other asset types in the structures category include bridges, tunnels, culverts/drainage structures, noise walls, overhead signs, and high mast poles.

An agency desiring to use the *NCHRP Report 632* taxonomy framework in its asset management plan could revise the retaining-wall asset type to the geotechnical asset type, and the geotechnical assets could be managed using guidance from this manual. In this scenario, the agency can manage all geotechnical assets in a single plan with objectives and measures that are of importance to executives. This approach may be preferred to increasing the list of asset types under the structure asset category and then developing a plan for each type of asset.

Additionally, in situations that involve non-corridor, geotechnical asset types, such as stockpiles and material sites (see Figure 5.1), these could be incorporated into the asset types under the facility category of the Interstate highway system framework presented in *NCHRP Report 632*.

Data and Data Management

Data are required for an asset manager to make decisions, just as data are required to make engineering design decisions. Although data are necessary in both activities, the efficient approach is to have just the right amount of data available for the level of decision-making needed. Within geotechnical engineering practice, this concept is employed by using field reconnaissance techniques for preliminary engineering studies and comprehensive subsurface exploration and testing programs to support final design. In this geotechnical design phase example, it could be viewed as a waste of resources to collect final design-level data when the structure locations are not even known. To translate this back to TAM, barriers to GAM implementation can arise if collected data is deemed to be excessive or not used in the decision-making process, resulting in a perception that funds are not being spent properly in the implementation process.

In a GAM implementation process, data will be associated with activities such as inventory, measurement and reporting, and financial planning, in addition to coordination among other assets and with stakeholders. The management of these data should be considered at the start of a program and as an ongoing process. Fortunately for GAM, data management is not a concept that needs to be researched for implementation, and there are accepted and applied practices that can be adapted for implementation, thus reducing the potential barrier for over-investment in data collection. These detailed references include:

- The Data Standard for Road Management and Investment in Australia and New Zealand (Austroads 2016) presents the advanced cross-agency data standard for transportation agencies in Australia and New Zealand that has developed over several years of asset management experience for multiple asset types, including geotechnical assets such as walls and slopes. The standard includes an adaptable taxonomy for different levels of sophistication in asset location referencing, asset data, and asset management practices. The standard is also developed to connect with ISO 31000, Risk Management: Principles and Guidelines and the ISO 55000 Series for asset management.
- *NCHRP Report 814: Data to Support Transportation Agency Business Needs: A Self-Assessment Guide* (Spy Pond Partners and Iteris 2015) provides methods for a transportation agency to evaluate and improve the value of their data for decision-making and data management practices.
- *NCHRP Report 632* (Cambridge Systematics, Inc. 2009) presents a practical framework for applying asset management principles and practices to managing Interstate highway system

assets. The report includes a taxonomy for asset categories and types and provides guidance on data and tools for asset management.

Knowledge of data management concepts from these sources can enable asset managers implementing GAM to adapt them as needed to draw efficiently from developed practices that have integrated with the practice of TAM. For a GAM implementation at a simple level of maturity, consideration of the data management functions can be a continual process improvement step that is tailored to each agency. The basic data management functions include:

- Definitions;
- Location;
- Accuracy requirements;
- Data collection practices such as frequency, responsibility, and resolution;
- Storage;
- Access;
- Integration with other systems; and
- Naming conventions.

Because each agency differs in practices for data and data management, no single best practice can be recommended. The literature review performed for this manual indicated that conflicting conclusions about approaches to support data and asset management can exist. For example, the USACE relies on spreadsheets because they are widely wide adoptable and familiar to users, whereas the IIMM (IPWEA 2015) indicates a preference toward development of specific proprietary software for asset management. Further, some domestic DOTs have developed or are developing agency-wide data governance plans, which should be considered as a process improvement step in the later stages of GAM implementation.

A synthesis from successfully implemented asset management programs indicates that data management need not be a burdensome task, as approaches can be adapted for different levels of GAM plan complexity and asset data details. As introduced in Chapter 4 of this manual and discussed in the IIMM (IPWEA 2015), which is based on more than 10 years of applied international asset management experience, a staged approach to data collection and management often is most practical, and not all programs will need to progress to an advanced level for all assets. Experience from established asset management programs supports a data collection and management approach that starts with higher-level details and then progresses to more precise information when a justified business case has been made for greater detail.

The discussion in the next section provides an introduction to the concepts of data and data management that can enable an agency starting GAM at a simple level of maturity to connect with the broader enterprise-level asset and risk management efforts.

Data Type and Function

For an asset manager, data collection and management should be considered an ongoing process to support the asset management process. A simple GAM implementation process, such as one that follows the template provided in this manual, can occur with a relatively low level of data sophistication. As GAM planning matures, the data complexity can be increased to match what is required and justified by the asset management process. Regardless of maturity level, the data to support asset management can be differentiated broadly on the basis of type and function. The type of data relates to the asset's source and characteristics, whereas the use of the data relates to the asset's function. These concepts are expanded in Tables 5.1 and 5.2.

Table 5.1. Example data types used in asset management.

Data Type	Description	Examples
Inventory Data	Static data related to physical asset location, geometric extents, design and construction details, and material and physical characteristics	Asset location relative to milepost, size of asset, type of asset, asset value, and traffic volume at asset location
Condition Data	Data that describe the condition of the asset (or specific elements of the asset) at a given point in time	Good, fair, or poor condition of the entire asset or asset elements
Performance Data	Data that indicate how an asset is performing in the context of a performance objective, such as technical performance or user perspectives	Asset impacts on other assets, mobility of traffic, financial and economic measures, or staff resources
Work Activity Data	Data that provide information about repairs, routine maintenance work, and rehabilitation actions	Maintenance work orders, SME support requests
Temporal Data	Data that capture changes in asset condition with time	Recurring inspection data, deterioration rates for an asset or asset elements

Data Sources

Data sources to support GAM can consist of newly collected data and existing data. When starting GAM, the asset manager is encouraged to use existing data where practical, as doing this can be an efficient step toward rapid, low-cost implementation. Many transportation agencies are large and complex organizations with several systems and information technology platforms that can provide data to support GAM. Due to this organizational complexity, the geo-professional or TAM manager may be unaware of all possible data sources or the permissions required to access the data. Once the range of data sources are known, an asset manager can be further challenged in reducing the data to an appropriate format that can provide useful knowledge for the GAM plan. As a result, even in a "data rich" situation, the asset manager can find it challenging to have enough of the "right" data. In a data rich organization, the asset manager should remain focused on obtaining only the data necessary for the decisions at the required level, and should avoid the trap of gathering too much data.

Table 5.3 summarizes potential data sources that can support asset management.

Table 5.2. Example functions for data used in asset management.

Functional Use	Example	Level of Use		
		Executive	Planning	Operations
Reporting	Asset performance measures	X	X	X
Planning and Design	Technical reports, and rehabilitation and reconstruction plans		X	X
O&M	Maintenance work planning			X
Risk Measurement	Risks to performance	X	X	X
Financial Planning	Annual budgets, project scoping	X	X	X
Investment Analysis	Life-cycle investment decisions	X	X	
Forecasting	Future performance trends	X	X	

Table 5.3. Common data sources for consideration in GAM implementation.

Data Source	Description	Potential Use in GAM
Legacy Geotechnical Inventory Data	Rockfall and slope hazard rating systems, monitoring data	Initial inventory development
Geotechnical Repair Projects	Prior distress and adverse event response reports, rehabilitation and reconstruction projects on deteriorating assets	Understanding frequency of events and calibration of deterioration and life-cycle cost models
Bridge and Structure Inspections	Department inspection data for bridges and possibly other structure assets, maintained in a federally mandated database, the NBIS	Inventory development for walls, slopes, and embankments associated with bridge, culvert, and tunnel assets
Enterprise Accounting Software	Business operations and financial data	Measurement of costs for assets through their life-cycles
Maintenance Work Orders, Maintenance Management Systems	Formal and informal records of maintenance activities	Measurement of costs and potentially the locations of O&M activities on geotechnical assets
Traffic Counts	Static data on traffic volumes and type	Estimation of risk and consequence magnitude
Highway Speed and Volume Data	Emerging data set with continuous traffic flow data that can be accessed for real time conditions or documentation of historical performance	Estimation of risk and consequence magnitude; measurement of traffic impacts resulting from geotechnical asset performance
USGS and State or Local Agency Hazard Maps and Reports	Geological and hydrological information in support of natural hazard identification and management	Inventory development; delineation of beyond-the-ROW hazard features
Traffic Accident Data	Agency or external records of traffic accidents that include information on dates, locations, consequences, and likely causes	Estimation of risk and measurement of safety impacts resulting from geotechnical asset performance
Road Inventory Logs	Existing inventory databases that have logged existing assets or features within the roadway; may include roadway photo logs	Inventory development and tracking condition changes with time
Pavement Condition Maps	Map products developed through pavement management systems that include inventory and condition data	Inventory development, measurement of changes in condition, cross-asset management opportunities
Emails	Agency communication records	Communication records for geotechnical asset performance
Construction Documents	Plans and as-built information for geotechnical assets or projects that include geotechnical assets	Design and construction phase information for geotechnical assets
Imagery	Photographs and digital terrain records	Asset records, observations, and measurement of asset changes
Media Reports	News stories that include documentation of events and consequences associated with adverse asset performance	Documentation of geotechnical asset performance and associated consequences
Internet	Online information portal	Free mapping and measurement tools, user stories and videos, historical records

Data Collection Methods

The GAM implementation process can apply flexibility to the means of starting an inventory. Likely methods and examples of data collection to support GAM include:

- Office- or desk-based data collection that uses existing files and internet resources;
- Visual observation, which involves viewing the asset and/or elements of the asset;
- Collection of basic physical parameters by non-destructively measuring characteristics such as asset and/or element dimensions;

- Collection of advanced physical parameters by installing measurement devices or intrusively examining the asset; and
- Remote techniques for data collection that use ground-based or satellite technology to capture asset characteristics.

Each method involves trade-offs between data quality and cost that should be considered in the selection of methods.

For the simple GAM implementation framework described this manual (and for use of the GAM Planner), office and visual observation are proposed to enable the quick establishment of a GAM asset inventory. With time and increased acceptance of GAM, other data collection methods can be adopted or developed should the need be justified.

Level-of-Detail Considerations

Asset managers who are collecting data to support GAM implementation are encouraged to consider the appropriate level of detail of the data in terms of the relative contribution the details will make toward decision-making that supports plan objectives. The following questions can be asked when establishing the level of detail for data to support an asset management process:

- What is the purpose of the data?
- Will the data support others in the agency?
- Can existing data be used initially?
- Are resources available to collect the data?
- Are resources available to manage and maintain the data?
- What level of accuracy is needed for decision-making?
- How frequently must the data be collected?
- What is the acceptable reliability of the data?
- What is the cost to collect the data relative to expected benefit?
- Is the current condition of the GAM asset known (and if so, what is the condition)?
- Is the asset critical to other assets or objectives?
- Will more detail change the decision outcomes?

There may be a desire to collect more data than initially needed, with the basis for collection being that the data will eventually have value, but this approach should be used with caution because, generally, costs and time will increase for increasing levels of data detail. The proposed implementation process in this manual encourages starting quickly to begin communicating potential benefits to decision-makers and ultimately to enable further implementation support and maturity. In keeping with this approach, the initial decisions about the level of data detail should consider impacts to the overall timing and the initial resource availability for GAM implementation.

Fortunately, geo-professionals adapting their design experience to asset management implementation can draw from their geotechnical experience, which has a historical reliance on decision-making with incomplete information. This same observational and judgment-based approach can be transferred to GAM.

Geo-Referencing Data

The location reference for transportation assets can have different levels of complexity depending on agency data resources, capabilities, technology, and the level of accuracy needed for the task at hand. In general, three methods of location referencing can be used simultaneously, depending on data management functions (Austroads 2016). The three methods involve assigning each asset (1) a **one-dimensional (1-D) location** that is referenced to a known location (e.g., a mile point or offset point from stationing); (2) a **2-D shape** with x and y lateral dimensions similar to a polygon outline on a plan view; and/or (3) a **3-D extent** that incorporates an elevation (z-dimension).

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

When integrating the GAM inventory into a map-based geo-referencing database system like the GIS systems common in many DOTs, each asset will be identified using a naming convention that maintains consistency in the database. Thus, for future compatibility, the asset manager should use a location naming convention consistent with their organization's established standard. Note that the route-based and segment-based systems may yield location names that look similar (e.g., Route 35, MP 90.3 versus Route 035B, MP 090.3). Thus, the asset manager is encouraged to confirm the method being used, and to meet with agency data management staff to determine recommended practices for compatibility.

The GAM implementation process described in this manual uses a geotechnical asset segment referencing system that is independent of the segmented reference system. As the GAM program matures, this initial asset segment referencing system may need to be aligned with the established standard referencing system that is used by the asset manager's organization. The geotechnical asset segment approach is recommended during initial GAM implementation in part because it allows for performance measurement for multiple and/or overlapping asset types with different geographical extents. Additionally, many agencies may find that the historical accuracy of geotechnical assets and associated events relies largely on rough field estimates that may not have a high degree of accuracy. By assessing assets along a defined length of roadway rather than at individual points, the effects of measurement inaccuracy and uncertainty are reduced.

The GAM Planner and the GAM implementation process described in this manual are intended to allow initial implementation without directly addressing geo-referencing and mapping the assets while providing a platform that can be expanded for future growth into map-based data presentation and analysis. Mapping tools such as those distributed by Google, Esri, and others typically cannot directly display data located with a Route/MP-based naming convention; however, when located using the established standard of the asset manager's organization, the mapping tools should be able to process the asset data for map display. The level of effort necessary to display the data on a map will vary significantly based on the mapping resources available within the agency.

The wide variety of available tools influences how geo-referenced data can be used to visually communicate the GAM inventory. Three scenarios are offered for consideration in map-based GAM data presentation:

- **Basic Implementation:** This scenario is described in the GAM implementation process in this manual and is intended to provide for future expandability to a mapping platform as the GAM program matures.
- **Point-Based Mapping Implementation:** This scenario involves adding latitude and longitude columns to the GAM Planner inventory, such as the coordinates of the start of each GAM asset segment. Latitude and longitude are easily mapped via many tools; however, this

representation of the spatial location of the data is not easily visualized without the aid of a mapping tool, whereas a Route/MP will be easily recognizable to the asset manager and a wide range of agency staff. For example, it is easier for staff to understand the location of Route 35, MP 90.3, versus 39.8283° N, 98.5795° W. Also, the assets being managed are linear by nature, and the inventory will have a point representation for the latitude/longitude of a linear feature following the roadway.

- **Spatial Database Implementation:** This scenario involves migrating the GAM Planner implementation process to a spatially enabled database that inherently recognizes spatial data. This process has occurred as part of the Alaska and Colorado GAM implementation programs; however, the process can be complex, and describing it is beyond the scope of this manual.

Structuring Data Management to Maturity

An aspirational approach to GAM implementation would involve ample resources and funds to create a program at an advanced level of maturity, but the reality for most agencies is that GAM implementation will occur in stages and with fewer resources and funds. This reality need not delay or impede the implementation of GAM, however, as complex or voluminous data are not necessary to begin implementation. In fact, too much data can be a barrier to implementation because the asset management team can become distracted by data management tasks that do not add value to the initial steps and decisions of a simple-maturity GAM plan.

Many agencies will have or are developing internal expertise in data management. The focus for GAM implementation should be on data accessibility and integration considerations to enable future integration into the DOT's enterprise data systems.

The implementation tools and framework presented in this manual are intended to enable agencies to start recognizing the benefits of asset management as soon as possible and with the assumption that resources for implementation will be limited. The previously presented concept of asset management maturity is a practice that can be adapted for GAM and data management. Selecting a simple GAM maturity is a feasible process within a resource-limited agency. Further, a simple level of asset management maturity can rely on lower levels of investment for initial data collection and advance these processes over time as justified by investment benefits. The data management practices adopted for a simple GAM implementation can adapt to developing agency data practices and resources, and may be advanced as GAM life-cycle savings are used to further investment toward increasing data management complexity, as suggested in Figure 5.4.

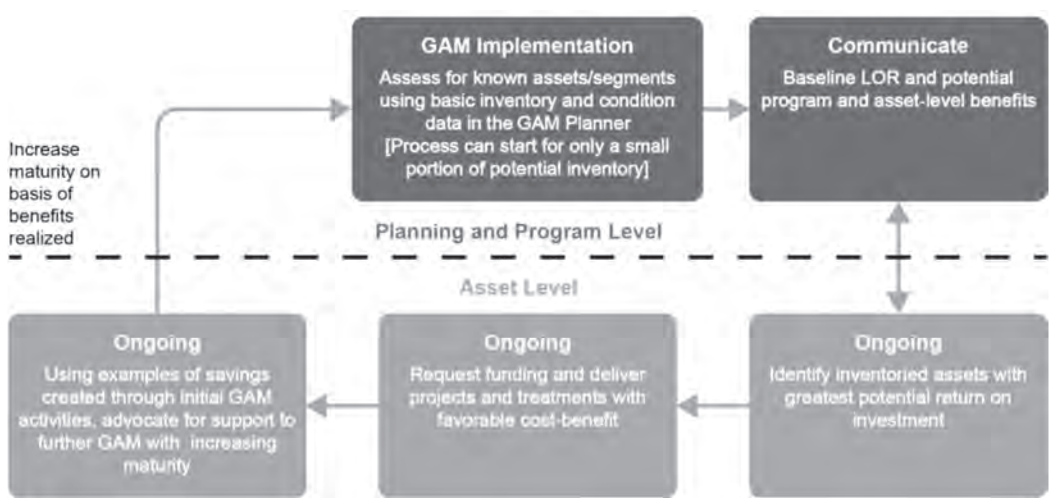


Figure 5.4. Conceptual approach for increasing GAM maturity with time.

CHAPTER 6

Asset Assessment and Performance Measures

Introduction

Performance management and asset management complement each other and are closely related. Because geotechnical assets have potential to impact agency performance objectives, GAM can connect with performance management concepts. Moreover, performance management activities help to support and enhance asset management within an agency. For example, performance management practices include establishing the measures and targets that are used to track asset condition and are reported in the TAM plan. Therefore, an agency that is implementing GAM may be interested in also implementing performance management practices. If the agency already engages in performance management, then there may be interest in integrating performance measures related to geotechnical assets with the developing GAM plan.

Chapter 4 in this manual introduced suggested performance measures for geotechnical assets, which include:

- Executive-level measures;
- LOR;
- Customer-level measures;
- Annual delay and closure times from adverse geotechnical asset performance; and
- Technical level measures, such as:
  - 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.

These measures are recommended to help track assets' performance over time. This chapter details how the listed measures could be integrated with an agency's broader performance management framework as GAM implementation matures. The framework and details on performance management provided in this chapter are summarized from the FHWA *Transportation Performance Management (TPM) Guidebook* (FHWA 2019). This guidebook is available online at https://www.tpmtools.org/guidebook/.

The discussion in this chapter supports the acceptance of GAM implementation among executives and agency staff who are focused on high-level performance. By using the GAM Planner that accompanies this manual (or a similar risk-based GAM process), those involved with GAM will have adaptable data and processes to support performance management needs.

Some agencies may experience low executive engagement toward performance management. In those situations, the information in this chapter can be used to support a "bottom-up" approach to performance management in a maturing GAM implementation that is consistent with FHWA guidance. At agencies that have a favorable culture toward performance

*"A **Strategic Direction** establishes an agency's focus through well-defined goals and objectives, enabling assessment of the agency's progress toward meeting goals by specifying a set of aligned performance measures. The Strategic Direction is the foundation upon which all transportation performance management rests."*
—TPM Guidebook *(FHWA 2019)*

management, the outcomes from even a simple GAM implementation can enhance the agency's performance management culture.

Components of Performance Management

The FHWA *TPM Guidebook* is a comprehensive guide developed to help DOTs, metropolitan planning organizations (MPOs), and transit agencies implement or enhance performance management at their agencies. The guidebook provides a helpful framework for visualizing nine distinct components of performance management. For each component, the guidebook describes key concepts, highlights the interrelationship between components, defines terminology, and outlines concrete steps for implementation. Figure 6.1 shows the high-level framework of performance management components as presented in the *TPM Guidebook.* The discussion in this section of the *GAM Implementation Manual* summarizes each component as it relates to geotechnical asset performance. For more details on performance management, readers are encouraged to consult the *TPM Guidebook*, available online.

Strategic Direction

Performance management begins with setting the strategic direction for the agency. Setting the strategic direction may be accomplished through the asset management program or other long-term planning activities within the organization. All the remaining components of performance management are influenced by the strategic direction. Likewise, the remaining components also inform the strategic direction, because performance management is an iterative and ongoing process. As an example of this framework step, many DOTs establish strategic performance directions related to the agency's contribution toward the safety and/or economic vitality of the state's citizens and system users.

