Appendices to *NCHRP Research Report 903: Geotechnical Asset Management for Transportation Agencies, Volume 2: Implementation Manual*

This document contains the following appendices to *NCHRP Research Report 903: Geotechnical Asset Management for Transportation Agencies, Volume 2: Implementation Manual* (the *GAM Implementation Manual*):

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

Appendix G: GAM Implementation Barrier Mitigation Strategy Matrix

These appendices supplement the *GAM Implementation Manual* by providing (1) additional details about the creation and use of the GAM Planner; (2) a worksheet template that can be used for asset- or project-level life-cycle cost investment analysis; (3) an annotated outline that can be used as a framework by an agency authoring an initial GAM Plan document; and (4) suggestions for strategies to mitigate barriers to GAM implementation.

Three additional files are available separately for download from the *NCHRP Research Report 903* webpage at www.trb.org:

NR903_GAM_Planner.xlsm

This file contains the spreadsheet-based (Microsoft Excel) tool developed in NCHRP Project 24-46, "Development of an Implementation Manual for Geotechnical Asset Management for Transportation Agencies." User information for the GAM Planner appears in Appendix A of this document.

NR903_NPV_Template.xlsx

This spreadsheet-based (Microsoft Excel) worksheet template is provided for use as 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 Appendix E of this document.

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 from the NCHRP Project 24-46 webpage:
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4065.

Appendix A: Using the GAM Planner

INTRODUCTION

This chapter provides step-by-step instructions for using the spreadsheet tool called the GAM Planner. The GAM Planner helps support the steps described in Chapter 2 of *NCHRP Research Report 903: Geotechnical Asset Management for Transportation Agencies, Volume 2: Implementation Manual* (the *GAM Implementation Manual*). One can use the tool to:

- Define a geotechnical asset inventory;
- Characterize geotechnical asset conditions and risk;
- Define life-cycle models for geotechnical assets; and
- Simulate future conditions and prioritize GAM investments given an expected budget.

The following sections detail the system and data requirements for the tool, describe how to use the tool, and show example illustrating the tool populated with data.

SYSTEM REQUIREMENTS

The GAM Planner is a Microsoft Excel spreadsheet tool that is designed to run in Microsoft Excel 2010 or higher. The tool has been tested in the Windows 7, Windows 10 and macOS 10.12 operating systems. ***Note: To use the tool, it is necessary to enable macros. Also, the Excel Solver must be installed. The Excel Solver is a plug-in provided with Excel.***

TOOL COMPONENTS

The GAM Planner consists of seventeen worksheets. It includes a start screen (**Main Menu**), two input worksheets (**Inventory** and **Asset Model Builder**), two results worksheets (**Summary Results**, **Detailed Results**), and twelve additional supporting model worksheets. Note that certain fields and tabs in the GAM Planner are hidden to streamline use of the tool. Other tabs are protected to ensure the integrity of the tool, and fields with calculations are restricted. To view hidden fields and tabs one can unprotect individual worksheets in Excel and enable viewing of worksheet tabs in the Excel preferences.

USING THE TOOL

To use the tool the tool user should first create asset models by clicking the *Create Asset Model* button on the **Main Menu**. Alternatively, one may use the version of the tool pre-populated with several example models for common types of geotechnical assets, editing these models or supplementing them as desired.

Once asset models have been defined, the user can enter details on the **Inventory** worksheet, including basic identifying information on each asset, and information on the asset's condition and risk level. One can then perform an analysis of future conditions using the **Summary Results** worksheet. This worksheet shows overall conditions and expenditures for all of the assets in the inventory. Details on a selected asset are provided on the **Detailed Results** worksheet.

In using the tool, one should enter data in white-shaded cells. Calculated values are shown in gray-shaded cells and cannot be edited by default.

Generally, all of the calculations in the tool are updated automatically, with two major exceptions. When a user updates an asset life-cycle model, it is necessary to click the *Solve* button to re-solve the model for the asset type. Also, to regenerate the random numbers used to predict asset deterioration, it is necessary to click the *Randomize Deterioration* button on the **Summary Results** worksheet. Other outputs of the tool are calculated automatically as the inputs are updated and the results are presented in the **Summary Results** and **Detailed Results** worksheets.

MAIN MENU

The **Main Menu** worksheet is the start screen that contains the navigation for the GAM Planner. On this worksheet the user has the option to create, edit, or delete an asset model; enter or edit inventory assets; see summary statistics; and view both summary and detailed results. The **Main Menu** worksheet is shown in Figure A-1.