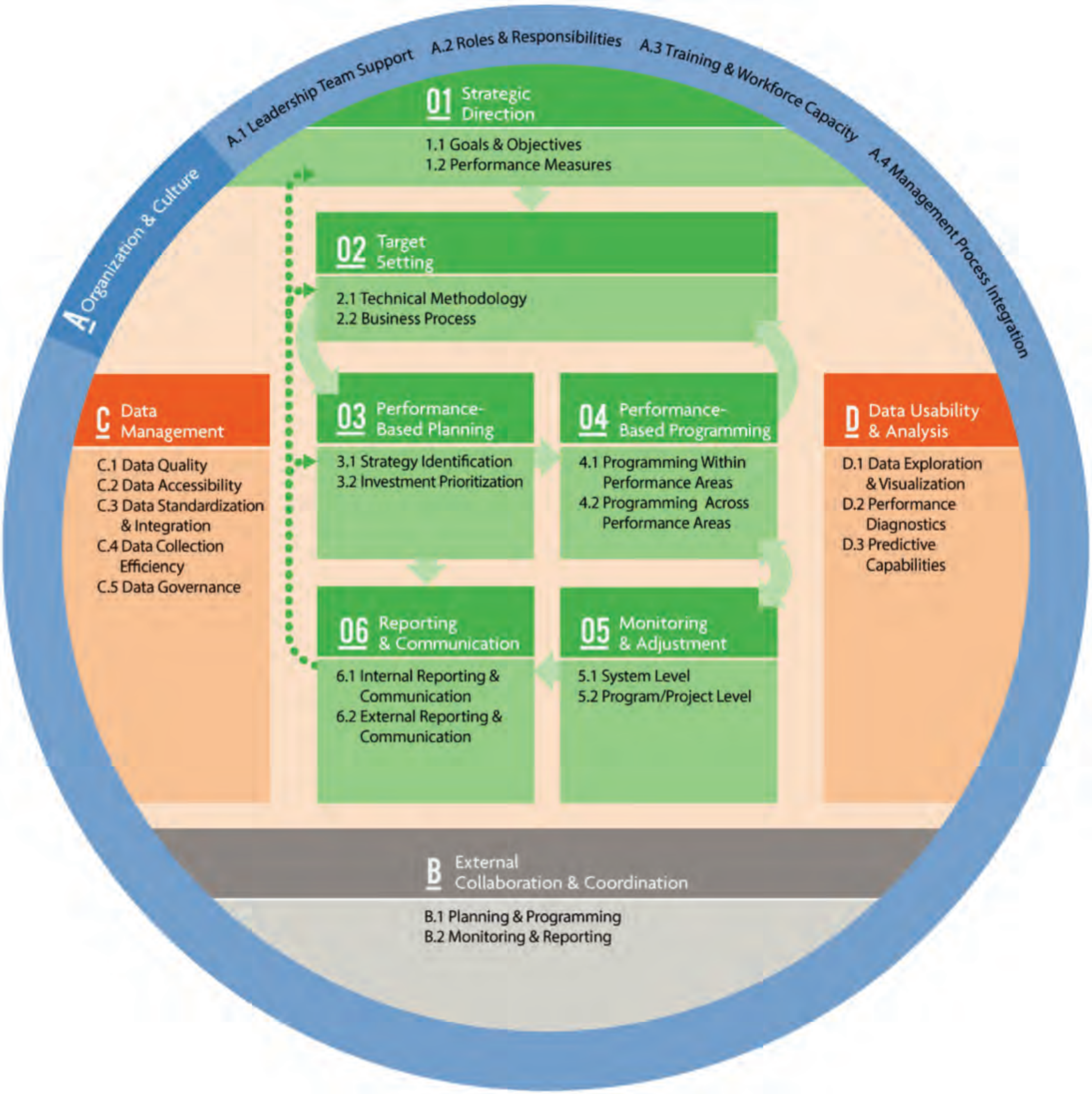
The *TPM Guidebook* identifies two subcomponents of setting strategic direction. These are (1) establishing goals and objectives and (2) determining performance measures. Once the agency's goals are set, objectives and measures help to communicate and support the desired outcomes. An objective is "SMART" if it is Specific, Measurable, Agreed-upon, Realistic, and Time-bound, as illustrated in Figure 6.2. As this acronym indicates, objectives are meant to add specificity to goals. Performance measures then enable agencies to quantify the goals and objectives and communicate progress toward achieving those desired outcomes. The suggested LOR performance measure for geotechnical assets in Chapter 4 is a measure that connects with strategic performance outcomes related to safety, mobility, and economic vitality.

Overall, it is key that the high-level strategic direction have both internal and external buy-in. Ensuring that it does requires continuous communication of the goals, objectives, and performance measures. Staff within the agency should be able to see how their work connects with the broader agency goals and direction. Likewise, buy-in from the public and regional partner agencies helps ensure that goals are relevant to all stakeholders.

__Target-setting__ is the use of baseline data, information on possible strategies, resource constraints, and forecasting tools to collaboratively establish a quantifiable level of performance the agency wants to achieve within a specific time frame. Targets make the link between investment decisions and performance expectations transparent across all stakeholders.
—TPM Guidebook *(FHWA 2019)*

Target-Setting

Once the goals, objectives, and performance measures are established, the next step in performance management is to set targets. Targets clearly state, in quantifiable terms, what performance the agency hopes to achieve. Target-setting involves observing a performance baseline and evaluating a trend of predicted performance into the future. The agency also may establish internal processes to coordinate data collection and analysis to monitor and adjust performance targets over time. As expected, data quality is important in target-setting activities as analyzing historical trends and forecasting future performance is completed using these data.



Source: TPM Guidebook (FHWA 2019)

***Figure 6.1. TPM framework as presented in the FHWA* TPM Guidebook.**

Figure 6.2. Elements of SMART objectives.

Performance-Based Planning is the use of agency goals and objectives and performance trends to drive development of strategies and priorities in the long-range transportation plan and other performance-based plans and processes. The resulting planning documents become the blueprint for how an agency intends to achieve its desired performance outcomes.

—TPM Guidebook *(FHWA 2019)*

The high-level target-setting activities of an agency are valuable for enabling a GAM implementation that connects with the agency's strategic direction. As a result, the asset managers and geo-professionals performing GAM should be familiar with the high-level strategic targets of the agency and look for opportunities to connect the performance of geotechnical assets with those targets. For example, if an agency has an aspirational target of zero fatalities to support a strategic safety performance target, tracking and reporting safety impacts from geotechnical assets is a means to connect GAM with high-level targets. With time, a target for safety performance from geotechnical assets can be established in this hypothetical example.

Performance-Based Planning

Performance-based planning involves strategy identification and investment prioritization. Using the baseline and forecasted performance from the target-setting activities, strategies are developed for achieving the desired level of performance. The agencies must then evaluate differing investment scenarios based on the ability to achieve performance targets and goals. Because this planning process is performance-based, the data and measures related to asset performance are key.

For performance-based planning of geotechnical assets, agencies should be using data and performance measures such as LOR to inform the long-term strategic planning for investing in these assets. Planning should not be done in a silo, or in isolation. Stakeholder involvement in this component of performance management is important to ensure that considerations and priorities from state or federal partners and from the public are taken into account.

Performance-Based Programming

The work of performance-based planning sets the stage for the performance-based programming component of the GAM implementation framework. Performance-based programming focuses on how the project-level work at DOTs helps make progress toward the agencies' goals and objectives. Programming involves the allocation and prioritization of resources both within and across performance areas. Within performance areas, projects are selected based on specific criteria that indicate how a project's outcomes will help the agency progress toward its goals. Agencies also may develop a methodology for prioritizing across areas. For example, resources could be allocated across various assets (e.g., pavement, bridge, and geotechnical assets). It is important to consider funding and resource constraints in the programming process because certain funding sources, such as bridge replacement funds, might have constraints on how the money can be used.

Monitoring and Adjustment

With the planning and programming aspects of performance management in place, agencies should be in the practice of monitoring progress toward the goals and targets and making adjustments where necessary. Monitoring observed results in program and project delivery should be ongoing, and when there are issues, data gaps, or missing information, agencies are encouraged to take action to make improvements and adjustments. This likely will not occur at the start of GAM implementation; rather, continuous improvement will help achieve the goals and targets in the most efficient way possible and help to move agencies from simply doing performance measurement to doing performance management.

The *TPM Guidebook* identifies two subcomponents of monitoring and adjustment: (1) *system-level* monitoring and adjustment and (2) *program/project-level* monitoring and adjustment.

Source: TPM Guidebook (FHWA 2019)

Figure 6.3. Relationship between inputs and outputs in the TPM framework.

__Performance-Based Programming__ is the use of strategies and priorities to guide the allocation of resources to projects that are selected to achieve goals, objectives, and targets. Performance-Based Programming establishes clear linkages between investments made and expected outputs and outcomes.
—TPM Guidebook *(FHWA 2019)*

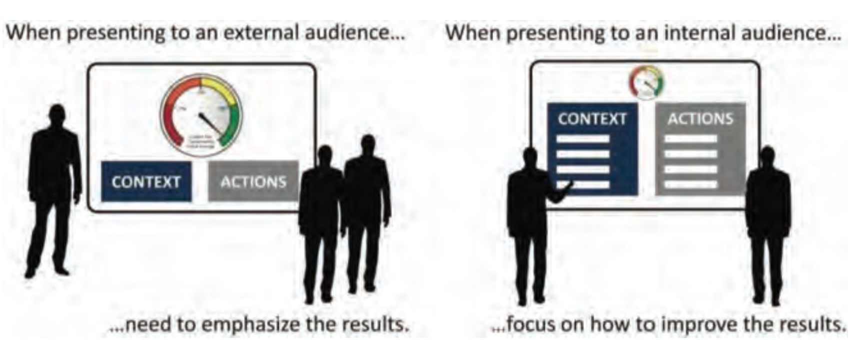
Each subcomponent involves determining the framework within which the monitoring will occur and then regularly assessing the results of the monitoring. Figure 6.3 shows how performance-based planning and programming feed the monitoring and adjustment step of performance management. Within and between these subcomponents, the agency must establish feedback loops to communicate goals, results, and adjustments related to the targets, measures, goals, and planning and programming decisions. In Figure 6.3, feedback loops can be imagined as arrows leading back from the monitoring and adjustment step to the planning- and performance-based steps.

Reporting and Communication

Documentation is an important aspect of performance management. It is important to document the goals, measures, and targets established for performance management, as well as the process used to determine or connect with high-level strategy and investment decisions and to prioritize projects. This documentation is essential to the reporting and communication process.

Reporting and communication is done both internally and externally, with the contents of the reporting tailored appropriately for each audience. Figure 6.4 illustrates the concept for considering the perspective of the audience in this framework step. Internal audiences, from executives to program/project managers to maintenance staff, need to be informed of performance progress and also need to understand how their work connects with the broader agency goals and performance targets. For a hypothetical GAM implementation, an example of internal reporting and communication could involve establishing a regular geotechnical asset performance working group with maintenance management staff to report on the measured performance of geotechnical assets and the treatment plans under consideration, followed by a request for feedback to ensure that asset condition performance data are being inventoried correctly.

__Monitoring and Adjustment__ is a set of processes to track and evaluate actions taken and outcomes achieved, thereby establishing a feedback loop to refine planning, programming, and target-setting decisions. It involves using performance data to obtain key insights into the effectiveness of decisions and identifying where adjustments need to be made in order to improve performance.
—TPM Guidebook (FHWA 2019)



Source: TPM Guidebook (FHWA 2019)

Figure 6.4. Tailoring reporting by audience.

Reporting and Communication is the use of products, techniques, and processes to communicate performance information to different audiences for maximum impact. Reporting is an important element for increasing accountability and transparency to external stakeholders and for explaining internally how TPM is driving a data-driven approach to decision-making.
—TPM Guidebook *(FHWA 2019)*

Externally, performance information is conveyed to customers, partner agencies, and government officials to increase transparency and accountability. In the context of a maturing GAM implementation process, this step may involve informational presentations to MPOs or local agencies that experience consequences associated with adverse geotechnical asset performance. Through these presentations, the agency can communicate the need for GAM and what is being done to manage risk and to ultimately reduce consequences to these organizations.

Organization and Culture

In the TPM framework, the organization and culture component of performance management surrounds all the other components, indicating the key and encompassing nature of implementing a culture of performance management. Performance management requires support from senior leadership and clearly defined roles and responsibilities to support TPM activities. Training to build workforce capabilities in performing TPM activities is key, as is integrating performance data with overall management processes. The *TPM Guidebook* provides implementation steps for creating a culture of performance management and describes the benefits of having an organization that supports TPM activities across the agency.

An ideal GAM implementation will have the benefit of high engagement from performance-oriented executives, but this may not be the situation for some DOTs. Low engagement from executives should not, however, be considered a barrier to implementing a culture of performance management for geotechnical assets. As a measure of good business practice and stewardship of public funds, regardless of executive engagement, the geotechnical staff and asset managers can follow and adapt the framework presented in this chapter to create a culture of performance management for geotechnical assets. Further, as the transition process for agency executives can often be connected to legislative appointments, the potential always exists for a performance-based executive team to be installed with a short implementation timeframe. In this scenario, the geotechnical asset manager may recognize early acceptance and adoption from executives if they can show that the GAM implementation is using and following an established performance-based framework.

Organization and Culture refers to the institutionalization of a transportation performance management culture within the agency, as evidenced by leadership support, employee buy-in, and embedded organizational structures and processes that support TPM.
—TPM Guidebook *(FHWA 2019)*

External Collaboration and Coordination

Collaboration and coordination with external partners and stakeholders is recommended in the subcomponents and implementation steps of many of the components in the TPM framework. It is also described as a foundational component that influences the data management and data usability and analysis components described in the next sections of this chapter. One main goal of promoting collaboration and coordination is to make the best use of limited resources across the agencies and partners involved. When local partners work toward the same targets and use the same performance measures as DOTs, agencies with limited staff time can pool resources, share data, and perform analyses. Geotechnical assets, in particular, can be under-resourced assets at DOTs. Continuous collaboration and coordination among partner agencies that are concerned with geotechnical assets can enable more effective use of asset data and analysis results. For example, a local agency within an agency district or corridor with a concentration of geotechnical assets could be a partner in the GAM treatment process as there is an overlap in needs and limited investment potential. In this scenario, both agencies may be able to realize efficiencies in coordinating the treatment of their respective geotechnical assets. The Swiss PLANAT program (which represents a more mature asset and performance management program) has facilitated these types of collaborative relationships that result in natural hazard risk-reduction benefits for multiple independent agency stakeholders.

Data Management

Engaging in effective performance management can be a data-intensive endeavor. Given that reliable and consistent data is at the core of performance management, data management is an important activity. The *TPM Guidebook* breaks this component into five subcomponents:

- Data quality,
- Data accessibility,
- Data standardization and integration,
- Data collection and efficiency, and
- Data governance.

Each data management subcomponent helps support the overall TPM activities in an agency. Along with the characteristics shown in Figure 6.5, they are important to informing management decisions that improve performance results and make progress toward agency goals.

Data Usability and Analysis

Performance management is not only contingent on *what* data an agency has, but on *how* it is used. It is a great step for agencies to have standardized methods of collecting data and ensuring its quality, but without usable analysis techniques and processes, an agency will not reach its full potential in performance management. In particular, data usability and analysis involves understanding and visualizing performance results and trends, understanding how influencing factors affect the performance results, and using data to predict future performance trends. These activities require specific skills, so agencies will benefit from developing these skills among staff so that they are able to efficiently use and analyze the data they have available.

TPM Requirements

FHWA has established requirements for TPM that are detailed in 23 CFR Part 490. This rule identifies the performance measures DOTs are required to use to assess performance of the Interstate and non-Interstate NHS as well as for other areas such as congestion, freight movement, and air quality. Additionally, the requirements for developing a TAM plan (TAMP) are detailed in 23 CFR Part 515. Although performance of pavements and bridges is reported in the TAMP, performance of geotechnical assets is not required by either the performance management rule or the TAMP rule. Should an agency choose to include geotechnical assets in its TAMP, the agency can follow a structure similar to what is in place for pavements and bridges.

Source: TPM Guidebook (FHWA 2019)

Figure 6.5. Characteristics of quality data.

External Collaboration and Coordination *refers to established processes to collaborate and coordinate with agency partners and stakeholders on planning/visioning, target setting, programming, data sharing, and reporting. External collaboration allows agencies to leverage partner resources and capabilities, as well as increase understanding of how activities impact and are impacted by external factors.*

—TPM Guidebook *(FHWA 2019)*

Data Management *encompasses a set of coordinated activities for maximizing the value of data to an organization. It includes data collection, creation, processing, storage, backup, organization, documentation, protection, integration, dissemination, archiving and disposal.*

—TPM Guidebook *(FHWA 2019)*

***Data Usability and Analysis** [involves] the existence of useful and valuable data sets and analysis capabilities available in accessible, convenient forms to support transportation performance management. While many agencies have a wealth of data, they are often disorganized, or cannot be analyzed effectively to produce useful information to support target setting, decision-making, monitoring or other TPM practices.*

—TPM Guidebook *(FHWA 2019)*

Once the agency has decided to include geotechnical assets in the TAMP, the first step is to determine what measures to use to assess performance of the assets. (Suggested performance measures for geotechnical assets are detailed in Chapter 4 of this manual.) Next, it is necessary to determine what constitutes the desired *state of good repair (SGR)* for that measure. Pavements and bridges are classified in terms of good/fair/poor condition. For geotechnical assets, the LOR grade described in Chapter 4 can be used in a similar manner. If desired, an agency could further group geotechnical asset LOR grades into "Good" (A or B), "Fair" (C), and "Poor" (D or F) categories. In some cases, assets could be classified even more simply as being in "Good" condition (A, B, or C, functioning), or "Poor" condition (D or F, non-functioning).

The next step is to project the future condition of geotechnical assets given the agency's current and/or expected level of investment. Agencies can then compare the forecasted condition relative to the desired SGR and determine the performance gap. Note that 23 CFR Part 490 calls for agencies to set 2-year and 4-year targets for the condition of NHS pavements and bridges. Two-year and 4-year targets also can be set for geotechnical assets, if desired. Then the projected condition can be compared to the desired LOR distribution or SGR at the 2-year and 4-year marks.

Performance measures related to geotechnical assets certainly can be included in the suite of performance measures an agency tracks and reports. Documentation on the performance management process employed for geotechnical assets will enhance an agency's TAMP as it goes above and beyond the required reporting on pavement and bridges. Discussions with state TAM managers in the preparation of this manual indicated a potential for withholding reporting of geotechnical assets from the TAMP, while still performing GAM, due to concerns over not being able to show favorable reporting results because of limited investment availability. Although this approach is understandable, using TAM plans and other communication methods to report geotechnical asset performance is encouraged. Agencies in some states (e.g., Colorado and Vermont) have started this practice, and it is anticipated that agencies in other states will begin to do so.

Additionally, documentation of geotechnical asset performance could have secondary benefits beyond the TAMP process, such as in documenting baseline conditions prior to a significant natural hazard event (e.g., regional flooding that disrupts a large portion of the system). With the availability of pre-event baseline conditions, an agency can include data that documents conditions prior to the event, which may enable more defensible support for emergency or other recovery funds sources.

CHAPTER 7

Risk

Implementing Risk in GAM

Risk management is an important step in the asset management process, as presented in the AASHTO *TAM Guide* and in federal authorizations that require states to develop risk-based TAM plans. The GAM Planner included with this manual is risk-based and will produced outputs that enable risk-based asset management. Starting risk-based GAM does not require a complicated risk assessment program, and agencies are encouraged to use simple assessment processes.

The concept of risk provides a rational means for considering unfavorable events and conditions because it considers both the likelihood of an unfavorable event occurring as well as the consequences of the event or condition. Including both likelihood and consequences provides important context. Consideration of likelihood alone would tend to overemphasize probable but minor events, whereas consideration of consequence alone would tend to overemphasize severe events that may be quite unrealistic. Risk is a particularly useful concept for the evaluation and management of geotechnical assets with a life-cycle approach, as likelihoods and consequences vary dramatically among geotechnical assets. Accordingly, the analytical GAM Planner has been developed to be risk-based and consistent with the concepts presented in this chapter.

This chapter introduces the concept of risk with discussions of risk terminology and sources of risk before presenting methods for estimating likelihoods and consequences to quantify risk. An important concept that is emphasized throughout the discussion of methods for quantifying risk is that, although the estimations of likelihood and consequence are typically approximate and based on some measure of judgment, **even imprecise or inaccurate estimates of risk will likely yield better management of geotechnical assets than a system that does not consider risk.** This is particularly true if the likelihood and consequence estimates are made consistently across assets. The chapter closes with a discussion of methods for presenting the results of risk evaluations of geotechnical assets. The content presented in this chapter is primarily intended as an introduction to risk concepts. More detailed, specific, and advanced discussion of risk topics are presented in Volume 1 of *NCHRP Research Report 903*, which provides an overview of the research that supports this manual. An introduction to risk-based concepts in the broader spectrum of agency TAM planning is provided in the April 2014 issue of FHWA's *Focus* magazine (FHWA 2014b) and in the five reports of the *Risk-Based Transportation Asset Management* series (available online at https://www.fhwa.dot.gov/asset/pubs.cfm?thisarea=risk). The five titles in this series are:

- *Evaluating Threats, Capitalizing on Opportunities* (FHWA-HIF-23-035);
- *Examining Risk-Based Approaches to Transportation Asset Management* (FHWA-HIF-12-050);
- *Achieving Policy Objectives by Managing Risks* (FHWA-HIF-12-054);
- *Managing Risks to Networks, Corridors, and Critical Structures* (FHWA-HIF-13-017); and
- *Building Resilience into Transportation Assets* (FHWA-HIF-13-013).