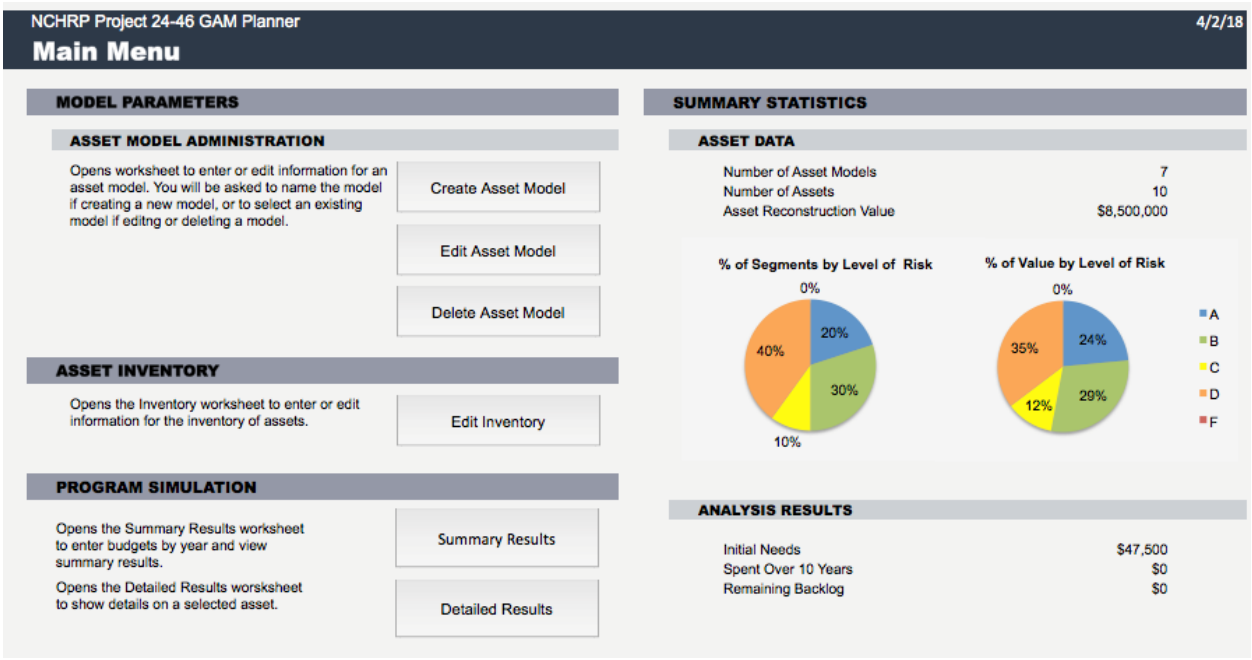


Figure A-1. Main Menu Worksheet

Model Parameters

The **Model Parameter** section of the **Main Menu** contains the options to create, edit, or delete asset models. Please note that the task of creating asset models should be done before entering assets on the **Inventory** worksheet, as an asset type is needed for each asset in the inventory. The **Model Parameters** section is shown in Figure A-2.

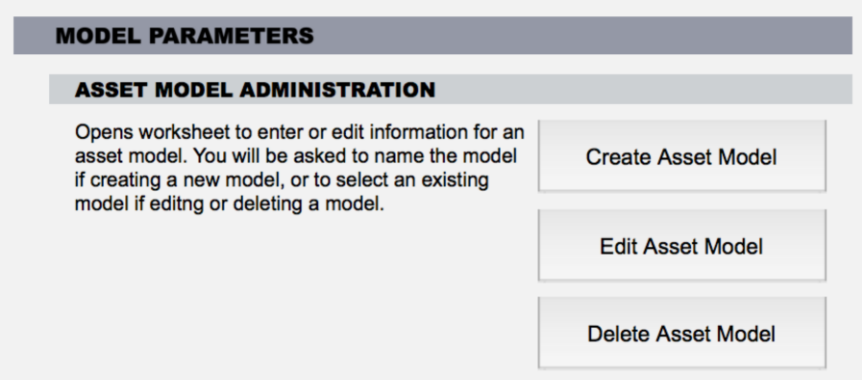


Figure A-2. Model Parameters

- Clicking *Create Asset Model* opens the **Create Asset Model** window, shown in Figure A-3, where the user will be prompted to enter the name of the new asset model. Once you enter a model name, click *Create New Model* and you will be taken to the new model worksheet where you can enter parameters for the new model. Click *Cancel* to close the window without creating a new asset model.