Risk Terminology

Several terms are commonly used to discuss the most important concepts related to risk. Unfortunately, the terms are frequently misused and confused, in part because definitions vary by application and by discipline, and likely also because the terms also are commonly used in non-technical contexts. Definitions for these terms, as they are used throughout this document, are:

- **Risk:** Risk is the product of the probability (or likelihood) of a hazard event occurring and the consequences of the event occurring. If the probability of a hazard event occurring is termed *probability of failure* (p_f), and the *magnitude of consequences* is represented by the symbol C, then

$$Risk = p_f * C.$$

  As an example, if the annual probability of a specific slope failing is 1 in 100 and the consequence of the slope failing is $1 million, the annual risk is $10,000 (calculated as 0.01 * $1 million = $10,000). A somewhat common mistake is to use the concepts of risk and probability of failure interchangeably (e.g., "The risk of failure is 1 in 100."). By definition, risk includes consideration of consequences, and should typically be expressed in terms of some unit of damage (e.g., dollars, deaths, hours of delay, and so forth). However, at the simplest level, risk can be expressed as a unitless measure of risk magnitude, with higher values representing greater risk relative to lower values.
- **Hazard:** A hazard is a potential event with adverse consequences. Hazards can be events that occur relatively suddenly (e.g., natural hazards like earthquakes, landslides, or floods), and hazards also can be events that occur in response to deterioration that has occurred over a relatively long period of time (e.g., an asset failure resulting from corrosion of the steel reinforcement for a MSE wall). Both types of hazards, and methods for estimating the likelihood of failure (i.e., the likelihood of a hazard event) are discussed later in this chapter.
- **Consequences:** With respect to risk, consequences are the quantified or scaled values of adverse impacts. Whereas the other component of risk (likelihood of failure) is a probability, consequences are physical—an event, condition, or change to an asset—and can be assigned a value. Most often, consequences are expressed in financial terms: dollars. Consequences can include impacts and costs that are not strictly financial costs (e.g., lost time, lost lives, and injuries), but for risk analyses, these consequences also are frequently expressed in financial terms, which allows all risks to be assessed using the same scale. Consequences are discussed further later in this chapter.
- **Reliability:** For engineering applications, *reliability* (r) typically is defined as the probability of success. Reliability is therefore the mathematical complement of the probability of failure, p_f:

$$r = 1 - p_f.$$

- **Vulnerability:** FHWA defines *vulnerability* as the extent to which a transportation asset is susceptible to sustaining damage from hazards (Choate et al. 2017). Herrera et al. (2017) apply a more mathematical definition: "Vulnerability is the likelihood that an event has the estimated consequences, given that the event occurs." The latter definition can be re-written in mathematical notation expressing vulnerability (V) as a conditional probability of the consequences (C) given the event (E):

$$V = P(C|E).$$

Based on the definition by Herrera et al. (2017) and the law of total probability, risk can thus be redefined in terms of vulnerability:

$$Risk = V * P(E) * Consequence\ Magnitude.$$

Herrera et al. (2017) refer to $P(E)$ as the *threat likelihood.* The definition of risk in terms of vulnerability is equivalent to the conventional definition, but the probability of failure, which also can be considered the probability of experiencing adverse consequences, is expressed as the product of vulnerability and threat likelihood.

- **Resilience:** Resilience generally is discussed in the context of disasters (e.g., related to condition or survival after events that occur due to natural hazards, extreme weather events, or terrorist activity). Various definitions of resilience have been proposed. According to FHWA Order 5520 (2014), resilience is the "ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions." FHWA's definition of resilience therefore combines two characteristics that are common among technical discussions of resilience. The first characteristic is adaptability with respect to hazard conditions that are changing, and in most discussions of resilience, changing with considerable uncertainty. The second characteristic is the ability to recover quickly from hazard events. The two characteristics are distinct from one another, but they are closely related for many disaster applications. For disaster applications, it is evident that both adaptation to changing conditions and recovering quickly from events are valuable characteristics.
- **Quantitative and Qualitative Assessments:** In general, the term *quantitative* is applied to analytical approaches that define parameters with specific, numerical values, and the term *qualitative* is applied to analytical approaches that define parameters in descriptive terms, usually as categorical data (e.g., categories A, B, C, D, and E; categories "good," "fair," and "poor"; categories Interstate, major highway, minor highway, and local roadway, and so forth). In the context of risk assessment, a quantitative assessment assigns numerical values for likelihood and consequence, whereas a qualitative assessment typically involves categorizing events in descriptive terms that are associated with ranges of likelihood values and consequence values. GAM practices frequently muddy the line between quantitative and qualitative assessments, with analyses that include both quantitative and qualitative elements. For example, most rockfall hazard rating systems (e.g., the RHRS initiated by the Oregon DOT) are primarily qualitative, with scoring elements based on categorical descriptions (e.g., low hazard, medium hazard, high hazard), but the category levels are associated with quantitative scores that are multiplied and summed to produce a final, qualitative score. By contrast, the GAM Planner included with this manual is strictly quantitative; its inputs are quantitative values of likelihood and consequence, and the output is "decision recommendations" based on rankings of the resulting quantitative values of risk. Although quantitative risk assessments are generally more rigorous than qualitative risk assessments, either approach can be used to produce a rational system for risk-based GAM.

For the most advanced GAM program examples, there is a distinct and consistent use of the terms risk *and* hazard *that enables clear communication among executive stakeholders who also understand the terminology. Deliberate and correct use of these terms is a recommended good practice toward enabling risk-based GAM and gaining support at the highest level of the agency.*

Sources of Risk

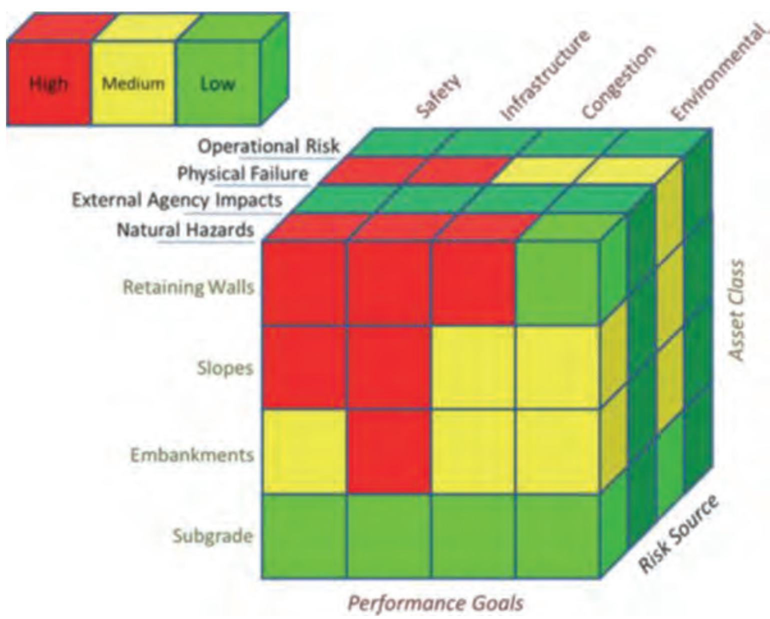
For geotechnical assets, physical failure (due to deterioration, overloading, and so forth) and geologic or natural hazard events (e.g., karst collapse events or rockfall and landslides beyond the ROW due to extreme weather events) are primary sources of risk. Physical failure/deterioration-based risks are fundamentally similar to the risks managed by conventional asset management programs for pavements and bridges. For asset management systems, risks associated with physical failure are characterized by consequences associated with continuous deterioration of all assets. Natural hazard risks are fundamentally different: natural hazard risks are a result of events that occur at unique points in space and time, likely not affecting most assets

For asset risks associated with physical failure, options exist for influencing both the likelihood and consequence. For risks associated with natural hazards, fewer practical management options are available to address likelihood, particularly when the natural hazard risk exists beyond the management boundaries of the agency.

but affecting certain others, often in a highly consequential manner. The analytical tools supporting management of physical failure risks and natural hazard risks reflect the differences in the fundamental nature of the two types of risk. Management of physical failure risks typically is accomplished using some form of performance or deterioration curve, whereas natural hazards management is based on probabilistic assessment of the hazard events.

Anderson (2016) presented the concept of a "risk cube" (Figure 7.1) as a means for considering and communicating risk across the various goals of an agency, for different asset classes and sources or risk. The example agency goals shown in Figure 7.1 are consistent with MAP-21 performance goals and include ensuring public safety, maintaining infrastructure condition, maintaining congestion at acceptable levels, and environmental protection. The example cube considers four types of geotechnical assets (retaining walls, slopes, embankments, and pavement subgrade), and four sources of risk (natural hazards, external agency impacts, physical failure, and operational risk). Each element of the risk cube represents the risk to a specific agency goal, for a specific asset class, from a different source of risk. In the example shown in Figure 7.1, the elements of the cube use colors (or shades of gray, when printed in black-and-white) to designate three qualitative levels of risk: The elements with the darkest shade correspond to the highest LOR; elements with the lightest shade, to a medium LOR; and those with a medium shade, to the lowest LOR. (The slight shading variation in the low-risk category reflects details of the Anderson study that are not important for this discussion.)

Anderson explains that the risk cube is not intended to replace risk *registers,* which capture more data than can be shown with the risk cube. The cube helps communicate risks and ensure that specific risks are not unintentionally neglected. The first step to "completing" a risk cube is to eliminate portions of the cube (i.e., remove elements from consideration in the analysis). For the example shown in Figure 7.1, there are 64 cells (sub-cubes) to be considered. However, entire planes can be removed by initial screening (e.g., the operational risk plane and the external impacts plane were neglected for the example of Figure 7.1). Once cells have been removed



Source: Anderson (2016)

Figure 7.1. Example risk cube with three qualitative levels of risk for each element.

by inspection, individual risk calculations can be calculated for the remaining portions of the cube. The method will vary by cell; for select high-risk cells, it may be desirable to complete a rigorous quantitative analysis, whereas for most other cells such an analysis would be unnecessary or infeasible. Anderson describes the risk cube as a tool for risk visualization and risk-based decision-making, noting that if risk-cube cells are defined quantitatively, summing and averaging various elements could be particularly useful.

Quantifying Risk

Geo-professionals and other technical SMEs routinely make judgments about risk, often relying on experience and intuition. Adapting this experience to the practice of quantifying risk in GAM requires estimates of the two parameters that define risk: likelihood and consequences. For both parameters, estimating quantitative values can be a subjective exercise that is similar to the intuition and experience-based process already familiar to geo-professionals. For an agency starting GAM at a simple level of maturity, estimation of risk is best considered a process that evaluates risk by an order of magnitude rather than as a precise estimate.

Risk analysis concepts may be less familiar to some staff involved in asset management, but some perspective is appropriate when considering the task of quantifying risk. Estimating a likelihood of adverse events or consequences does not involve the precision used in quantifying parameters for engineering design analysis. For a risk analysis, informed judgment is entirely appropriate and supported by literature on the subject.

For GAM, consideration of risk, even with uncertainty, is recommended over omitting consideration of risk altogether. Uncertainties are never completely eliminated, no matter how precise the analysis. Further, those implementing GAM should recognize that risk is not solely an engineering function, and many agency executives will understand both the concepts and the uncertainty inherent in the process. Thus, communication of risk estimates can support acceptance of GAM, as these concepts are commonly understood among both executives and geo-professionals.

Established and accepted approaches for estimating likelihood and consequences are outlined in the next sections of this chapter. By adopting similar processes, agencies can estimate risk exposure across geotechnical assets. These processes also will allow for comparison of risk estimates among assets with values that are relative to one another, even if the underlying estimates are uncertain. The relative correctness of the estimates makes them useful for evaluation, comparison, and management.

Estimating Likelihood

In the absence of a known probability value, estimation of likelihood is encouraged through subjective processes. Strictly speaking, probabilities cannot be measured, but they can be estimated based on past experience. Past experience is generally derived from two main sources of information: the judgment of experts, and the historical frequency of hazard events or failures. Estimates of likelihood based on past experience, whether expert judgment or historical frequency, are generally improved by considering present and historical asset condition. For example, consider the annual rate of failure for retaining walls for a hypothetical agency. The rate may be 1 in 1,000 for all walls, but 1 in 10,000 for walls with favorable inspection ratings, and 1 in 100 for walls with very poor inspection ratings. Thus, using the rates that are conditioned on inspection ratings will result in more accurate risk estimates than using the overall failure rate for all walls.

The GAM Planner relies on a semi-qualitative approach for estimating likelihood. The simplified approach is designed with the intent of enabling GAM implementation in agencies with constrained resources and limited inspection data. As a GAM program matures, and if justified, the precision and measurement for estimated likelihoods can be increased through the inclusion of more precise consequence data or historical performance statistics that inform specific probability values. To support GAM, the following examples provide greater precision in the estimation of likelihood:

- **Colorado DOT Retaining-Wall Program:** The Colorado DOT's retaining-wall management system (Walters et al. 2016) is an example of using expert judgment to estimate likelihood of adverse consequences from retaining-wall performance. The Colorado DOT system considers two types of consequences: maintenance needs and mobility. The researchers explain that other types of consequences, particularly safety and environmental impacts, do result from adverse performance of retaining walls, but consideration of maintenance and mobility consequences was deemed sufficient to produce risk-based rankings equivalent to the rankings that would result if all types of consequences were considered. For the first version of the Colorado DOT's wall management system (called "Tier 1" in the report), the likelihoods of maintenance consequences and mobility consequences were not explicitly estimated. Instead, the wall condition score, which was based on inspection results and varied from 1 to 4, was used as a surrogate for likelihood of mobility consequences and likelihood of maintenance consequences. The resulting risk scores were therefore not true measures of risk, but the researchers explain that the system rankings should be comparable to those from a truly risk-based system, assuming the wall condition index is closely correlated with likelihood of wall maintenance and likelihood of wall failure. The second version of the Colorado DOT's system (Tier 2) also is based on wall- and element-level condition scores from inspection ratings, but instead of using the condition scores directly (as in Tier 1), the scores were correlated to likelihood values established based on input from experts, some within the Colorado DOT and some gained from consultants. In addition, two distinct condition scores were used. The same four-point scale used for Tier 1 was used for maintenance consequences, which are shown in Table 7.1. The maintenance consequences were subdivided into consequences on structural elements of walls and consequences on secondary ("cosmetic or ancillary") elements. For the likelihood of mobility consequences, shown in Table 7.2, the National Bridge Inventory ratings were used as predictors. Although the National Bridge Inventory ratings range from 0 to 9, the ten rating values were grouped together in four ranges upon establishing the likelihood scores from expert judgment.
- **Network Rail Earthwork Asset Management Program:** In the United Kingdom, Network Rail has a risk-based management system for the nearly 200,000 cut slopes, embankments,

Table 7.1. Estimates of likelihood of experiencing maintenance consequences for the Colorado DOT's wall management system.

Condition State	Description	Likelihood of Maintenance Consequences	
		Structural Elements	Secondary Elements
1	New condition or no noticeable condition loss	0	0
2	Acceptable performance, prior maintenance/repair evident	11%	7%
3	Deterioration or condition loss occurring	59%	37%
4	Potentially unstable conditions	98%	66%

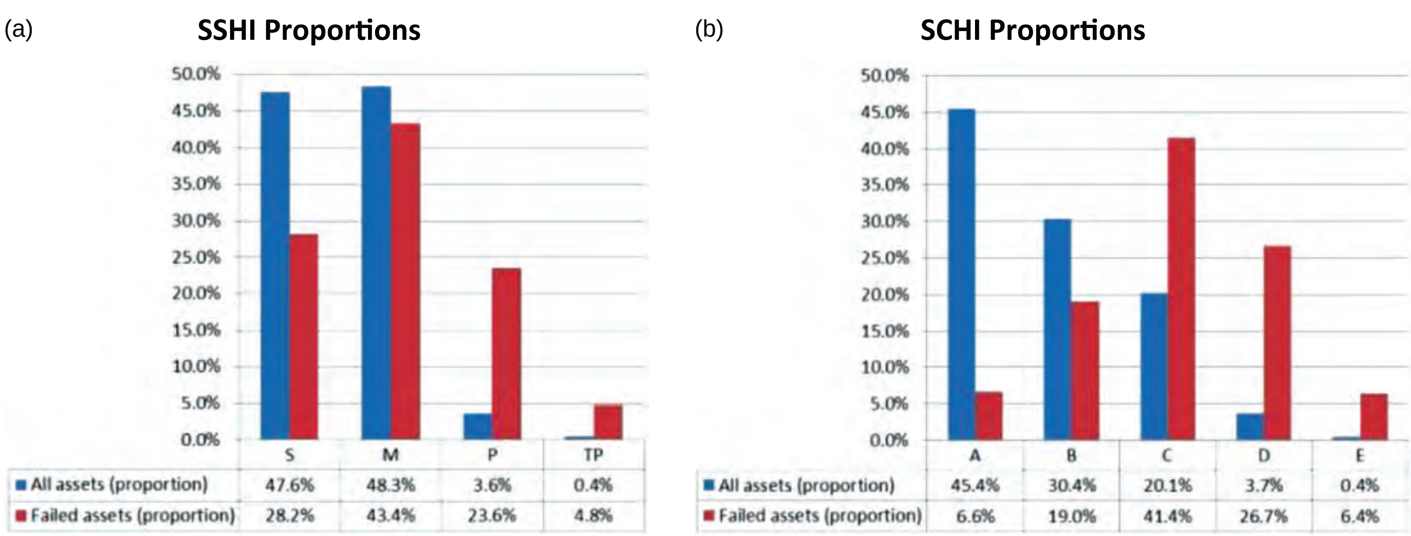
Source: Walters et al. (2016)

Table 7.2. Mobility impact likelihood estimates for the Colorado DOT's wall management system.

National Bridge Inventory Score	Likelihood
7–9	2%
5–6	5%
3–4	26%
0–2	78%

Source: Walters et al. (2016)

and rock slopes supporting the nation's rail system. In 2013, following a series of six derailments resulting from historic rainfall in 2012, the agency updated its methodology for estimating hazard index scores, a surrogate for likelihood of failure, from inspection data. The initial hazard score methodology had been established in the early 2000s, based on expert judgment. This initial hazard score was used to assign a soil slope hazard index (SSHI) based on presumed correlations between various visual observations of distress and five types of failure modes (e.g., deep rotational, shallow rotational, and so forth). Greater values of SSHI were intended to correspond to greater likelihoods of failure, with slopes assigned classifications of "Serviceable," "Marginal," "Poor," or "Top Poor" based on the SSHI score. After a review prompted by the 2012 derailments, the initial SSHI methodology was deemed unsatisfactory based on the observation that approximately 70 percent of slope failures were occurring in slopes deemed Serviceable or Marginal, as shown in Figure 7.2(a). The hazard rating system was calibrated using observations of approximately 1,000 failed slopes. As described by Power et al. (2016), the calibration procedure involved determining correlation between failure rates and approximately 200 differing slope characteristics, with the updated hazard score influenced most by characteristics with greatest correlation. The updated soil cutting hazard index



Source: Power (2015)

Note: The SSHI Proportions figure (a) shows the old system and the SCHI Proportions figure (b) shows the updated system based on observed failures. In (a), "S" indicates Serviceable; "M," Marginal; "P," Poor; and "TP," Top Poor. In each column, "All assets" appear on the left and "Failed assets" appear on the right.

Figure 7.2. Proportion of all Network Rail slopes and failed slopes using differing slope hazard classification levels.

The Network Rail program demonstrates the value of GAM process improvements with time after implementation versus delaying implementation in favor of greater data certainty.

(SCHI in Figure 7.2) was used to assign five hazard levels from A (least likely to fail) to E (most likely to fail). As seen in Figure 7.2(b), the percentage of failures from each category is more reasonable than under the previous system, considering the total quantity of all slope assets in each category.

Three important conclusions follow from the Network Rail example. First, the agency's efforts show the value of calibrating *hazard scores* (a Network Rail term that estimates likelihood) to observed failure rates. The agency's updated methodology for scoring hazards (e.g., measuring likelihood) produces a distribution of scores that more closely matches observed failure rates several years after the first implementation processes began. Because they are better predictors of actual performance, the updated scores should lead to more accurate rankings and better decision-making. Second, collection of condition and performance data over a multi-year time period enabled the accuracy of decision-making to be improved. Network Rail's updating procedure was feasible only because the agency had an inventory of slopes with physical characteristics, condition data in the form of visual observations for all of the assets, and performance data regarding whether or not each slope had failed. This second conclusion follows from the first. Third, the agency's hazard scoring system shows the advantages of combining expert judgment and observed performance to improve the subjective estimates through calibration with observed performance. It is important to recognize that performance history can have uncertainty, particularly with respect to low-frequency events and particularly if there is not much performance information (e.g., in the early stages of an agency's tracking efforts). The Network Rail example provides evidence of the value of combining both types of predictions and the value of conditioning the predictions on available physical and condition information.

Estimating Consequences

Consequences of adverse events can take many forms: damage to roadways and adjacent facilities, injury or death to roadway users, delays due to detours, or other less quantifiable consequences, such as reputation. The two challenges of estimating consequences are (1) to account for all potential consequences and (2) to quantify the consequences consistently. As for estimating likelihood, adopting consistent procedures for estimating consequences helps achieve estimates of risk that are reasonable, at least relative to one another, which leads to appropriate rankings and facilitates better decision-making. Perhaps the most straightforward approach to quantifying consequences is an economic approach that assigns monetary values to all consequences. Agencies have also adopted other, context-specific measures of consequence (e.g., use of traffic counts of affected vehicles).

Tracking geotechnical asset expenditures with unique accounting codes will improve consequence estimates over time, and agencies will gain valuable information regarding the frequency of events, which can be used to improve likelihood estimates.

In economic terms, consequences can be divided into *direct costs* and *indirect costs.*

- **Direct Costs:** This term refers to costs incurred by the owner agency for maintenance, repairs, and replacements. Dominant sources of direct costs include labor and material costs associated with design, construction, maintenance, and repair/rehabilitation operations. Importantly, direct costs include not only the amounts paid by agencies to external entities (e.g., contractors), but also internal costs (e.g., costs associated with agency personnel time, agency equipment, agency materials, and so forth). Indirect costs refer to all other costs incurred by any entity as a consequence of the adverse event.
- **Indirect Costs:** This term refers to a category that includes safety costs (i.e., injuries and fatalities); costs associated with user delays (also known as *mobility costs*); lost productivity; costs associated with lost economic activity; and environmental costs. Indirect costs are an important consideration, particularly in relation to large events, for which indirect costs can be several times greater than direct costs.

Indirect costs may be perceived as more difficult to estimate than direct costs, but resources are available to support the process, such as the *User and Non-User Benefit Analysis for Highways*

(AASHTO 2010) and similar, agency-specific documentation that is used in traffic design or pavement management. Individuals involved in GAM implementation are advised to seek the engagement of other agency staff who can provide guidance on indirect costs should there be unfamiliarity with the concepts, as this experience typically exists within an organization.

Several techniques exist for estimating direct costs. In order of increasing complexity, the methods include judgment (or "ballpark estimate"), using costs from historical agency records, conventional estimating techniques, and obtaining quotes from potential contractors. In reality, estimates often are based on combinations of these methods. For example, a conventional estimate using unit costs from historical records is generally a sound method for estimating direct costs. To improve cost estimates over time, agencies can track expenses related to maintenance and repair of geotechnical assets using unique accounting codes. Such a technique has been planned as part of the Colorado DOT's retaining and noise walls asset management program (Walters et al. 2016).

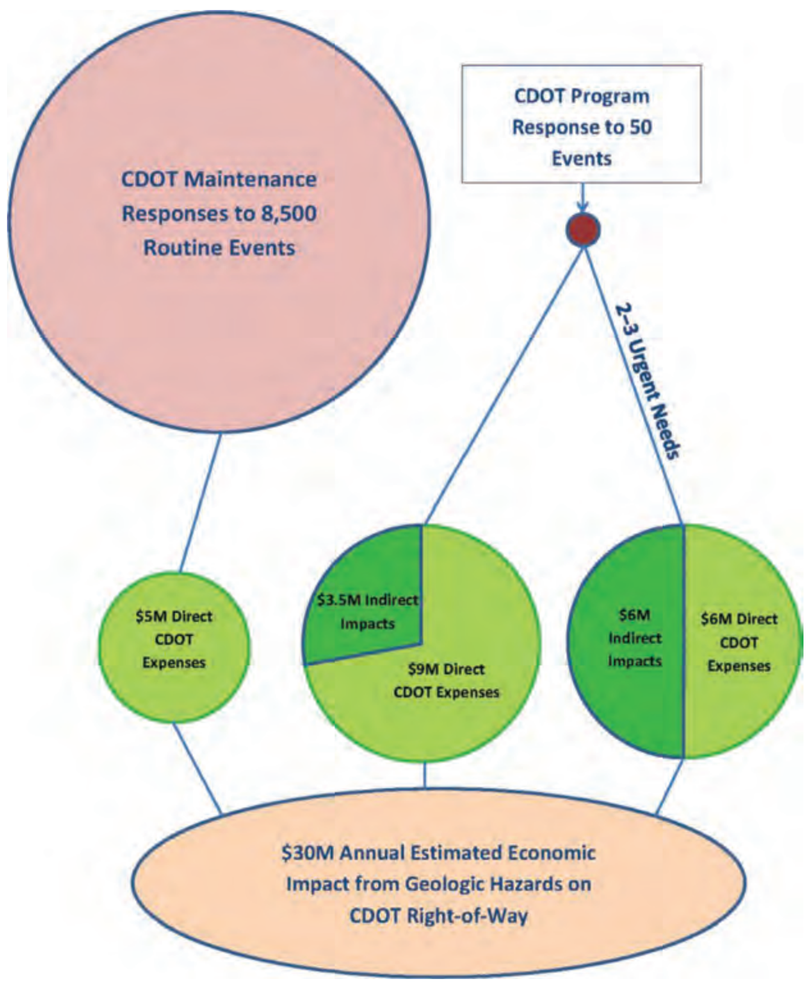
The manual for the NHI "Slope Maintenance and Slide Restoration" course (Collin et al. 2008) includes guidance for developing cost estimates for slide repairs, as well as general information regarding the economics underlying risk-based decision-making. The manual lists items that should be considered in a cost estimate for slide repairs via "remove-and-replace." The list highlights the breadth of items to be considered for a relatively simple repair project, and includes items that might frequently be overlooked in agency cost estimates because they represent internal costs. The list from Collin et al. (2008) is reproduced here:

- Site investigation and monitoring required prior to, during, or following construction;
- Mobilization of personnel and equipment;
- Traffic control (e.g., signs, barrels, flag personnel, and so forth);
- Excavation of deleterious material;
- Hauling and spoiling of excavated material;
- Acquisition of replacement material (e.g., rock fill, "shot" rock, and so forth);
- Placement of replacement material;
- Repair/replacement of damaged signs, guardrail, pavement, shoulders, and so forth;
- Seeding and erosion control following construction; and
- Overhead or administrative costs.

It is important to remember that indirect costs are largely borne by external entities, which makes it difficult for an agency to track them. Assigning monetary values to some indirect costs also has uncertainty because the costs are not fundamentally economic in nature (e.g., fatalities). The AASHTO *User and Non-User Benefit Analysis for Highways* (2010) provides guidance for quantitative estimates of indirect costs, and this guidance was incorporated into the Alaska DOT&PF GAM program (Thompson 2017). In addition to these resources, financial and other SMEs within an organization can offer experience estimating the magnitude of indirect costs. These resources can be consulted when evaluating indirect costs in risk analysis, both to gain familiarity with the process and to establish awareness of connections between geotechnical assets and indirect cost consequences.

In addition, efforts have been made to quantify indirect costs associated with failure of geotechnical assets, particularly those associated with natural hazards. For example, a report for the Appalachian Regional Commission (HDR 2010) examines the costs associated with a 2009 rockslide along I-40 just south of the Tennessee border. The slide led to a 6-month closure of the Interstate, cost $10 million to clean up, and the official detour was more than 100 miles long. Fortunately, the incident caused only minor injuries and did not lead directly to any deaths or major injuries. The authors of the report estimated transportation costs associated with the detour to be $175 million. Transportation costs included in the estimate were vehicle operating costs associated with the detour, diversion travel time costs (i.e., lost time of users), emissions costs, and costs associated with impacts on the detour route, including increased congestion and increased pavement maintenance needs. The estimated transportation costs did not account for impacts on the local and regional economies. To include information on these impacts, the report authors interviewed representatives from seven local development districts in the area. Reported effects documented from the interviews included decreases in lodging revenue between 50 percent and 80 percent, and decreases in restaurant and retail business between 30 percent and 90 percent, among other impacts.

Vessely et al. (2017) performed a similar evaluation of economic impacts associated with geohazards on the Colorado DOT's system. Figure 7.3 shows the results of this study, including the three types of events considered in the analysis: routine maintenance events, less consequential geohazard events, and urgent geohazard events. In Figure 7.3, routine maintenance events form the left branch of the diagram and more critical events are on the right branch. Within the "events" branch, a further division shows the less consequential geohazard events in the middle of the diagram and the urgent geohazard events on the right.



Source: Vessely et al. (2017)

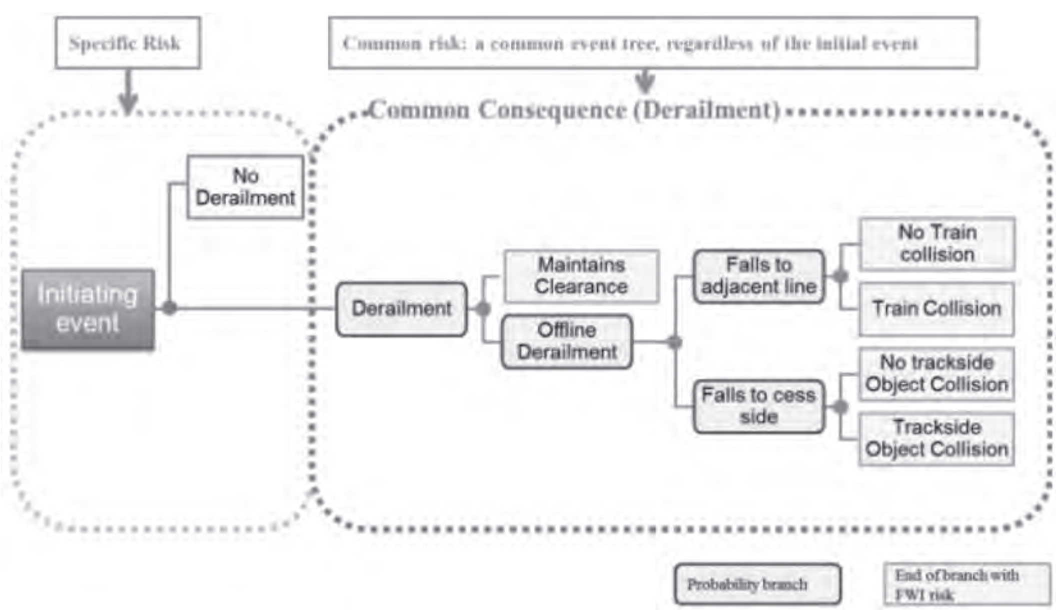
CDOT = Colorado Department of Transportation

Figure 7.3. Summary of direct and indirect economic costs to the Colorado DOT's system associated with geologic hazard events.

Routine maintenance events were evaluated based on a review of Colorado DOT work orders between 2010 and 2015. The average annual direct cost for these events was $5 million based on the work-order totals. Indirect costs associated with the routine maintenance events were neglected. More consequential events were evaluated using data from the Colorado DOT Geohazard Program, which initiated a data management program for impactful events in 2014. The results shown on the right side of Figure 7.3 reflect the Geohazard Program data for 2014 and 2015, which indicated 50 geohazard events per year, with one-fifth of the events causing road closures with a total annual duration of 250 hours. Vessely et al. (2017) note that neither study year included the types of major events that have, in the past, led to more significant delays (e.g., the 2004 and 2010 rockfall events in Glenwood Canyon). Two or three events per year were deemed urgent, requiring the use of external contractors. These events, represented on the far right side of Figure 7.3, had total costs approximately equal to all of the other 50 annual geohazard events combined, as well as a greater proportion of indirect costs compared to the less urgent events. Vessely et al. estimated indirect costs according to AASHTO's *User and Non-User Benefit Analysis for Highways* (2010). The indirect costs included in the study are costs associated with delays, operating expenses, environmental impacts, and accidents. The Vessely et al. analysis is evidence of the value of agencies tracking costs associated with routine maintenance as well as more significant geohazard events. Such information is useful for quantifying consequences and implementing a risk-based system for GAM.

Some agencies have adopted non-monetary measures for consequences. For example, Network Rail uses "Fatalities and Weighted Injuries" (FWI), which Power et al. (2016) describe as a "widely used safety metric." A primary advantage of using FWI is that the methodology for estimating FWI is consistent across asset management systems within Network Rail; there is nothing unique about geotechnical assets with respect to predicting FWI.

The procedure for evaluating FWI is outlined in Figure 7.4. The evaluation assumes some initiating event to have occurred. Evaluation of the likelihood of such an initiating event was discussed in the previous section of this chapter regarding Network Rail's calibration of likelihoods



Source: Power et al. (2016)

Figure 7.4. Network Rail: Chain linking events with common consequences.

based on observed failure rates; however, for the purposes of estimating FWI, the occurrence of the initiating event is treated as a certainty. From the initiating event, a series of evaluations are made along the *event chain* shown in Figure 7.4. The "links" on the chain line up on branches, and each branch of the chain is associated with a distinct set of probabilities. The sets of probabilities vary as a function of track and train characteristics.

Practical Applications for Risk-Based GAM

The inventory and assessment process incorporated into the GAM Planner quantifies risk in terms of likelihood and consequence. The approach is based on successful practices and is intended to support a simple level of GAM maturity. As the outcomes from GAM are realized and temporal (time-based) data on asset performance is obtained, organizations will have the opportunity to increase precision in risk-based concepts.

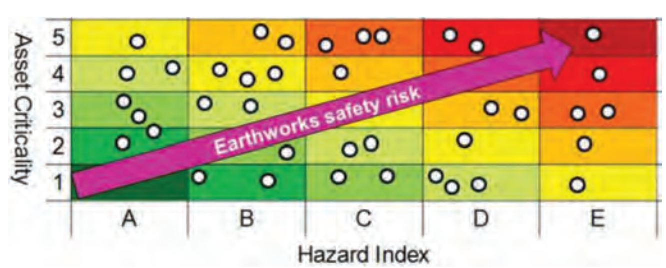
For asset managers and geo-professionals who are implementing GAM using this manual, simply having an awareness of these risk-based concepts is all that is recommended. Once the agency gains familiarity with GAM and feedback from stakeholders becomes available, the implementation process can, where justified, consider process improvements to the asset risk analysis such as those discussed in the Colorado DOT and Network Rail examples. To the benefit of agencies now starting GAM implementation, these prior examples will continue to mature, thus enabling future agencies to realize gains more quickly.

Ranking Risks

Regardless of the level of precision in risk analysis, it is useful to summarize the evaluations of risk across assets to communicate the results. The simplest approach is one-dimensional: create a list of assets, ranked by risk value, in a risk register similar to the GAM Planner inventory. Many agencies have adopted two-dimensional graphics with *likelihood* on one axis and *consequence* on the other. Figure 7.5 shows an example of such an approach, which is used by Network Rail. (Note: "Hazard Index" is a surrogate term for likelihood in the Network Rail program, and "Criticality" relates to consequence). For the two-dimensional graphics ("risk matrices"), assets that fall farther from the origin are associated with greater risk exposure.

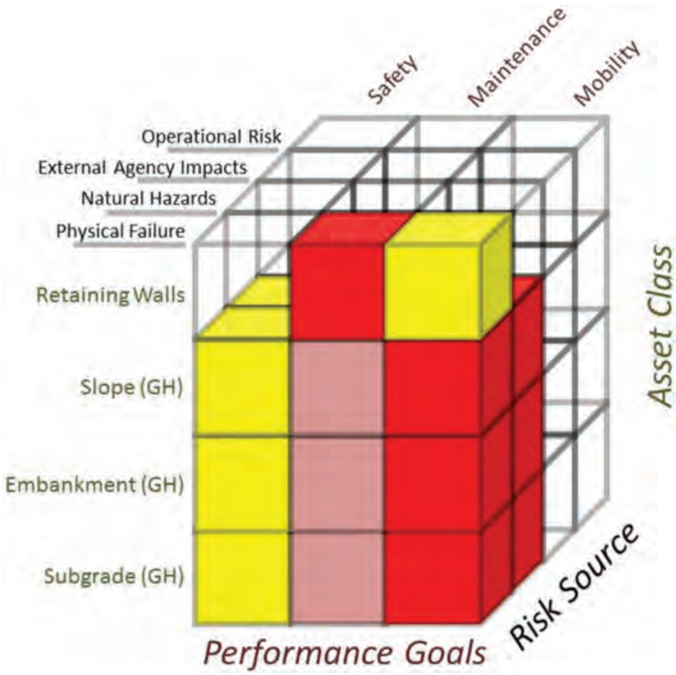
Variations in color or shading often are used to help communicate the magnitude of risk. In the full-color version of Figure 7.5, the colors shift from dark green (bottom left) to lighter greens, then yellow, orange, and red as the safety risk increases. The darkest red (at the upper right corner) indicates the greatest risk level.

Evaluations of risk also can be presented three-dimensionally using the risk-cube concept developed by Anderson (2016) and introduced in this manual in Figure 7.1. Figure 7.6 illustrates



Source: Power (2015)
Note: In the color version of this matrix, the cell at top right is deep red, signifying the greatest safety risk.

Figure 7.5. Example of risk rating matrix from Network Rail.



Source: Power (2015)

In this image, the darkest shading (red in the full-color image) indicates the highest relative risk exposure. GH = normalized gradient slope.

Figure 7.6. Example of communication of risk exposure areas, sources, and asset types at the Colorado DOT.

a risk cube based on relative magnitude for measurable exposure areas and risk sources for GAM. This figure could be further supplemented by using quantitative risk analysis results to indicate the specific monetary risk values used by the Colorado DOT in each cell, thus offering an alternative means of communicating the results.

Aggregation of Risks

In addition to ranking risk, the output from a GAM risk analysis can enable an organization to evaluate cumulative or aggregated risk among groups of assets. This process involves examining assets for which multiple risks exist. For example, in GAM implementation, this could involve locations with several assets near or in the same segment. Figure 5.2 shows a retaining wall and slope asset within a segment. By considering aggregation of risk, an organization can both identify concentrations of risk and realize opportunities in management.

The evaluation of aggregated risk can benefit calibration of models, communication, and treatment prioritization activities. With respect to calibration for a simple GAM program, areas with high concentrations of risk in the GAM Planner inventory can be reviewed subjectively to determine if the output is representative of poor system performance. To illustrate this point, if several high-risk GAM assets are located within a relatively short length of roadway, this area should be apparent to operations and executive staff, even without a GAM inventory. In a more precise risk analysis process, such as the Colorado DOT wall example, the agency can compare the estimated monetized risk exposure values with actual system performance in terms of annual maintenance expenses and mobility consequences. Although it is not necessary to have an exact match, if the exposure estimates are within an order of magnitude of known performance, the comparison could suggest calibration between the modeled risk and the actual risk performance.

Aggregation of risk also can benefit visualization of where concentrations of risk may exist, effectively creating separate GAM corridors. These GAM corridors can then be a means to prioritize treatment based on potentially differing performance expectations or criticality among various corridors. Additionally, it is important to consider all geotechnical assets when there is concentration of risk, for several reasons:

- Treatments of one asset may adversely affect another asset;
- Treatment of a single asset may not reduce the total risk in a corridor, as risk remains from other assets; and
- Treating multiple assets in the same location at the same time may offer efficiencies.

Chapter 8 provides further discussion of how to prioritize treatments.

CHAPTER 8

Practical Implementation of GAM in the Agency

Introduction

Chapters 3 through 7 of this manual have provided additional background information for asset management and supporting data collection, assessment, and analysis processes that help enable GAM to realize benefits across the TAM spectrum; however, processes and data alone will not enable GAM. This chapter proposes specific steps and additional tools that can help executives, asset managers, and geo-professionals implement GAM.

Any organization will have a mix of individuals with differing levels of motivation for completing a target task and differing levels of ability for completing the task. To accommodate the unequal engagement of agency staff, the implementation approach in this manual is purposely simple and flexible. This *GAM Implementation Manual* focuses on a stated outcome of obtaining executive buy-in. For individuals with high levels of motivation and ability, the guidance in this manual can be an additional resource to use in an agency-specific GAM implementation process.

The simple implementation plan and GAM Planner described in Part B of the manual are intended to enable agencies without GAM plans to quickly start implementing of GAM with a minimal investment of time and resources. Starting quickly enables benefits to be realized sooner while also setting the stage for advancing the maturity level of asset management as justified by favorable business outcomes.