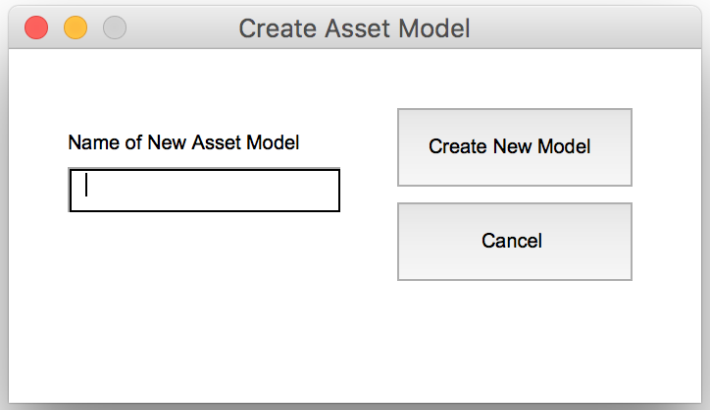


Figure A-3. Create Asset Model

- Clicking *Edit Asset Model* opens the **Edit Asset Model** window, shown in Figure A-4, where you can select the model you wish to edit. You will be prompted to choose a model from the list of models. Once you have selected a model, click *Edit Selected Model* to navigate to the selected model where you can edit the model parameters. Click *Cancel* to close the window without choosing an asset model to edit.

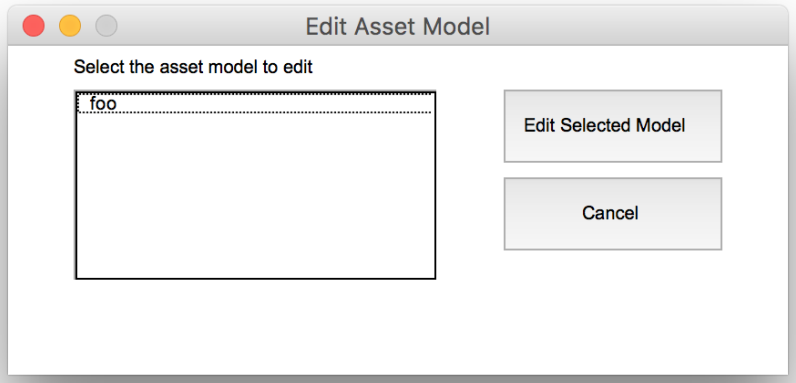


Figure 5.4. Edit Asset Model

- Clicking *Delete Asset Model* opens the **Delete Asset Model** window, shown in Figure A-5, where you can select the model you wish to delete. You will be prompted to choose a model from the list of models. Once you have selected a model, click *Delete Selected Model* to delete the selected model. A message will appear, confirming that you want to delete the model. Click *Cancel* to close the window without deleting an asset model.

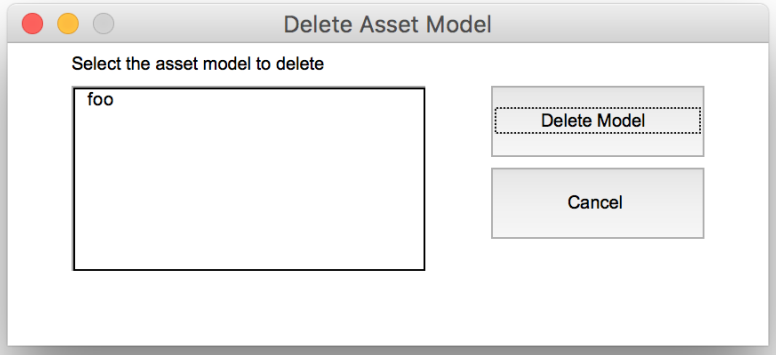


Figure A-5. Delete Asset Model

Asset Inventory

The **Asset Inventory** section of the **Main Menu** contains the options to enter or edit the inventory of assets. Please note that the task of creating asset models should be done before entering assets on the **Inventory** worksheet, as an asset type is needed for each asset in the inventory. The **Asset Inventory** section is shown in Figure A-6.