For maximum flexibility in the implementation process, the guidance in this chapter is purposely presented *not* as a linear process that builds step upon step. Rather, use of the guidance in this chapter will allow the GAM implementation effort to adapt to the people, process, and data available in each agency while representing forward progress toward a more mature and comprehensive GAM program (see Figure 8.1).

GAM Team Implementation

Asset management is a cross-disciplinary process. Regardless of how the roles and responsibilities of the agency's asset management staff are formally structured, the asset manager for geotechnical assets should expect to work with staff from other disciplines within the organization, including:

- **O&M,** to understand work performed or needed for geotechnical assets;
- **Budget and Financial Planning,** for development of short- and long-term financial plans;
- **Traffic and Safety,** to understand what opportunities exist for measuring the traffic disruption or potential safety incidents that result from adverse geotechnical asset performance;

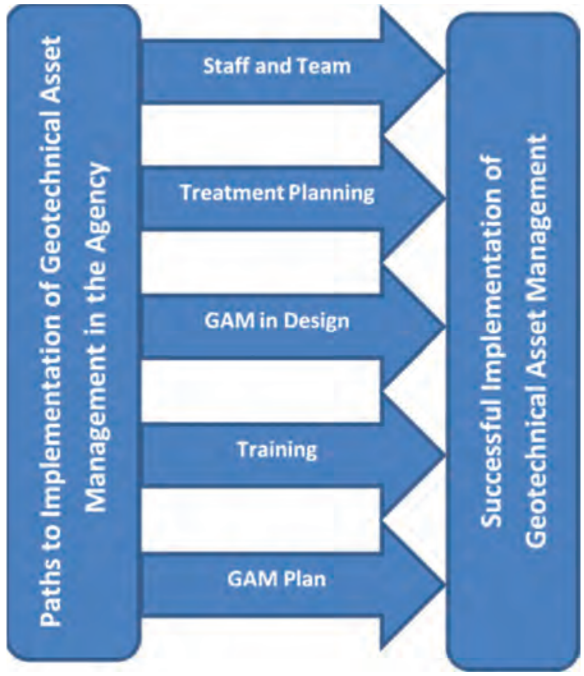


Figure 8.1. Beneficial paths toward implementation of GAM.

- **Enterprise Information Technology,** or other groups responsible for tracking expenses associated with geotechnical assets (this may also be an O&M staff function);
- **TAM (and Other Planning Groups),** to stay apprised of current asset management and strategic performance planning;
- **Engineering and Project Delivery,** to engage staff involved in design or other influential decisions for geotechnical assets;
- **Data Management and/or GIS,** to develop compatibility with established data systems and improve the communication of results through mapping or geo-referenced data systems used by the organization;
- **Other Asset Groups (such as Bridge and Pavement),** to support cross-asset management options; and
- **Executive Management,** for agreement on performance objectives, consensus-building, and program support.

Interacting with staff from the disciplines listed will be helpful at any level in the GAM implementation process. Additionally, individuals from these disciplines may be able to support process improvements in the GAM program. For example, budget and planning staff may have the financial background to assist with improving life-cycle cost models for geotechnical assets. Data management professionals are an emerging discipline in some organizations and may be able to provide skills that enable the GAM inventory process to improve through use of mobile collection tools and data standardization process improvements.

The level of engagement across disciplines and roles will vary, but disengagement from a discipline should not prevent implementation of GAM. At a minimum, every DOT that receives federal funds must have a TAM plan, which provides the opportunity for geotechnical assets to be included, as these geotechnical assets are important contributors to the performance of pavement and bridge assets. Even an agency that has low levels of engagement (or disengagement) from multiple disciplines will likely have some cross-disciplinary staff who understand the purpose and need for GAM and who will be stakeholders and advocates to the process.

For agencies that choose not to formally incorporate geotechnical assets into the TAM plan or that may experience disengagement from executive and planning disciplines, the opportunity for a "bottom-up" implementation of basic asset management steps will still exist and can be pursued by geo-professionals based on good stewardship of public funds.

Aspirational GAM Team Structure

Examples from domestic and international agencies indicate that the furthest progress in GAM implementation has occurred when an individual or groups of individuals who are given the responsibility for GAM work with other asset managers while supported by a high level of interest from executives, financial directors, and maintenance managers within the agency. In these existing management programs, the duties of the "geotechnical asset manager" make up a full-time or nearly full-time assignment without conflicting design or construction duties. Based on the success of existing programs, this approach would be the ideal structure for implementing and developing a GAM program to maturity.

In the more mature GAM programs at Highways England and Network Rail, multiple agency staff are involved in GAM, with additional support provided by consultants. The sustained success of GAM implementation in these organizations suggests the potential for multiple agency staff to be dedicated to GAM as programs mature in the United States.

Other GAM Team Structure Approaches

As used in this chapter, the term *geotechnical asset manager* references the individual who takes on the responsibility for starting the GAM implementation, whether the implementation is a dedicated role or undertaken as an ancillary or voluntary duty. Thus, the geotechnical asset manager can be an agency geo-professional, asset management SME, or other interested stakeholder with availability to start the program. To assist with a broad adoption of GAM, the implementation process in this manual has purposely been developed such that a geotechnical asset manager does not need to be a geotechnical engineer or other geo-professional.

It is anticipated that most DOTs will not be able to formally establish a high-functioning, cross-disciplinary team at the start of GAM implementation. In these situations, the GAM implementation team can be as simple as a single individual who starts the inventory and assessment process using the GAM Planner introduced in Chapter 2. Even starting implementation based on development of a small inventory of 10 geotechnical assets as an ancillary work duty can be considered progress and should not be discounted.

Staff organizational structures for TAM programs vary by DOT, but typical roles involve some form of senior-level enterprise asset manager working in parallel with or within other functional disciplines such as design, construction, O&M, financial, and administration. Many agencies also utilize asset management working groups or advisory teams. Composed of executive-level representatives, these working groups or teams provide strategic oversight of the senior/enterprise asset manager and supporting functional disciplines contributing to the TAM program. Figure 8.2 provides a conceptual view of this centralized asset management structure. Examples from international public infrastructure organizations with advanced asset management programs and cultures indicate that asset management also can be a lead function that directs the other functions of planning, design, and operations.

For an agency starting GAM implementation, the geotechnical asset manager role conceptualized in Figure 8.2 could be a duty added to the manager's existing TAM functions and located within the engineering or geotechnical design divisions, incorporated into bridge or pavement management groups, or placed within the O&M function. If the GAM implementation takes

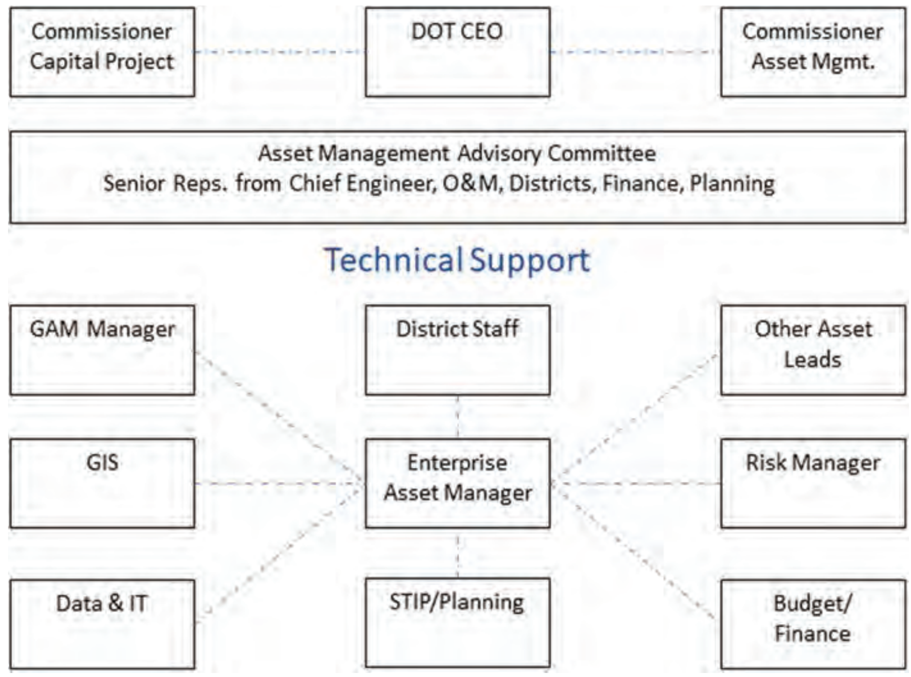


Figure 8.2. Conceptual view of U.S. DOT organizational structure for TAM program.

place outside of the enterprise asset management function in the agency, the geotechnical asset manager should work to interact with the TAM program on a regular basis to enable future integration into the enterprise program.

To assist with consensus-building and communication, the geotechnical asset manager can form a cross-disciplinary GAM working or steering group that will facilitate building the relationships necessary to support GAM. The purposes for a working group include developing a wider base of support in the agency, sharing of information, coordinating activities that influence asset management, and developing the business cases for GAM across several disciplines.

Asset Management Treatment Program Development

Treatments are the actions an agency takes in the management of assets. As listed in the GAM Planner, treatments can be described in four basic categories: Do Minimum, Maintain, Rehabilitate, and Reconstruct. (Because the fifth treatment category, Restore, is triggered only when an asset fails, it is discussed separately in this manual.) As of 2018, very few state DOTs were specifically funding GAM implementation. Among state DOTs that were funding GAM, the investment amounts were generally small. For DOTs moving forward with GAM implementation, obtaining funding for GAM treatments may involve incorporating a course of standard maintenance activities (i.e., Maintain treatments) or obtaining funds already encumbered from existing budgets. Thus, a deficit condition relative to modeled needs can be expected at the start of implementation.

The geotechnical asset manager can employ a range of prioritization approaches to satisfy the most pressing investment needs when implementing a GAM program that is funded below total need. These prioritization approaches can be applied at any time after inventory and assessment have begun. Additionally, in the absence of any funding for proactively mitigating

GAM-identified risks, the program still offers value in the communication of probable consequences from the failure to invest.

Figure 8.3 presents a conceptual GAM treatment prioritization process. This process is intended to identify the treatments that enable an agency to obtain the greatest progress toward objectives given an expected investment capacity that is well below the modeled needs. Specific treatment projects can involve efforts to Maintain, Rehabilitate, or Reconstruct geotechnical assets. Using a prioritization approach is recommended to enable a favorable implementation environment for GAM among executive and TAM stakeholders. Because DOTs are complex organizations, the process should not be viewed as a series of rigid steps that will guarantee success. Rather, the prioritization process offers options that may enable acceptance of GAM and ultimately win investment support from executives.

Implementing Risk-Informed GAM Prioritization Decisions

Once a simple, initial GAM inventory has been created for a collection of assets and use of the GAM Planner (assessment model) has begun, the geotechnical asset manager has the opportunity to use the *Initial Recommendation* outcome from the model to propose asset management options using risk management and investment practices at the project-specific level. This process can and should start before the inventory is complete, because value is lost by delaying further implementation steps while striving for a more complete inventory or while authoring comprehensive plan documents. It is important that the geotechnical asset manager not be distracted by the admittedly worthy goal of having a nearly complete inventory before initiating other asset management steps. Rather, the asset manager is encouraged to use the information available for the current asset inventory and begin implementing steps that will enable the agency to realize the benefits from GAM as soon as possible.

Once a favorable investment situation has been identified, the opportunity exists to realize benefits, and delays will become lost value to the agency.

Risk Management Concepts for GAM Prioritization

In this manual, Chapter 7 presents background information about risk concepts and techniques for analysis of risk within a TAM framework. Once the geotechnical asset manager has obtained estimates of risk from assets, even at a simple qualitative level, those risks can be managed following the approaches detailed in this section. Management options include:

- **Accept or Tolerate the Risk (Acceptance):** This option is a common practice for agencies that have no GAM program;

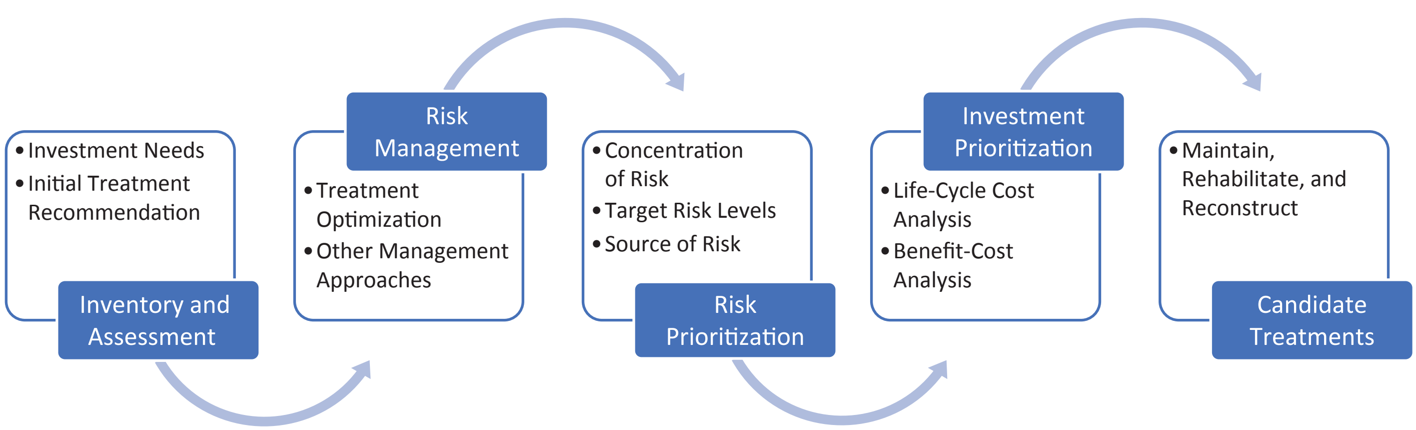


Figure 8.3. GAM treatment project prioritization process.

- **Apply a treatment:** This option is taken to reduce or remove the risk (e.g., by applying draped or anchored mesh to contain rockfall);
- **Transfer the Risk:** This option typically involves transferring specific risks to a local or federal jurisdiction or through insurance programs); or
- **Terminate the Risk:** In some situations, risks to the DOT can be eliminated (e.g., by devolving the highway or establishing an alternate route).

For a risk-based GAM program, the asset manager would assess the potential benefits of each of these risk management options. Figure 8.4 illustrates how these management options can refocus geotechnical asset risk from an unquantified "thing" into a known and accepted *residual* risk, thus enabling the reduction of overall geotechnical asset risk to the DOT.

NCHRP Project 08-93, "Managing Risk Across the Enterprise" (Proctor et al. 2016) adds a fifth management option, **"Take Advantage."** Although this option may exist for geotechnical assets at some time in the future, the contractor's final report on this NCHRP project indicates that this option can occur only after careful evaluation of risk has identified that the potential upside exceeds the likelihood of negative consequences. Agencies will need to have developed an informed understanding of the risks from their geotechnical assets before they can evaluate the potential for realizing opportunity in a risk-based GAM program.

In a DOT GAM program, the two most frequently used risk management options will be either (1) to accept (or tolerate) the risk or (2) to apply a treatment. Options also exist to *transfer* or *terminate* the risk. The rest of this section provides brief descriptions of the four management options. Although they are used less often, the options to transfer the risk or to terminate the risk are included because potential value can be realized by investigating and applying them.

- **Acceptance of Risk:** By default, a DOT with geotechnical assets but without GAM essentially opts to accept all the risks—known and unknown—from geotechnical assets that can impact the agency. Although omitting consideration of these risks can be an acceptable management option, it is important to understand that *these risks still exist.*

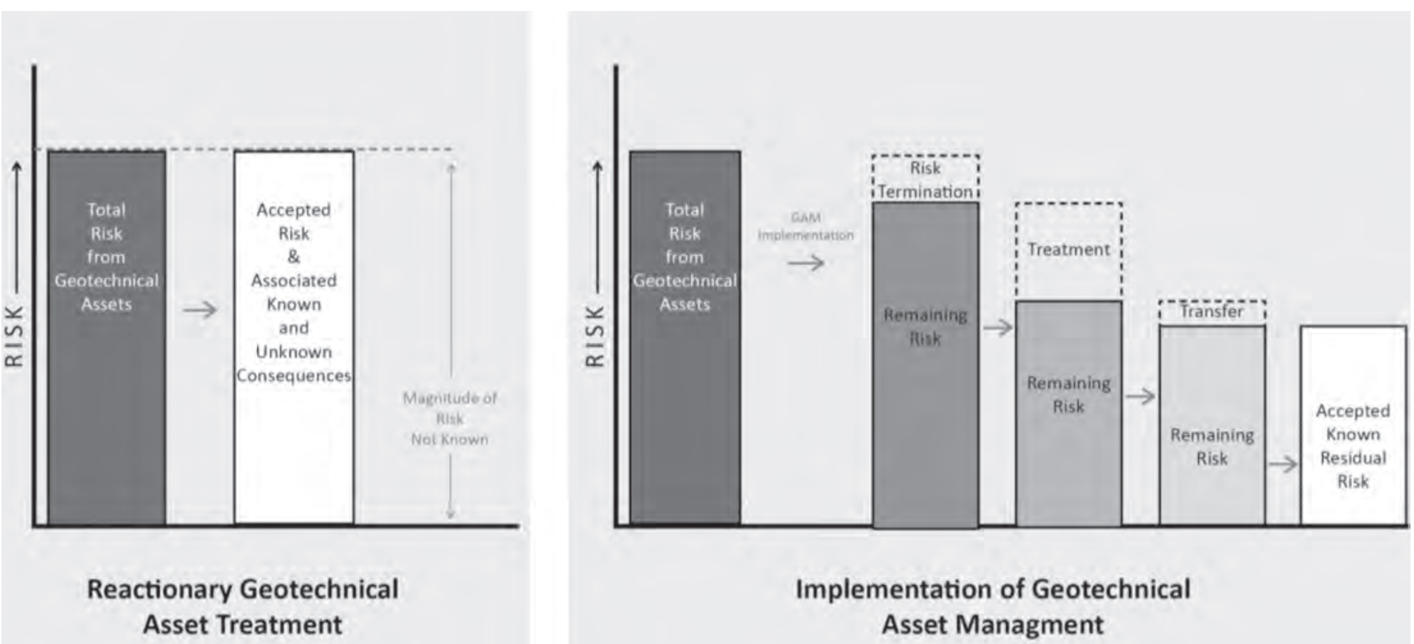


Figure 8.4. Conceptual reduction of risk through management options.

By initiating the simple GAM model described in Part B of this manual, an agency can quantify its current risk exposure from geotechnical assets in relation to the agency's performance objectives for asset condition, economic vitality and mobility, and safety. Even if the agency chooses not to act on the investment recommendations from the GAM Planner, at a minimum the agency will be better informed as to the geographic distribution and magnitude of risk exposure for the inventoried geotechnical assets. In other words, the agency will be able to increase its awareness of *known* risks while reducing the amount of *unknown* risks. Communicating GAM model outcomes in terms of a known risk acceptance can be a valuable step toward gaining support for further GAM implementation, as executives are more likely to be receptive to communication that quantifies the current risks being accepted through legacy operational practices.

- **Treatments:** Basic treatment options familiar to asset managers have been discussed in Part B of this manual. Four treatment options that are frequently used by agencies are supported through the Do Minimum, Maintain, Rehabilitate, and Reconstruct initial recommendations in the GAM Planner.
- **Transfer of Risk:** Risk transfer involves shifting the ownership of the asset *risk* (and responsibility for its management) to a different entity. This can be accomplished through outsourced, performance-based maintenance contracts or by obtaining insurance, as available, to cover potential events or occurrences. The transfer of ownership applies to the *risk*, not to the asset itself. An example of risk transfer through insurance could involve damage caused by vehicle accidents where the driver is at fault. In this situation, the driver's vehicle insurance can be a source of funding for repairs.

  The literature suggests that transfer of risk has not been considered specific to GAM; however, examples exist of public-private partnerships in which the O&M risk of transportation assets is agreed to be the responsibility of private entities. Other examples of risk transfer can be drawn from the Swiss PLANAT program, where cost sharing among affected stakeholders is used to transfer portions of natural hazard risks within a multi-agency framework. Additionally, options may exist for using insurance to cover financial impacts (e.g., from natural hazard events above a certain recurrence level or for damage affecting third parties). Often, federal agencies such as FEMA or FHWA will help pool risks for state or local entities and assist in recovery from major loss. This process essentially serves to "transfer" the risk of catastrophic loss from natural events from the state or local agency to the federal agency.

  Although uncommon, options for risk transfer can exist and should not be eliminated from consideration. If deemed viable, these options would require significant input from other agency programs, such as maintenance, legal or risk management, and executive management. The asset manager is encouraged to evaluate if any risk-transfer options may exist.
- **Termination of Risk:** Risk *termination* (sometimes called risk *avoidance*) consists of ceasing the activity that generates the risk. An extreme example of risk termination could involve permanently abandoning portions of the network that creates high levels of risk. Less extreme approaches to risk termination could involve limiting travel in certain corridors at times of high hazard to reduce risks to traveler safety. This approach is similar to closing a mountain pass during times of high avalanche hazard or evacuating coastal towns prior to landfall of a hurricane. These actions do not necessarily reduce mobility, but they can reduce safety risk exposure. At the project/asset level, risk termination can occur via alignment changes or other means of avoiding a hazard or threat.

Evaluation of Changes in Risk for Asset-Level Alternatives

The GAM Planner that accompanies this manual evaluates risk at the program level for performance objectives related to asset condition, safety, and economic vitality and mobility. Once a treatment recommendation is known for an existing asset, the geotechnical asset manager can optimize any future asset-level investments by considering the potential trade-offs in the LOR that would result from asset-specific alternatives. The next sections in this chapter provide an introduction to project-level risk considerations for treatment alternatives.

- **Risk Treatments:** As discussed in Chapter 4 of this manual and in the user information for the GAM Planner, treatment options for geotechnical assets at the individual asset level consist of: (1) Do Minimum, (2) Maintain, (3) Rehabilitate (Rehab), (4) Reconstruct (Renew), and (5) Restore (which is triggered by the model when an asset fails (reaches an O&M Condition level of 5).

  For each treatment category, several alternatives may exist that could be further evaluated on the basis of their relative improvement to economic and risk management criteria. Table 8.1 presents examples of potential asset-specific alternatives in each treatment category and the risk management considerations that could be used to make a selection among those alternatives.

  For each treatment alternative, an asset-level life-cycle cost can be estimated to aid in selection of the preferred investment alternative when there is commonality among mobility and safety impacts for each alternative. This process would be similar to bridge type selection, in that the *function* of the bridge is similar for each type alternative, but different life-cycle cost impacts can be evaluated. In situations that involve trade-offs among safety impacts or broader economic impacts, a cost-benefit model would be recommended to evaluate which alternative provides the greatest benefit. (Additional information about asset-level life-cycle cost estimates and cost-benefit models is provided later in this chapter).
- **Maintenance Planning:** With respect to maintenance planning, the GAM implementation process should consider the value of developing guidance for the agency staff involved in GAM activities related to new and existing assets. In the discussions with state DOTs that took place in the preparation of this manual, the majority of the agencies indicated knowledge of routine or regular work by agency maintenance staff in the maintenance of geotechnical assets; however, the DOTs also indicated that this work is not typically documented or directed by geotechnical or TAM staff unless there is a problem or a request for assistance. In many agencies, records of DOT maintenance work activity on geotechnical assets are not maintained or are kept separately from TAM or geotechnical staff data about the assets. A process improvement that can occur during implementation of GAM is the development of proactive maintenance planning that includes financial planning and scheduling or frequency of work recommendations. Similar to the development of design plans for reconstruction and rehabilitation, maintenance planning can be incorporated as a process improvement as part of the GAM implementation. This practice may be a shift from the current, segregated practices in some agencies that rely on the experience of DOT maintenance staff, who are assumed to be doing the appropriate maintenance activities and at the correct timing. When these experienced maintenance staff are invited to participate as stakeholders in the change, they can contribute their expertise and knowledge base to the planning process.

Incorporating Risk into the Prioritization Process

The output from a program-level asset management analysis, such as that generated by the GAM Planner that accompanies this manual, will enable asset managers to communicate risk and investment needs at the program level in addition to a treatment recommendation for each asset/segment (e.g., Maintain, Rehabilitate, or Reconstruct). Realistically, the output from a GAM assessment will likely indicate investment needs that are well in excess of the funding ability of an agency. As a result, the agency may struggle to fund GAM recommendations, even though potential exists for a positive cost-benefit. This situation simply confirms a commonly

Table 8.1. Example alternative treatments per asset type and treatment category.

Geotechnical Asset	Treatment Category	Asset-Specific Alternatives	Investment and Risk Considerations
Slope	Maintain	Conduct periodic scaling and debris removal. Conduct frequent ditch cleaning.	Each alternative will present a different threat to traveler safety and level of effort for maintenance staff.
Slope	Rehabilitate (Rehab)	Install draped mesh. Install anchored mesh. Install barriers.	Although lower in initial cost, barrier or draped-mesh alternatives may pose a higher threat to safety when compared to anchored mesh.
Slope	Reconstruct (Renew)	Flatten the slope inclination. Install a retaining wall.	One alternative may impact environmental resources or require property acquisition while the other adds a more complex asset to the network.
Embankment	Rehabilitate (Rehab)	Install reinforcements. Conduct a partial reconstruction of the embankment. Install groundwater drainage. Add buttress fill.	Each alternative will have a unique design reliability that will result in differing impacts to future maintenance needs.
Wall	Maintain	Clean and inspect wall drainage elements. Rinse wall elements. Use instrumentation and monitoring (I&M).	Cleaning and rinsing actions require annual investment and resources but can slow deterioration rates. I&M may have lower cost and provide early warning of problems, but it will not slow deterioration.
	Rehabilitate (Rehab)	Add structural reinforcement. Repair/replace deteriorated facing systems.	Each alternative should consider the service life of the rehabilitation method relative to the required remaining service life of the wall asset.
	Reconstruct (Renew)	Rebuild the wall to current design standards.	Select a wall type based on the required service life and lowest life-cycle cost.

(continued on next page)

Table 8.1. (Continued).

Geotechnical Asset	Treatment Category	Asset-Specific Alternatives	Investment and Risk Considerations
Subgrade	Maintain	Increase frequency of pavement treatment.	Evaluate the trade-off between higher initial costs and the potential for reduced pavement maintenance.
		Install and maintain drainage improvements.	
	Rehabilitate (Rehab)	Install ground improvements.	Several improvement technologies exist and can be evaluated using resources such as those at www.GeoTechTools.com.
	Reconstruct (Renew)	Reconstruct the roadway and place improved subgrade materials.	Each alternative will have different initial costs, potential ROW impacts, O&M costs, and expected life-cycle duration that should be considered in the option selection process.
		Relocate the roadway away from the poor subgrade.	
		Incorporate a structural solution to span the poor subgrade.	

understood fact of infrastructure investment: that more needs exist than funds are available, regardless of asset criticality.

Given this reality, the potential for successful GAM implementation improves when investment needs and opportunities are evaluated further, resulting in asset-level maintenance, rehabilitation, or reconstruction treatment projects that produce the highest potential for realization of TAM and other performance objectives. For example, an agency may only be able to dedicate $1 million for GAM treatment recommendations, yet several individual and bundled treatment project alternatives can be proposed. Additional prioritization steps can be performed to build support from stakeholders in the competition for limited resources.

The geotechnical asset manager should recognize that simply communicating investment needs and the potential benefits from increased funding may not be enough to gain full executive and TAM stakeholder support. Although executives may understand the investment needs and the consequences of deferring investment, they also have to balance the needs of other investment priorities. To illustrate the challenge, consider a situation in which 10 programs require investment, but insufficient funds exist to cover all programs to the maximum extent. Of these programs, five programs involve federally authorized requirements that must be followed, three programs already receive discretionary funding, and two programs are new efforts (including a GAM program) that have identified investment needs. In this example, the new programs need to demonstrate benefits that show why their programs should receive funds that likely will need to come from other, already-funded programs (essentially taking money from other programs that are already demonstrating value). To overcome this barrier to full implementation, further risk-prioritization steps at the asset and treatment-selection level can be beneficial in illustrating how best to allocate limited funds. Moreover, having "shelf-ready" treatment projects ready for delivery can be extremely helpful if some level of partial funding is available on short notice.

Treatments can be evaluated in many potential ways, and the prospect of incorporating prioritization steps into a GAM implementation can seem overwhelming, especially if it is done without stakeholder input. Therefore, the discussion in the next section presents a broad framework within which prioritization options can be used by a geotechnical asset manager to connect with enabling stakeholders. Figure 8.5 presents a conceptual view of the prioritization options. Each approach can start as a simple conversation with executives and TAM managers, either during the "communicating results" step of the GAM workflow or at any time when an opportunity arises to discuss goal-setting.

Selecting Treatments Based on Risk Concentration

The LOR measure developed through the GAM assessment can be used to support the optimization of treatment project options. As discussed in Chapter 4, LOR provides a quantified measure of the safety and mobility consequences that may occur as a result of the adverse performance of a geotechnical asset segment. The LOR grade also can serve as a geographic indicator of the distribution of risk from geotechnical assets.

In evaluating the geographic distribution of geotechnical asset risk, there will likely be locations where individual highway segments contain multiple geotechnical assets. For example, a segment may contain a wall or embankment on the outboard side of a roadway and a slope asset on the uphill side, or two separate retaining walls on each ROW boundary. The surrounding terrain also will influence the concentration or quantity of geotechnical assets. For example, a road may pass through steeply sloping ground or cross a low-lying flood plain with continuous embankments.

At locations with a concentration of geotechnical assets, treatment selection should consider *all* geotechnical asset risk. Reasons for this approach include:

- Treatment of one asset could adversely influence the performance of another asset;
- Treatment of only one asset may not achieve the desired total risk reduction, as risk from other assets remains; and
- A scale efficiency may be possible to realize by treating multiple assets in the same location at the same time.

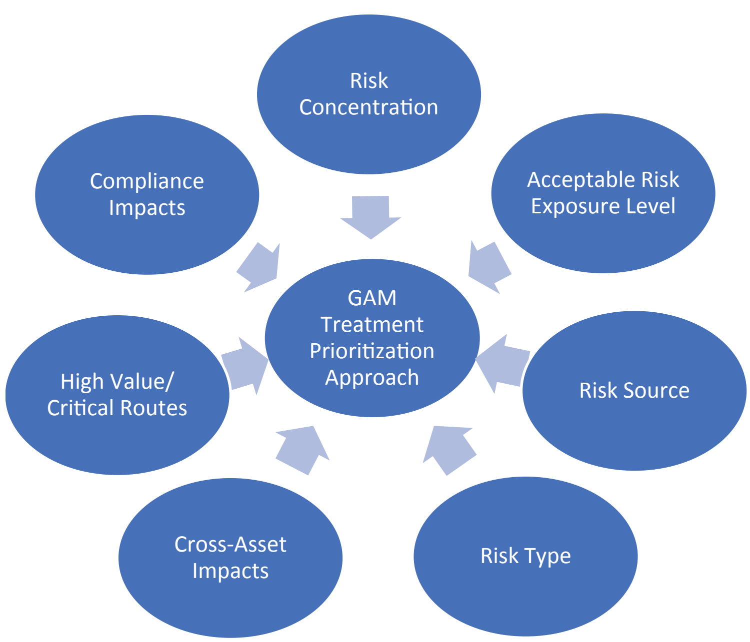


Figure 8.5. Treatment prioritization focus areas for GAM implementation.

Selecting treatment approaches based on risk concentration thus presents both an opportunity and a hazard: The opportunity is the potential for improved cost-benefit relationships through scaling efficiencies. The hazard is that under-allocation of resources could create a perception that benefits are not being realized.

The inventory developed through the GAM Planner will present a LOR measure for each segment. Thus, the data can be reviewed to identify segments with multiple LOR grades, indicating multiple assets at approximately the same location, and also lengths of roadway with joined or close-proximity assets. These areas of risk concentration can be considered corridors with a relative greater concentration of risk from geotechnical assets, and thus represent areas where GAM investment may yield a higher ROI because of the efficiency of treatment in close proximity. Conversely, these corridors also can be locations where GAM investment potential is not fully realized because of overlapping risk exposure that limits treatment effectiveness if only some of the high-risk assets are treated per plan.

Once multiple corridors of concentrated GAM risk have been identified, a comparison of total risk levels between corridors can be a means of prioritizing investment among corridors. For example, consider an agency that has three hypothetical corridors, each requiring approximately $5 million of investment and 2 years to complete the treatments. The agency also can only invest $5 million over each 2-year period. One option would be to invest in each corridor equally, which would require 6 years to reduce the risk in the corridors to the desired level. Another option is to prioritize the corridors in series for treatment. After 6 years, the end result of risk reduction is the same, but in the second option, two of the corridors would realize improvements sooner, which may have a secondary benefit of improving the agency's reputation among the users of those corridors.

Another approach could involve presenting the identified corridors to executives for consideration given other agency objectives. In this situation, one corridor may be judged by executives to have a higher criticality over the others, and treatments could then be prioritized to complete work first on the corridor with higher criticality. Again, the agency realizes the benefits of GAM implementation sooner.

Selecting Treatments to Acceptable Risk Exposure Level

The inclusion of risk-based processes in GAM enables an agency to quantify and measure the current asset risk to performance objectives and, with time, to track and forecast changes in risk that occur in relation to investment levels. As a result, the distribution of asset grades among the LOR categories provides the asset manager a means to communicate the current estimate of risk exposure from inventoried geotechnical assets. For example, even with an incomplete inventory, an asset manager could report that the LOR of 60 percent of the inventory is above a grade of C and the remaining assets are split, with 20 percent of the remaining assets in each of the D and F categories. Further, if the D and F grades for these assets correspond to levels of risk that are undesirable to executive-level safety and economic performance objectives, the asset manager can use the LOR grading system to quickly communicate the outward performance threats from geotechnical assets to stakeholders who may not understand the asset-specific technical performance indicators.

Through this communication step, the asset manager can work with executive and TAM staff on guidance and concurrence for acceptable risk levels from geotechnical assets. Through these processes, over time, targets for LOR grade distributions could be established as a means for defining the acceptable LOR from geotechnical assets.

For example, a $1 million preservation treatment project might improve the LOR grade from C to B for 20 segments, whereas the same funds, directed at an individual asset segment reconstruction, might improve the grade for that segment from D/F to A but would leave 19 segments at C. Should the agency have a performance goal for reducing total risk from geotechnical assets, and if the goal is measured based on the LOR grade distributions, distributing the $1 million maintenance project across the 20 asset segments could be seen as obtaining greater progress toward a risk reduction goal.

Screening Treatments Based on Risk Source

As discussed in Chapter 7, physical failure/deterioration and natural hazards are common sources of risks for geotechnical assets. In general, physical deterioration is a risk source for all constructed assets within the ROW, such as pavement, bridge, and some geotechnical assets. With regard to constructed assets exposed to physical deterioration, the agency typically owns these assets and has several options in design and O&M life-cycle phases for influencing the likelihood and consequence components of the risk to the agency's performance objectives. Natural hazards, on the other hand, often present risks related to natural events. For risks associated with natural hazards, fewer management options may be available to address likelihood, particularly when the natural hazard exists beyond the management boundaries of the agency.

Risks from natural hazards can include major or regional flooding events that affect many agencies and citizens; earthquakes; debris flows and rockfalls that originate from natural features beyond the ROW or other boundaries of the agency; or mega-scale landslide features that preexisted roadway construction but continue to impact operations. Of note, larger scale natural hazard events often have many consequences to non-users of the network, both public and private, and as a result, risk is shared among the affected stakeholders.

Because two principal risk sources affect geotechnical assets, an asset manager has an opportunity to consider risk source in the prioritization of treatment. As an applied example of this differentiation, the mature Network Rail GAM program is directed toward assets within the Network Rail boundary. The Network Rail Earthwork Asset Policy (Network Rail 2017) identifies the management of risks from outside the boundary as an area for future improvement, but this has been treated as a process improvement step to be placed under consideration after several years of implementation of asset management for assets within the boundary.

Based on the differentiation of risk source and the location of those risks, the geotechnical asset manager can incorporate *source of risk* into treatment prioritization planning using the following considerations:

- Differentiate GAM investment categories between those that address physical deterioration and those that address natural hazards.
- Distinguish between natural hazard and physical failure in design and operational decisions for geotechnical assets within the ROW. Examples include:
  - Evaluate embankment and slope stability within the ROW based on natural hazard design event recurrence intervals that match other assets in corridor, such as the 100-year design flood elevation or precipitation event;
  - Evaluate embankment and slope stability within the ROW based on design inputs such as geometry, materials, and ease of maintenance that influence physical deterioration rates, and communicate estimated life-cycle costs for differing design options; and
  - Communicate the value of preservation and maintenance activities in managing the deterioration rate of existing geotechnical assets.
- For features beyond the ROW:
  - Through discussions with executives, establish the agency's management approach and acceptance level for risks from geotechnical features beyond the ROW or other boundary;

– Communicate with non-agency stakeholders who share in the risks from assets beyond the ROW and evaluate the feasibility of making joint investments toward risk management; and
– Evaluate options for risk transfer of natural hazard risk.

The intent of including risk source in the GAM treatment prioritization process is to enable an agency to employ a wider range of risk management options for natural hazards. Case study of these risk sources in the United Kingdom and Switzerland indicate that options for incorporating risk-transfer or pooled-investment strategies may offer a means of reducing risk for a lower agency investment cost.

Selecting Treatments Considering Risk Types

The risk-based process presented in this manual can enable an agency to differentiate between various types of risks that geotechnical assets may pose to an agency's performance objectives. The LOR grade framework presented with the GAM Planner assumes an equal weight between risk to safety and risk to mobility and economic vitality. If desired, an agency could evaluate the inventory data and choose to prioritize GAM treatments that manage safety risk over those treatments that manage mobility and economic safety risk. A similar scenario could involve separately considering risks from natural hazard sources, or weighing those risks differently based on executive input.

A decision on GAM treatment prioritization between risk types should incorporate input from executives. The asset manager should be aware of the option to incorporate risk type in selection of treatments, as this step may identify additional investment opportunities. For example, if a geotechnical asset presents a relatively high risk to safety objectives, the asset manager could request funding from agency sources that are directed at safety improvement or hazard reduction. In this scenario, the financial plan for geotechnical assets may be improved through incorporation of funds dedicated to safety treatments, thereby potentially increasing investment in all geotechnical assets.

Prioritizing Treatments Based on Risk to Other Assets

The historical use of rockfall hazard rating systems is a form of prioritization of slope assets over other geotechnical assets. Although the geotechnical asset manager is encouraged to inventory and manage all assets, situations may occur in which treatment decisions and investments within the inventory are prioritized on the basis of impacts to other, non-geotechnical assets. For example, the asset manager may be able to obtain investment support from a pavement management program when presenting LOR grades for subgrade and embankment assets that also influence pavements condition. Alternatively, a bridge asset management program may support treatments for embankment and wall assets that enable performance of a bridge asset. In these scenarios, the asset manager can access support for GAM through a cross-asset approach.

Incorporation of Agency Value and Criticality into Treatment Selection

Within many transportation agencies, certain corridors or sections of network will have a critical or high-value designation relative to other corridors or sections. These designations typically are based on executive input and reflect the importance of the asset to broader economic or other strategic goals. As a result, these existing criticality designations can be another means to guide risk-based prioritization for GAM treatment decisions. If a hypothetical statewide GAM inventory contains 1,000 assets and 50 of those assets are located within a critical corridor, it may be possible to obtain greater levels of support for the 50 assets within the designated critical corridor. The geotechnical asset manager can seek stakeholder support due to the potential for geotechnical assets to impact performance of strategic or high-value corridors even if the concentration of GAM risk or assets is low.

Risk management is not necessarily about reducing risk, but rather about making informed decisions that connect with agency strategy and objectives. Even the most precise risk process will be ineffective if it is not connected to performance objectives.

Treatment Selection Based on Compliance Requirements

The GAM assessment process presented in this manual is developed around the potential for the asset condition to impact safety and mobility performance objectives. However as discussed in Chapter 7, geotechnical assets can present threats to additional risk types or to agency objectives such as environmental or regulatory compliance. The potential for geotechnical assets to influence compliance with local or state regulations or to increase litigation risks can be a means for prioritizing treatment decisions.

Implementing Life-Cycle Cost Investment Prioritization Processes

Through the implementation of GAM, even with an incomplete inventory, an agency will be able to communicate the risk from geotechnical assets to TAM goals and other strategic objectives. In addition to risk communication, a simple GAM implementation process can gain support from executive and planning stakeholders by prioritizing asset management treatment decisions on the basis of life-cycle cost and/or benefits of investment.

For an agency starting GAM, this investment prioritization process does not need to be complex. The well-established GAM programs for highways and rail in the United Kingdom have matured through process improvements that built upon learned asset knowledge and thus improved reliability in decision-making. Whether the agency is experienced or new to GAM, any decision will have uncertainty, regardless of asset maturity level. For an agency in the early stages of GAM, incorporating processes such as basic life-cycle cost analyses in design and operational decisions enables a systematic and defensible approach to making decisions that can later be updated based on observed performance outcomes. A goal of project-level investment analysis is to enable the geotechnical asset manager to decide what specific treatment alternative will result in the least life-cycle cost and the greatest benefit over the duration of the required project performance period.

Making proactive asset management decisions using simple investment analysis is preferable to continuing more passive legacy approaches while waiting for greater certainty and precision.

The selection of a technique for conducting LCCA will depend on the available data and the required context for the decision. For example, the process can be a simple summary of total cost for each phase of the life-cycle or each year of service, and can progress to more detailed approaches that incorporate both direct and indirect (or user) costs with expected probabilities of realization of benefits. Regardless of agency engagement and progress in GAM, the investment in new geotechnical assets should be evaluated by geotechnical staff with a life-cycle approach to demonstrate good stewardship of taxpayer funds.