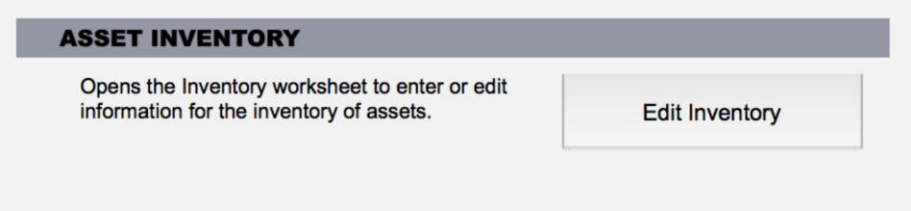


Figure A-6. Asset Inventory

Program Simulation

The **Program Simulation** section of the **Main Menu** contains options to navigate to the **Summary Results** and **Detailed Results** worksheets. The **Program Simulation** section is shown in Figure A-7.

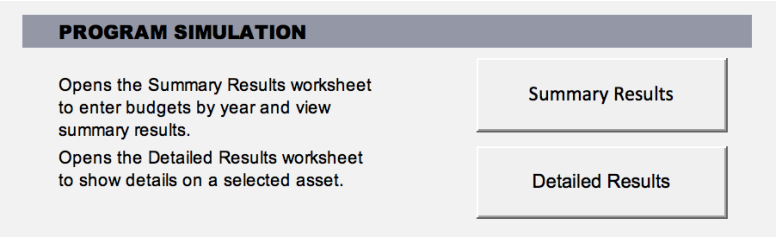


Figure A-7. Program Simulation

- **Summary Results** opens the **Summary Results** worksheet, where you can enter yearly budgets see the impact on the simulation results.
- **Detailed Results** opens the **Detailed Results** worksheet, where you can see the simulation results for a selected asset.

Summary Statistics

The **Summary Statistics** section of the **Main Menu** contains the **Asset Data** and **Analysis Results** for the current data and parameters entered. The **Summary Statistics** section is shown in Figure A-8.

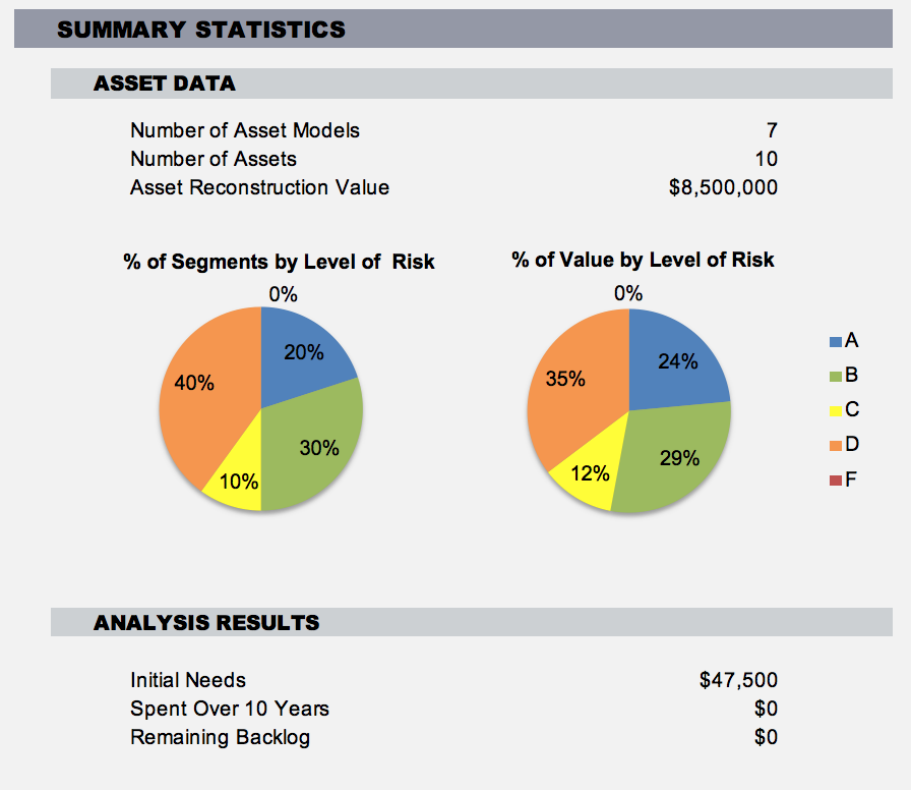


Figure A-8. Summary Statistics

- The **Asset Data** section contains a summary of the assets currently in the system, including the number of asset models, number of assets, and total reconstruction value of the asset inventory. This section also shows pie charts with the distribution of the asset inventory by level of risk (A to F). The left pie chart shows the percentage of segments at each risk level, and the right pie chart shows the percentage of assets weighted by reconstruction value at each level.
- The **Analysis Results** section shows initial investment needs, the amount simulated as spent over a ten-year period based on the inventory data and budgets enter in the **Summary Results** worksheet, and the remaining backlog (unmet needs) at the end of the analysis period.

ASSET MODEL BUILDER WORKSHEET

The **Asset Model Builder** worksheet details the life-cycle model for a selected asset type. The worksheet describes, for a given asset type, how the asset deteriorates over time, what treatments can be performed, and the costs and effectiveness of those treatments. Also, it details the costs incurred if no specific treatment is performed, termed the "do minimum" cost, and the costs incurred in the event the asset fails. Note: When using the model, one defines what constitutes an "asset failure," which may range from a temporary loss of service (during which mandatory maintenance is performed to return the asset to service) to catastrophic failure of the asset requiring complete reconstruction.

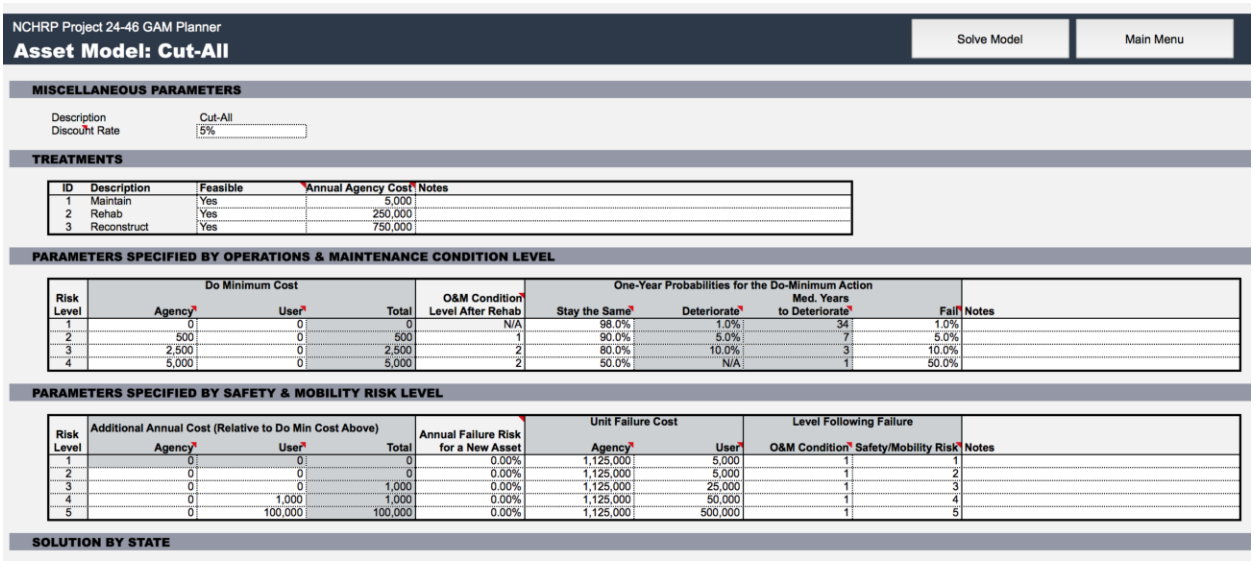
Two parameters are detailed: (1) the Operations & Maintenance (O&M) Condition level, and (2) the Safety/Mobility Risk Level. Both of these parameters are specified on a five-point scale, with 1 indicating the best condition/lowest level of risk, and 5 indicating the worst condition/highest level of risk. The Safety/Mobility Risk Level is an average of the Safety and Mobility Risk levels described previously.

Three potential treatments may be defined: (1) Maintain, which keeps the asset in the same condition/risk level; (2) Rehabilitate (Rehab), which has a user-defined effect; and (3) Reconstruct, which restores the asset to the best condition and lowest level of risk. If no specific treatment is performed, the model may simulate a "do minimum action" and specify the resulting agency and user costs. Also, the model simulates the case the asset fails (reaches an O&M Condition level of 5), which results in a treatment of Restore. The user specifies the agency and user costs of this treatment, as well as the resulting condition and risk levels in the event this treatment is triggered.