For investment analysis at the individual asset level (i.e., the project level), options can include a net present value (NPV) or benefit-cost analysis. In general, NPV analysis is useful for alternatives that have mostly a direct-cost impact that can be compared with other options. A benefit-cost analysis is useful when the decision process includes both direct costs and indirect or user costs that may vary depending on differing likelihoods of treatment success.

Life-Cycle Cost

An asset's initial cost, or design and construction cost, represents a portion of the asset's life-cycle cost, but typically is not all of the life-cycle cost. Even a simple, low-threat asset such as an embankment with gentle side slopes will require life-cycle maintenance of vegetation for aesthetic, safety, and erosion-control purposes. In the case of the embankment example, as the slope inclination increases, the corresponding life-cycle maintenance expenses also may increase for activities such as difficult mowing of vegetation, required edge-of-roadway safety protection devices, or increased erosion control; however, initial construction of an embankment with steeper slopes could require less material, resulting in a lower initial cost. This example thus presents a life-cycle investment trade-off, with one scenario requiring more embankment material in construction (higher initial cost) but having a low life-cycle maintenance cost and another scenario requiring less embankment material (lower initial cost), but having greater life-cycle maintenance needs. This example is simplified, but it illustrates the need for systematic processes to estimate and evaluate the costs **over the life of an asset.**

Another example could involve options for differing design cut inclinations into a slope with highly erodible material. One option creates a steep slope that requires no ROW acquisition, whereas the other option creates a gentle slope that requires ROW acquisition and more time for the design phase. The steeper slope option results in high annual costs for removal of eroded debris, however, and may even create a safety threat. Conversely, the gentle slope can sustain vegetation and has almost no post-construction cost impacts. For this example, the total cost of ownership of the steep slope will be significantly greater than the total cost of the gentle slope.

Regardless of GAM implementation status or level of maturity, consideration of the cost over the whole required project life is an important step in asset management. As the above scenarios indicate, decisions made in the planning and design phases can have notable impacts on the costs in later life-cycle phases. This concept of decisions in individual life-cycle phases influencing the total life-cycle cost is illustrated in Figure 8.6. Geotechnical staff and asset managers are encouraged to include LCCA for selection of new geotechnical assets and project-level treatment decisions. Through this practice, geotechnical staff are able to demonstrate and communicate life-cycle based planning and investment decisions, thus enabling greater support for GAM among executives and financial stakeholders.

NPV Analysis

The NPV approach to project-level LCCA can be a relatively simple process and can be implemented both within and outside of the GAM implementation process. A simple NPV analysis will evaluate the direct financial costs throughout the service or life-cycle analysis period of the

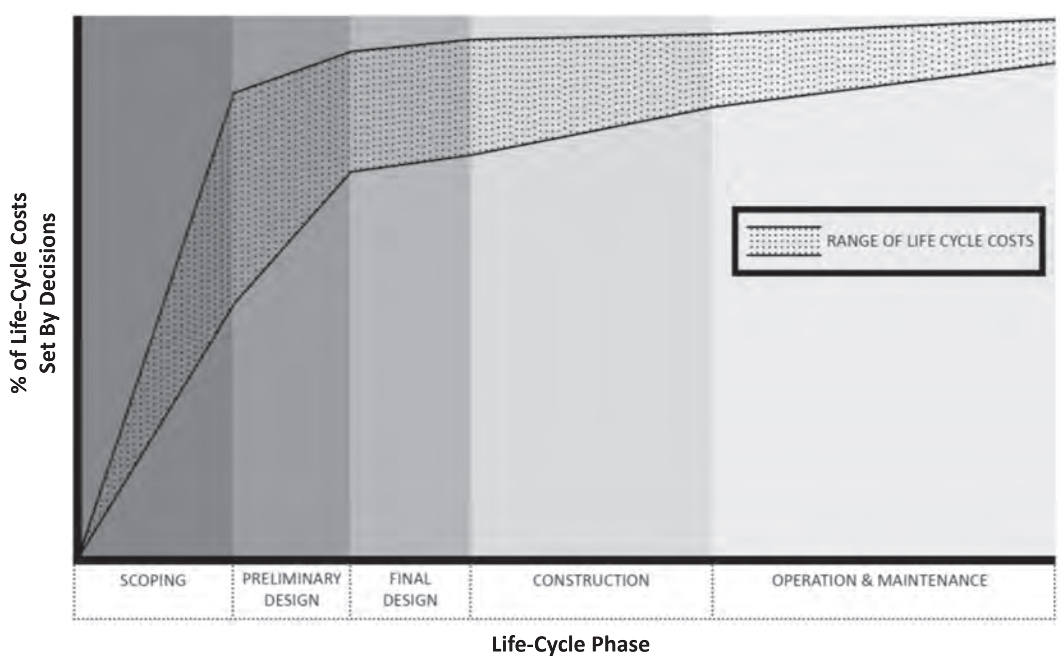


Figure 8.6. Influence of decisions on total life-cycle cost.

asset. By performing the NPV analysis for each potential treatment option, an asset manager or designer can quantify which option presents the least life-cycle cost to the agency. NPV analysis is more suitable in situations that involve similar levels of risk among the analysis options.

The NPV analysis sums estimated costs over the life-cycle of a treatment option with the future costs discounted for inflation. To illustrate this discounting effect, a $1,000 future cost next year would be equivalent to $960 in current dollars this year with an assumed 4 percent rate of inflation, or discount rate. As a result, the NPV gives greater weight to the initial-year treatment costs than it gives to future costs.

When performing the NPV, it is important to use a common evaluation period (or "evaluation life") for all alternatives. For this to occur, the life of the longest-life alternative can be used to establish the evaluation period. Alternatively, a desired performance period for the project or corridor, such as 50 years, can be set for the analysis period. When comparing options with unequal life spans, the NPV analysis can assume that the shorter-span treatments will be performed again in the future, at a discounted value in current dollars. However, when comparing options with differing life spans, it is important to consider the potential for a significant remaining service life or value to exist for one or the other alternative at the end of the analysis period. For example, one alternative may have a 50-year life-span, which is also the analysis period, whereas another alternative requires reconstruction at 40 years. In this scenario, the NPV could suggest the wrong alternative because the second option will have a large remaining service life (30 years) at the end of the 50-year period. To address this differential, the asset manager could adjust the analysis period to a duration that approximates a similar end of service life, or judgment could be applied, acknowledging that there is uncertainty in the assumptions.

The NPV approach is a suitable process for evaluating treatment alternatives that have similar benefits or indirect, non-agency cost impacts, such as in the project-level analysis of different embankment side slopes discussed earlier in this section. In the previous embankment scenario, the expected service life and risk exposure are similar between the treatment options, and the analysis would be evaluating the financial outcome due to differences in construction and operational direct costs.

The inputs to NPV analysis for geotechnical assets would include:

- Design and construction costs (initial costs);
- Useful life of treatment alternatives;
- The desired total service life or useful life of the asset (life-cycle period); and
- An assumed discount rate (inflation cost).

To assist with project-level treatment planning, a template worksheet for NPV analysis is described in Appendix E and has been provided as a downloadable file from the *NCHRP Research Report 903* webpage. This template can be used for project-level design and O&M phase treatment prioritization in situations where impacts among alternatives are mostly related to direct costs. By using this NPV framework, an agency can select treatment options or new assets based on the least life-cycle cost, which is a key outcome of TAM. The agencies also will develop a quantifiable understanding of the scale of future costs that should be included in financial planning for the O&M phase of an asset. This NPV analysis process at the asset level is an important consideration when evaluating rehabilitation design options because the potential exists for rehabilitation treatment life-cycles to exceed the intended remaining life. This would be analogous to constructing a robust rehabilitation treatment that raises the asset condition and life-span above that required by the system.

Table 8.2 presents the results of a conceptual NPV for a project-level analysis comparing two embankment asset reconstruction options. In this example, the agency can acquire the ROW

Table 8.2. Hypothetical NPV analysis for two embankment reconstruction options.

Cost Type	Cost Description	Embankment Reconstruction Option 1: Gentle Side Slopes with ROW Purchase	Embankment Reconstruction Option 2: Steep Side Slopes Within the ROW
Design Cost	Design needs are similar between options	$10,000	$10,000
ROW Cost	Option 1 requires purchase of ROW	$20,000	0
Construction Cost	More embankment material required for Option 1	$100,000	$80,000
Total Initial Cost	Year 0 cost	$130,000	$90,000
Annual Maintenance	Option 2 O&M cost is three times greater due to need for erosion repairs on steeper slopes and roadway barrier maintenance	$1,000	$3,000
50-Year Present Worth Value of Annual Maintenance	Cost in current dollars for 50 years of annual maintenance using a 4% discount rate	$21,500	$66,500
Net Present Value	**Sum of initial and annual maintenance costs in current dollars**	**$151,500**	**$156,500**

to construct an embankment with gentle side slopes that do not require a safety barrier at the roadway. A second option exists: to construct the embankment within the ROW. However, the steeper embankment side slopes will require greater annual maintenance to preserve the asset, and roadway safety barriers are required because of traffic safety design standards adjacent to steep slopes. Even though this is a conceptual example, the analysis suggests that the lower initial cost option may not be the lowest life-cycle cost option, depending on the analysis period. Thus, the geotechnical staff and asset managers are encouraged to consider the NPV when selecting final treatment options at the project level. Without the NPV, the agency is unable to demonstrate that decisions are being made using the least life-cycle cost approach.

Cost-Benefit Analysis

In a more sophisticated life-cycle analysis, the costs can be separated into direct financial costs to the agency (as presented in the NPV discussion) and user or other indirect costs. The indirect costs of geotechnical asset treatment options can include financial estimates of delays, accidents, injuries, and other adverse impacts associated with the different project-level treatment options.

To illustrate the contribution of indirect costs, a hypothetical embankment asset may have a LOR of F and a recommendation for rehabilitation in the GAM Planner output. During project-level scoping, one rehabilitation option may consist of groundwater drains and subgrade stabilization with an “MSE patch” and a second option may consist of installing soil nails in a more robust rehabilitation concept. The first option has a lower initial cost and is considered to have a useful life of 15 years. The second option has a much higher initial cost but is anticipated to last more than 60 years, which is the desired useful life for the asset segment. In this scenario, the savings in user costs associated with not having to rebuild the first rehabilitation option every 15 years can be considered a benefit in the comparison of options.

Thus, the "benefit" in a cost-benefit analysis for geotechnical asset treatment alternatives can be defined as the estimated reduction in costs and risk that occurs when comparing treatment options that have different life-cycle performance characteristics. If the useful life of an asset is uncertain, which is often the case for geotechnical assets, then judgment is encouraged in defining the planning horizon until performance data become available as GAM implementation continues.

For project-level option selection purposes and simplified communication with stakeholders, the analysis outcome can be presented in terms of a benefit-cost ratio (BCR), which is the ratio between benefits and cost. The BCR is a measure of the estimated investment performance for a treatment that compares the stream of net benefits (risk reduction) generated over a project life-cycle to the initial cost. For a BCR, only the initial financial cost to the agency is included in the denominator (as opposed to user cost and future cost, which are included in the numerator) because the focus is on maximizing the returns of the current budget, which is not affected by future or user cost.

In general, a BCR greater than 1 suggests that the ROI exceeds the initial cost. However, the estimation of benefit often will rely on assumptions for indirect costs for safety and mobility benefits, and additional considerations will relate to agency risk tolerance. As a result, potential projects with a BCR lower than 1 should not be automatically rejected. Rather, for an agency starting GAM, a comparison of BCRs among project-level treatment options may be preferred to focusing entirely on the value relative to a neutral cost-benefit ratio (e.g., BCR = 1).

Enabling Success Through Cross-Asset Collaboration

The options that have been discussed for risk management and investment analysis can guide the geotechnical asset manager through the process of implementing asset management at the asset level in a DOT that likely has a limited investment capacity for GAM. These steps should not be considered only within the silo of geotechnical assets, however, as opportunities in management strategies may exist among various asset groups. Project planning that focuses on managing the risk for more than one asset group has the benefit of cost savings, improvement to performance measures for both assets, and ultimately enables quicker realization of agency-wide strategic goals.

The geotechnical asset manager is encouraged to review treatment options with other asset managers to identify where opportunities exist for cross-asset collaboration. By sharing risk or investment with other asset groups, there can be a potential for greater benefit to exist. Examples may include:

- Partnering with the bridge asset manager for a program of salt rinsing for both retaining walls and bridges;
- Jointly investing in specialty contractor support for both culvert and ditch cleaning (below slope assets);
- Working with pavement management on mutually beneficial treatment strategies for high-risk subgrade assets;
- Conducting a geospatial analysis among different assets to highlight where opportunities for cross-asset strategies exist because of proximity or overlap of assets; and
- Analyzing needs by asset type in a given corridor to determine the optimal time for work that incorporates needs for multiple asset types.

Implementing Data-Driven and Defensible Treatment Selections

Based on the current regulatory environment, GAM implementation at DOTs will be a voluntary process and thus must be able to compete for support on a sound business case rather than on the need for federal compliance as exists for pavements and bridges. The discussion of risk treatment, risk prioritization, and investment prioritization has been intended to inform the geotechnical asset manager of steps that can be considered for GAM implementation beyond the program-level inventory and assessment stage. Simply informing executives and TAM staff of a need for beneficial programmatic investment may not be a successful strategy, as every agency has more investment needs than dollars.

Evidence from the few, but successful, GAM-related programs across industries and countries indicates that benefits from asset management can be realized for geotechnical assets when the process relates to the highest-level objectives of the agency. In the examples studied, the programs were able to demonstrate measurable risk and performance project- and asset-level benefits to executives, which enabled the sustainable function of the program. Thus, the geotechnical asset manager is encouraged to use the steps discussed in this chapter as soon as possible to gain early executive support.

The success of GAM implementation will depend on having the flexibility to adjust to differing levels of executive engagement, investment capacity, agency risk tolerance, and acceptance of performance measures. By using data-driven processes to make risk and investment decisions, the GAM implementation relies on a defensible foundation that has the necessary flexibility to adapt to agency-specific culture. For example, one agency may readily adopt GAM performance measures for LOR or performance ratings of "Good," "Fair," and "Poor," but another agency will struggle because of dissimilar measures among all assets. By considering the different risk management and investment analysis steps described in this manual, the asset manager can adapt the GAM implementation approach to suit the needs of the specific agency.

Incorporating GAM into Design

Much of this manual has focused on managing the life-cycle and risk of existing assets, but the incorporation of asset management considerations into the design process for new assets is an important step in a GAM implementation. Incorporation of asset management considerations during the design process makes it feasible to accrue additional benefits to the organization and also can aid in communicating a culture of asset management.

Considering GAM During Design

Most established and long-standing design methods for geotechnical assets are developed around the concepts of the *safety margin* and *reliability*. As these design methods were established before the development of asset management practices, the safety and reliability framework generally is directed at complete failure of the asset, or a total loss of service life. For example, retaining-wall design methods consider failure modes, such overturning and sliding, in addition to global stability of the ground encompassing the asset. For design, the failure mode check is based on the assumed condition that the wall completely overturns and essentially no longer functions as a wall. Except for complex, numerically based methods that consider precise amounts of deformation or movement, the design method and inherent uncertainty in geotechnical engineering does not allow a designer to reliably design a wall that only leans 5 degrees and does not fail.

From an asset management perspective, assets that experience "failure" from the geotechnical design perspective can continue to serve their intended purposes, although they may do so with increased risk to agency objectives. For example, a slope asset that generates rockfall on any given day would have a safety factor of just below 1 at the time of the rockfall, meaning that the stresses within the slope at that time are not able to resist the mass of the fallen rock. When rocks are not falling, however, the safety factor would be above 1, as the slope can support the rock. Agencies and designers rely on standards and guidance to establish recommended practices for the margin of safety (or safety factor) that dictates how much above 1 the slope should be in the design condition.

In a typical GAM program, some assets will have been designed using these safety and reliability frameworks, and other, legacy, assets will have been designed to lesser standards or not designed at all. In the United Kingdom, for example, most of the assets in the Network Rail network were initially constructed during the 1880s, before geotechnical design was even a recognized practice. The implementation of GAM allows Network Rail to operate a network that is made up of numerous assets that would not meet a modern design standard.

The difference between design methods and system performance may influence the scale of an asset management program, but the difference also provides an opportunity for designers to consider GAM in the design of new assets. For this to occur, designers can consider:

- What is the desired operational life of the asset under design?
- What is the estimated O&M cost of the asset, including rehabilitation cycles?
- What is the organization's O&M capacity for the asset (e.g., can the asset be maintained with current/planned staff and resources)?
- What can be changed in design to influence the asset's life-cycle cost?
- What is the organization's tolerance for consequences to operations?
- What is the role of materials in relation to life-cycle cost (e.g., concrete or timber facing for a wall)?
- How do roadway and asset alignment changes influence life-cycle cost?
- What roles do the selected design method and the safety factor have in the life-cycle cost?
- Can the design incorporate elements or components that enable more reliable life-cycle assessment (e.g., sacrificial corrosion coupons, instrumentation, or warning systems)?

Ideally, consideration of GAM during design will involve input from other disciplines. For example, the following input should be solicited when possible:

- Maintenance staff should be encouraged to provide level-of-effort estimates for different design options, such as time for cleaning shoulder ditches below slope assets or for maintaining vegetation on different embankment slope inclinations;
- Budgeting or accounting staff may be able to provide actual costs for estimating labor and equipment costs anticipated in O&M;
- Project designers can be asked to provide material quantities and/or cost estimates for different design options;
- ROW staff can provide estimates of acquisition costs and timelines for various boundary arrangements, should assets be near the ROW; and
- Geotechnical design report requirements can be amended to require estimation of life-cycle cost magnitude for recommended alternatives.

Although obtaining input from these sources is ideal, the geotechnical designer can proceed with consideration of life-cycle costs should the opportunity for cross-disciplinary input not exist. Simple qualitative estimates can be used to differentiate high life-cycle cost options from low life-cycle cost options. Alternatively, conventional cost estimation processes and databases can be used to improve precision, if justified.

The Role of Standards and Guidance

Standards and guidance, such as the safety factor, can influence the asset management characteristics of an asset. A detailed discussion of the relationship between the safety factor and reliability in geotechnical engineering and natural hazards is a complex topic, as discussed in Lacasse (2016). For a maturing GAM program, this topic can be considered for new or future asset designs and based on the managers' understanding of agency risk tolerance gained through the management of existing assets. Rehabilitation design work also should consider how standards relate to the required remaining service life for a corridor or system.

Training for GAM

Training in asset management is a necessary enabling process for successful implementation of a GAM program. Options for training specific to GAM are limited at this time, so training to support GAM can be directed toward developing skills needed in both TAM and GAM. Such training can be accomplished through a variety of methods, with perhaps the most appropriate means being development of a course for the NHI or incorporation of GAM into existing TAM courses. NHI provides training and education for highway professionals, and NHI training and courses are well known to DOTs.

Suggested topics in such a course might include:

- Introduction to TAM;
- Overview of GAM (e.g., the topics in this manual), including:
  - Purpose and need for GAM;
  - Implementing GAM (e.g., the list of steps and model in Chapter 2);
  - Linking TAM to GAM;
  - Examples of GAM practices;
  - Getting started;
  - Overview of GAM planning tools (e.g., the GAM Planner); and
- Risk concepts and life-cycle costs.

The Earthworks Policy (i.e., the GAM plan) for Network Rail was first issued in 2011 and the current (seventh) issue was released in March 2017. This living document provides strong evidence that successful GAM relies on regular process improvements throughout implementation and increasing levels of program maturity.

Developing the GAM Plan

Asset management often is described as a journey or culture, in contrast to a fixed-duration process with a final endpoint, such the design and construction steps for a new bridge. The GAM plan is best considered a "living" document that summarizes the agency's current plans and is expected to be modified and updated in response to changes in strategy or changes to the asset management steps. Because of the cross-disciplinary nature of asset management, the GAM plan should be a means to communicate the strategy for geotechnical assets to the broad range of stakeholders.

Introduction to Agency-Specific GAM plans

Implementation of GAM and development of a GAM plan are intended to be mutually independent processes. GAM implementation consists of the processes that enable asset management. A GAM plan is simply the document or other means of communication that summarizes the processes and data for management of geotechnical assets. Should executive and TAM staff be disengaged from and disinterested in creating a GAM plan, the benefits of asset management can still be realized by a geo-professional implementing even a portion of the processes presented in this manual. Thus, the benefits of GAM can still be realized in the absence of a formal GAM plan.

For an agency that is willing to develop and incorporate GAM into transportation or performance management, the initial GAM plan can be a brief document that is developed without complex data analysis or specialized training. Although complex asset management plans do exist domestically and internationally, the plans from these programs are better viewed as aspirational examples of how GAM documents may evolve after programs have matured. Evidence from the evolution of these programs indicates that the asset management plan often is a regularly updated document that summarizes performance and presents process improvements over prior plans.