Solving the asset model entails performing an optimization to determine what treatment should be performed for each combination of condition level and risk level to minimize life-cycle costs. The model also calculates the one-year cost of deferring recommended action. The benefit of performing the recommended treatment is that it saves life-cycle costs relative to deferring action.

On this worksheet, white-shaded cells are input cells and can be edited by the user. Shaded cells should not be edited; they contain default values or formulas. The sections **Miscellaneous Parameters**, **Treatments**, **Parameters Specified by Operations and Maintenance Condition Level**, **Parameters Specified by Safety & Mobility Risk Level**, and **Solutions by State** are populated with default values that users can change to fit the asset model they are building.

Each time a new model is created on the **Main Menu**, this worksheet is copied along with the name of the new model. Once all of the model parameters are filled in, click *Solve Model* to generate the model results. The section **Solution by State** contains the model results that are calculated from the input cells in this worksheet. A partial view of the **Asset Model Builder** worksheet illustrating all of the data input fields is shown in Figure A-9.



NCHRP Project 24-46 GAM Planner

Asset Model: Cut-All

Solve Model | Main Menu

MISCELLANEOUS PARAMETERS

Description	Cut-All
Discount Rate	5%

TREATMENTS

ID	Description	Feasible	Annual Agency Cost	Notes
1	Maintain	Yes	5,000	
2	Rehab	Yes	250,000	
3	Reconstruct	Yes	750,000	

PARAMETERS SPECIFIED BY OPERATIONS & MAINTENANCE CONDITION LEVEL

Risk Level	Do Minimum Cost			O&M Condition Level After Rehab	One-Year Probabilities for the Do-Minimum Action				Notes
	Agency	User	Total		Stay the Same	Deteriorate	Med. Years to Deteriorate	Fail	
1	0	0	0	N/A	98.0%	1.0%	34	1.0%	
2	500	0	500	1	90.0%	5.0%	7	5.0%	
3	2,500	0	2,500	2	80.0%	10.0%	3	10.0%	
4	5,000	0	5,000	2	50.0%	N/A	1	50.0%	

PARAMETERS SPECIFIED BY SAFETY & MOBILITY RISK LEVEL

Risk Level	Additional Annual Cost (Relative to Do Min Cost Above)			Annual Failure Risk for a New Asset	Unit Failure Cost		Level Following Failure		Notes
	Agency	User	Total		Agency	User	O&M Condition	Safety/Mobility Risk	
1	0	0	0	0.00%	1,125,000	5,000	1	1	
2	0	0	0	0.00%	1,125,000	5,000	1	2	
3	0	0	1,000	0.00%	1,125,000	25,000	1	3	
4	0	1,000	1,000	0.00%	1,125,000	50,000	1	4	
5	0	100,000	100,000	0.00%	1,125,000	500,000	1	5	

SOLUTION BY STATE

Figure A-9. Asset Model Builder Worksheet

Miscellaneous Parameters

The **Miscellaneous Parameters** section, shown in Figure A-10, contains the description of the model as entered in the **Create Asset Model** window and the discount rate.

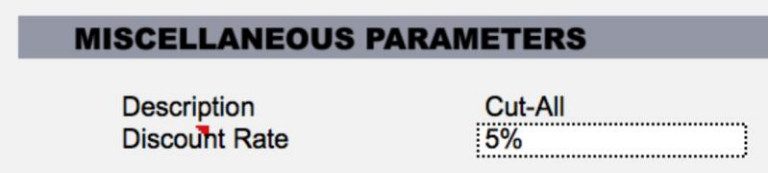


Figure A-10. Miscellaneous Parameters

1. The **Description** is the name of the model as entered in the **Create Asset Model** window. Once the new model has been created, the model name cannot be changed. The only option is to delete the model and create a new one with the corrected name.
2. Enter the **Discount Rate** representing the time value of money for life-cycle cost calculations. The default value for this parameter is 5%.

Treatments

The **Treatments**, shown in Figure A-11, determine which treatments are available to assets of this type and at what cost. The following steps describe how to define treatments.

TREATMENTS

ID	Description	Feasible	Annual Agency Cost	Notes
1	Maintain	Yes	5,000	
2	Rehab	Yes	250,000	
3	Reconstruct	Yes	500,000	

Figure A-11. Treatments

1. Determine whether each type of treatment is **Feasible**. This will affect the initial recommendations that are available for this type of asset.
2. Enter an **Annual Agency Cost** for each treatment type. This is the agency unit cost for the treatment. For the default models, costs are specified per 0.1 mile segment.
3. Enter any **Notes** about the treatment.