The intent of this manual is to enable DOTs to start GAM in a voluntary implementation environment without the dedicated federal funding received for management of assets such as bridges and pavements. To enable success under voluntary implementation, GAM needs to have a business reason to exist. The business case can be made through the connection of GAM to executive-level objectives and competition with other assets on the basis of life-cycle benefits and ROI. Without connecting to high-level objectives and executive goals, GAM could just be an internal (program-level) exercise in ranking problems. Geotechnical assets need to compete against other assets; therefore, the GAM plan should be considered as a communication tool directed at maintaining the connection with executive and TAM representatives, while also emphasizing the benefits of GAM across the spectrum of all transportation assets and funding needs.

For an agency undertaking voluntary GAM implementation with limited funds, the plan framework summarized in the next section is suggested as a means for 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. Once the connection is made to real or forecast benefits, evidence from successful GAM programs indicates a potential for long-term viability that allows for process improvement and increasing plan complexity. An example annotated outline for a simple GAM plan document that follows the framework described is offered in Appendix F.

Plan Objectives and Measures

The GAM Planner provided with this manual is constructed around TAM objectives for asset condition, safety, and mobility and economic vitality. The resulting inventory and assessment process is therefore constructed to simply connect to these objectives. Other objectives and measures are possible, and the precision for condition and assessment can be increased, but the GAM Planner is purposely directed at agencies with minimal resources that need to quickly realize and communicate benefits to stakeholders.

To manage risk from geotechnical assets to the stated performance objectives, the following objectives and measures are suggested for inclusion in a GAM plan document and for communication with TAM and executive stakeholders. Based on examples from successful GAM programs, presenting measures such as those below at only a single point in time and with only 1 year of tracking, will have limited value after the initial implementation presentation. The benefit of recurring communication of measures will be realized with time as trends become evident and can be compared with investment levels.

Example objectives and measures to consider for a GAM plan include:

- **GAM Objective 1: Safety Performance**
  - **Reporting Measures:** Number of deaths, injuries, and accidents on annual basis resulting from adverse events from geotechnical assets.

GAM managers are encouraged to develop shelf-ready candidate treatment recommendations or projects that can quickly answer the hypothetical question from executive and TAM staff, "If given $X amount of dollars for GAM, what could be done that shows a good return on investment using taxpayer funds?"

   - **Commentary:** Although these data may exist through either department data anecdotal means, the asset manager is encouraged to report what is known. This reporting can serve two functions: (1) communication to stakeholders who may not know a safety threat exists, and (2) increasing reporting frequencies from agency staff once they know the data are tracked and used for asset management and project planning.
- **GAM Objective 2: Manage Risk to Safety and to Mobility and Economic Vitality**
   - **Reporting Measures:** (1) Estimated percent of inventory complete, and (2) LOR grade distribution (e.g., number of A through F GAM segments).
   - **Internal Measure:** A "shelf" list of geotechnical asset treatment projects (e.g., three to five) of varying investment levels that demonstrate a favorable benefit to cost ratio and/or life-cycle ROI. Treatments can include:
      - Asset reconstruction or rehabilitation designs, and
      - Maintenance treatment programs.
   - **Aspirational Measure:** Some agencies may be able to track the known closure and delay times associated with events or treatments for geotechnical assets. This may occur or can occur after requesting GAM planning discussions with traffic or operational groups in a DOT. Should these data be readily available, their inclusion is recommended in the GAM plan for communication of performance. Alternatively, this can be an aspirational measurement improvement target of the plan.
- **GAM Objective 3: Asset Condition**
   - **Reporting Measure:** Percent of assets at each O&M condition level.
   - **Aspirational measure:** O&M cost for geotechnical assets.
   - **Commentary:** Most agencies collect data on maintenance work orders; often, however, these data are not reliable or accessible across the agency. Through enterprise software and improved business processes at many DOTs, these data are anticipated to become more reliable for GAM planning in the future. As an aspirational GAM implementation goal, the geotechnical asset manager should emphasize the value in tracking work orders to the individual asset maintenance.

Inventory and Condition Summary

The GAM Planner that accompanies this manual can allow an agency to start an inventory for geotechnical assets that documents condition at the asset level. Agencies also have the opportunity to adapt existing geotechnical inventories into a system that enables asset management across the spectrum of geotechnical assets and for similar objectives. Other geotechnical asset inventory methods exist, such as the element-level inspection program for retaining walls at Colorado DOT (Walters et al. 2016); however, a greater commitment of resources often is necessary to implement such programs, and the resulting implementation costs for more initial inventory detail should be compared with the expected benefit.

Having asset inventory and condition data by itself does not enable an agency to recognize the benefits of asset management. The benefits are realized through improved decision-making processes in support of risk management and objectives that are of importance to agency executives.

Although a thorough level of detail could be provided in the inventory and condition section of an asset management plan, brevity is suggested in the GAM plan, as executives and other non-geotechnical stakeholders may not have time or the technical background or experience to comprehend geotechnical asset performance criteria. These details can be added in future updates as part of process improvements and feedback from interested stakeholders.

Gap Analysis

Asset management plans typically include discussion explaining the analysis of the "gaps" in asset management performance. The gaps are the differences in how the assets are performing now, relative to the desired performance. The purpose of a gap assessment is to identify the differences between the current and projected asset conditions in relation to the goal of achieving or maintaining the desired SGR. Within the gap analysis, strategies can be proposed to address performance gaps. In a new asset management program, such as a GAM implementation, the gap analysis offers an opportunity to communicate to stakeholders the current performance.

The geotechnical asset inventories for most agencies are anticipated to be minimal at the start of GAM implementation, and it may take several years to move toward completion. Therefore, the gap analysis in a new GAM plan can be as simple as discussing the estimated total inventory size relative to the completed inventory size, together with suggested strategies to close the gap. An example strategy to expand the inventory in a new GAM plan may involve collaboration with maintenance program staff or utilization of bridge inspection staff to collect information on assets observed near inspected bridges.

For mature asset management programs with complete inventories, a gap analysis may include:

- Defining the desired LOR or SGR targets for geotechnical assets;
- Establishing existing conditions;
- Simulating future conditions;
- Comparing existing and projected future conditions to the desired SGR and any 2- and 4-year targets that may have been established for geotechnical assets;
- Calculating the one-time investment that would be required to close any gaps projected to occur between the targets and projected conditions, as well as between the desired SGR and projected conditions;
- Incorporating the identification of strategies to address the gaps as part of an investment strategies development process.

Life-Cycle Cost and Risk Management Analysis

The discussion on asset management treatment prioritization in this chapter has outlined several steps that can be used by an asset manager in the selection and recommendation of asset treatment projects. For this portion of the GAM plan, the text can present the selected methods of risk and investment prioritization. For example, should the agency choose to manage geotechnical assets on the basis of concentration of risk, the locations (corridors) of concentrated risk can be presented and possibly prioritized. Alternatively, should the agency choose to manage assets based on acceptable risk levels, the process for selection of risk targets can be summarized and the assets currently below the target LOR can be identified.

Financial Planning and Investment Analysis

Financial Plan for Geotechnical Assets

A clear financial plan can benefit the long-term GAM implementation process by developing an informed budgeting process. For the state TAM plan, as put forward by MAP-21 and pursuant to 23 U.S.C. 119(e)(4), the FHWA requires each state DOT to establish a process for developing a financial plan that identifies annual costs over a minimum of 10 years. The state's TAM plan must contain the following minimum components:

- The estimated cost of expected future work to implement investment strategies contained in the asset management plan;
- The estimated funding levels that are expected to be reasonably available to address the cost of future work types;
- Identification of anticipated funding sources; and
- An estimated value of agency's pavement and bridge assets and the needed investment to maintain the value of these assets.

The MAP-21 and FAST requirements do not extend beyond pavement or bridges, but the FHWA recommends that state DOTs apply some or all elements of the asset management plan rules to other asset programs. Thus, the GAM plan has flexibility in this section, particularly as the start of implementation. For a GAM implementation at a simple maturity level, the financial planning and analysis section of the agency's GAM plan can discuss the following agency-specific information:

- **Funding Sources and Processes:** How investment in the life-cycle of geotechnical assets is occurring now;
- **Historical Funding Trend:** Data obtained from across the agency, summarized to indicate the known and unknown investment amounts in geotechnical assets, including operational expenses;
- **Estimated Need:** The feasible or likely expected annual investment plan for geotechnical assets based on planned treatment projects (given that the GAM inventory will likely indicate an investment need greater than can be fulfilled); and
- **Alternative Funding Scenarios:** How available dollars can be re-allocated to support GAM, such as by adding funds to O&M budgets to support maintenance treatment recommendations.

Geotechnical Asset Valuation

An optional but aspirational portion of the financial plan within a GAM plan would be the valuation of geotechnical assets. Asset valuation is a new requirement under FHWA rules for bridges and pavement. Asset valuation also has been practiced by the transportation authorities in other nations, such as the United Kingdom, Australia, and New Zealand since the 1990s. Valuation capitalizes the infrastructural assets of an agency and provides a clear indicator of the growth (or decay) of the total capital stock of the agency. Asset valuation can be completed for geotechnical assets and may also create a more compelling case for investment justifications.

In addition to showing an effort to comply with FHWA rules for other assets, an agency can estimate valuation for several purposes, including process improvement, risk mitigation, resilience consideration, policy development, transparency to public stakeholders, accountability, and economic vitality. Three commonly accepted approaches to asset valuation are the market approach, cost approach, and income approach. A cost approach is one that incorporates factors such as age, condition, and functional obsolescence of the assets. Market and income approaches generally are not appropriate for geotechnical assets, because these assets are not transferred through sale or generate income.

The process for geotechnical asset valuation does not need to be complicated. For each geotechnical asset within the ROW, it is possible to estimate a replacement value, using procedures similar to those for estimating replacement values for other assets (e.g., culverts and bridges). Additionally, if the initial cost of the asset has been documented, the replacement value can be calculated simply as the inflation-adjusted original cost. More information on asset valuation strategies is presented in *NCHRP Research Report 898: A Guide to Developing Financial Plans and*

Performance Measures for Transportation Asset Management (Spy Pond Partners, LLC, KPMG, and University of Texas at Austin Center for Transportation Research 2019).

Overcoming Barriers to GAM Implementation

As part of the formulation for this implementation manual, staff from several DOTs were contacted to understand the geo-professional, TAM, and executive perspectives that may exist when starting implementation of GAM. The contacted staff provided agency perspectives involving differing geologic terrains, agency structures, asset management maturities, performance objectives, risk tolerances, and investment capabilities. Additionally, staff performing GAM within the established programs of Network Rail, Highways England, and a pipeline operator were contacted to understand how the respective programs function and are moving toward more advanced maturity. The findings from these discussions were considered in developing the GAM implementation process with respect to the following influence areas:

- People (executive, TAM/planning, and geo-professionals);
- Systems and data; and
- Processes.

The agency discussions provided an understanding of the perceived barriers to GAM implementation as well as what has enabled GAM implementation where it is occurring. As with many programs in large organizations, execution and implementation challenges can exist; yet, several options typically are available to staff that enable achievement of the desired objectives. To assist staff performing GAM implementation, Appendix G to this manual contains a summary matrix of options that can be considered to address the commonly perceived challenges in the overall implementation process.

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Glossary and Abbreviations

This glossary presents definitions for common terms and abbreviations used throughout the *GAM Implementation Manual*.

Assessment	Evaluation of data or other information for the purpose of making decisions or judgments.
Asset	An item, thing, or entity that has potential or actual value to an organization. This value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. Note: Several other definitions exist; this definition is the international form from the International Organization for Standardization (ISO).
Asset management	A coordinated activity of an organization to realize value from assets beyond the right-of-way (ROW) or boundary.
Asset manager	An individual who takes on the responsibility for starting geotechnical asset management (GAM) implementation. The geotechnical asset manager can be an agency geo-professional, an asset management subject matter expert, or another interested stakeholder. To assist with a broad adoption of GAM, the implementation process described in this manual has purposely been developed such that a geotechnical asset manager does not need to be a geotechnical engineer or other geo-professional.
Benefit-cost analysis	A life-cycle cost analysis (LCCA) method that considers the benefits and costs of an asset over the analysis period, with costs discounted to current costs. Benefit-cost analysis can be of value when the decision-making process includes both direct costs and indirect costs (or user costs) that vary depending on the likelihood of treatment success.
Condition	The performance or physical state of an asset.
Consequence	An outcome from an event or condition. For risk-based GAM, consequences are quantified or scaled values of impacts from asset performance incorporated into the determination of risk exposure.

Corridor	A defined or informally designated portion of a transportation system that may be used for planning, operations, communication, or other agency purposes. For GAM implementation, corridors can be designated for areas with concentrations of geotechnical assets and/or risk.
Critical asset	An asset that has the potential to significantly impact the achievement of the organization's objectives. Critical assets can be safety-critical, environment-critical, or performance-critical, and they can relate to legal, regulatory, or statutory requirements.
Data	A collection of facts from which conclusions may be drawn.
Deterioration	A process of degradation of an asset throughout the life-cycle.
Do Minimum	An asset management treatment option consisting of performing only the minimum level of work needed to keep the asset in a condition that allows for traffic conveyance without performing actions that add or preserve life-cycle value. Do Minimum actions typically occur only when a mobility interruption or safety impact has occurred and immediate action is required.
Earth-retaining structure	See *Retaining-wall asset.*
Element	In the practice of bridge inspection, an *element* is an item that can be visually observed, measured, and evaluated on the basis of condition. For geotechnical assets using this taxonomy, elements could include items like retaining-wall facing systems, permanent erosion controls on embankments, or draped rockfall mesh on slope assets.
Embankment asset	A type of geotechnical asset consisting of a constructed fill (composed of rock, soil, or other engineered materials) that enables a roadway to maintain a required design elevation above lower-lying ground. This manual encourages use of a threshold embankment height of 10 feet (3 m).
Functional value	The value an asset provides to the function of the infrastructure system.
GAP analysis	A process that assesses the difference between current practices and performance and planned or aspirational performance.
GAM	Geotechnical asset management.
Geo-professional	Geotechnical and geology professionals that support infrastructure project delivery and GAM.
Geotechnical asset	An embankment, slope, subgrade, or retaining-wall asset.
Geotechnical element	A geotechnical asset that is an element of another asset (e.g., substructures for bridges, rock reinforcement in tunnels, or aggregate base courses for pavement).
GIS	Geographic information system. A data management system that is also able to present data geographically for improved communication.

Hazard A hazard is a potential event with adverse consequences. Some hazard events can occur relatively suddenly (e.g., natural hazards like earthquakes, landslides, floods, and so forth), and other hazard events can occur in response to deterioration that has occurred over a relatively long period of time (e.g., corrosion of steel reinforcement for a mechanically stabilized [MSE] earth wall). See also: *Natural hazard.*

IIMM *International Infrastructure Maintenance Manual.* Currently in its 5th edition, this publication of the Institute of Public Works Engineering Australasia (IPWEA) applies the ISO 55000 asset management standards to infrastructure asset management.

Intangible value The value that an asset contributes to the network but that cannot be directly quantified.

Inventory A collection or listing of data for an asset. Inventory can include data about the asset or data that relate to the asset (e.g., traffic volume at the asset location).

Inclusion Any and all non-earth modifications (e.g., pipes, bars, tendons, strips and sheets) that may, for example, contribute drainage or strength to a geotechnical asset.

ISO International Organization for Standardization. With respect to asset management, ISO Standards 55000, 55001, and 55002 respectively provide (1) an overview of the subject of asset management and the standard terms and definitions; (2) requirements specifications for an integrated, effective management system for asset management; and (3) guidance for the implementation of such a management system.

Level of risk (LOR) An executive-level performance measure for reporting the risk exposure to objectives from an asset.

Level of service (LOS) A measurable set of parameters, or combinations of parameters, that reflect the actual and desired social, political, environmental, and economic outcomes delivered by an organization. Having quantitative and/or qualitative features, LOS can include parameters related to safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost, and availability.

Life-cycle Stages involved in the management of an asset, project, or infrastructure system.

Maintain A treatment option that assumes the asset will be maintained in a state of near-continuous operation and maintenance through planed actions. **Maintain** treatments are regular, frequent, but short work activities and often involve tasks that may be considered routine maintenance carried out on an approximate annual basis. These treatments also can include preservation work that is needed to fulfill an asset's originally intended service life. In general, a **Maintain** treatment option will be performed to enable an asset to deteriorate at a rate that is equal to or better than the originally intended or assumed rate.

Maturity	With respect to asset management, a measure of how advanced an organization is with respect to asset management (e.g., initial, core, or advanced). (The three basic maturity levels are discussed in Chapter 3 of this manual and summarized in Figure 3.3.)
Natural hazard	For purposes of this manual, natural hazards involve hazards like rockfall, debris flows, or other rapid slope movements that originate beyond the ROW but may pose a safety threat or involve mobility and maintenance impacts to assets owned or maintained by an agency, and thus impact the agency's performance objectives.
Net present value (NPV)	A project-level LCCA to evaluate the direct financial costs throughout the service or life-cycle analysis period of the asset. The NPV analysis consists of the summation of estimated costs over the lifecycle of a treatment option with the future costs discounted for inflation. (A downloadable, spreadsheet-based template for calculating NPV for use in conjunction with the GAM Planner is available from the *NCHRP Research Report 903* web page.)
Objective	A result to be achieved through planned action. An objective can be strategic, tactical, or operational.
O&M	Operations and maintenance.
Performance measure	A measure of performance for an asset. Performance measures can be *inward-facing* (e.g., directed toward executive or technical staff decision-making), or *outward-facing* (e.g., directed toward the asset's impact on customers or the public).
Reconstruct (or Restore)	A treatment option that results in a significant asset performance improvement to a new or nearly new condition, effectively resetting the asset's service life. A Reconstruct treatment process also may be applied to reduce safety and/or mobility consequences in addition to a resetting the service life.
Rehabilitate (Rehab)	A treatment option that improves the condition of an asset to a higher condition level. Typically, the improved condition obtained through Rehab also extends the asset's service life.
Resilience	Per FHWA Order 5520 (2014), resilience is the "ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."
Restore	In the GAM Planner, a treatment category triggered by the model when an asset fails (i.e., reaches an O&M Category of 5).
Retaining-wall asset	A type of geotechnical asset consisting of structures that hold back soil and/or rock materials to prevent sliding of material onto a roadway or other structure, or to retain material that supports a roadway or structure. Retaining walls may include gravity walls, soil nail walls, concrete cantilever structures, or mechanically stabilized earth (MSE) walls. Retaining walls will have vertical or nearly vertical faces, and the recommended threshold inclination is 70 degrees between a wall and an embankment or slope.
ROW	Right-of-way
Risk	ISO 31000 defines *risk* as "the effect [good or bad] of uncertainty on objectives."

Segment	A pre-defined inventory length used in the location process for geotechnical assets. In the GAM Planner provided with this manual, a default segment length of 500 feet (approximately 0.1 mile) is used.
Service life	The period over which an asset and/or the transportation system at the asset location is expected to perform, or has performed.
Slope asset	A type of geotechnical asset consisting of cut excavations that enable a roadway to traverse through surrounding higher ground. Slopes differ from embankments in that slopes are excavated into terrain whereas embankments are constructed. Slopes can consist of soil, rock, and mixtures of soil and rock. A 10-foot threshold for slope minimum height is recommended unless the asset is judged to create an unacceptable hazard to the safety of users and others.
SME	Subject matter expert (e.g., an agency geologist or geotechnical engineer, asset management professional, or maintenance manager).
Stakeholder	An individual or group, either within an organization or external to it, which can be affected by or has an interest in an asset and/or decisions about the asset.
Subgrade asset	A type of geotechnical asset consisting of earth material below the engineered pavement layers that 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 threats from karst (sinkholes) and underground mining. A subgrade asset also may include an unimproved subgrade that presents a measurable hazard from geologic conditions below the roadway.
TAM	Transportation asset management.
TAMP	Transportation Asset Management Plan.
Tangible value	Value that is measurable in terms of financial value or other measurement criteria.
Taxonomy	A means for classifying and describing the hierarchical order or relationships for the components of a system.
Treatment	An action performed on an asset during the asset's life-cycle. Treatment categories for geotechnical assets (as identified in the GAM Planner) include Do Minimum, Maintain, Rehabilitate (Rehab), Reconstruct (or Renew), and Restore.
USACE	United States Army Corps of Engineers
UK	United Kingdom
Valuation	A process that determines the value of an asset in terms such as replacement value, market value, or appraisal value.
Wall	In GAM (and in the GAM Planner), a retaining wall.
Workflow	A series of processes, procedures, or steps that lead to a desired outcome.

Appendices (Available Online)

Seven appendix documents accompany the *GAM Implementation Manual.* Together with two appendix documents that accompany Volume 1 (the research overview), the GAM Planner, the NPV Template tool, and a training presentation, these documents 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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