Parameters Specified by Operations & Maintenance Condition Level

The **Parameters Specified by Operations & Maintenance Condition Level** section, shown in Figure A-12, defines the agency and user costs of performing the minimum action required at each condition level, the condition level resulting from the rehabilitation treatment, and the one-year probabilities for the **Do Minimum** action.

PARAMETERS SPECIFIED BY OPERATIONS & MAINTENANCE CONDITION LEVEL

Risk Level	Do Minimum Cost			O&M Condition Level After Rehab	One-Year Probabilities for the Do-Minimum Action				Notes
	Agency	User	Total		Stay the Same	Deteriorate	Med. Years to Deteriorate	Fail	
1	0	0	0	N/A	96.0%	3.0%	17	1.0%	
2	500	0	500	1	93.0%	5.0%	10	2.0%	
3	2,500	0	2,500	2	90.0%	5.0%	7	5.0%	
4	5,000	0	5,000	2	50.0%	N/A	1	50.0%	

Figure A-12. Parameters Specified by Operations & Maintenance Condition Level

1. Enter a unit cost to the **Agency** for the **Do Minimum** action.
2. Enter a unit cost to the road **Users** for the **Do Minimum** action.

3. The **Total** do-minimum cost combines the **Agency** do-minimum and **User** do-minimum costs. This is a calculated field and cannot be edited.
4. Enter the **O&M Condition Level After Rehab**. This is the operations and maintenance condition level following rehab treatment if feasible.
5. In **Stay the Same**, enter the probability of the asset staying in the same condition for the **Do Minimum** action.
6. **Deteriorate** is the one-year probability the asset will deteriorate to the next O&M Condition level. This is a calculated field and cannot be edited.
7. The **Median Year to Deteriorate** is the number of years to deteriorate to the next condition level given the specified probability of remaining in the same condition. This is a calculated field and cannot be edited.
8. In the **Fail** column, enter the one-year probability of failure. Note this probability is independent of that specified by Safety & Mobility Risk Level.
9. Enter any **Notes** about the parameters.

Parameters Specified by Safety & Mobility Risk Level

The **Parameters Specified by Safety & Mobility Risk Level**, shown in Figure A-13, are the additional annual costs (over and above the do-minimum costs discussed in the previous section), the annual failure risk for a new asset, the Agency and User Unit Failure Cost, and the operations and maintenance (O&M) condition and Safety/Mobility Risk Level following failure.

PARAMETERS SPECIFIED BY SAFETY & MOBILITY RISK LEVEL

Risk Level	Additional Annual Cost (Relative to Do Min Cost Above)			Annual Failure Risk for a New Asset	Unit Failure Cost		Level Following Failure		Notes
	Agency	User	Total		Agency	User	O&M Condition	Safety/Mobility Risk	
1	0	0	0	0.00%	4,000,000	5,000	1	1	
2	0	0	0	0.00%	4,000,000	5,000	1	2	
3	0	1,000	1,000	0.00%	4,000,000	25,000	1	3	
4	0	5,000	5,000	0.00%	4,000,000	50,000	1	4	
5	0	50,000	50,000	0.00%	4,000,000	500,000	1	5	

Figure A-13. Parameters Specified by Safety & Mobility Risk Level

1. Enter the additional annual cost to the **Agency** in addition to the do-minimum agency maintenance cost discussed in the previous section for risk levels 2-4.
2. Enter the additional annual cost to the **User** in addition to the do-minimum user maintenance cost discussed in the previous section for risk levels 2-4.
3. The **Total** additional annual cost is the sum of the **Agency** and **User** costs.
4. Enter the probability of **Annual Failure Risk for a New Asset**. This is the annual failure risk. This risk is independent of the failure risk specified by O&M Condition level above.
5. Enter the **Agency Unit Failure Cost**. This is the unit cost to the agency of an asset failure.
6. Enter the **User Unit Failure Cost**. This is the unit cost the road user of an asset failure.
7. Enter the **O&M Condition** level resulting from restoration of an asset following failure.
8. Enter the **Safety/Mobility Risk Level** from restoration of an asset following failure.
9. Enter any **Notes**.

Solution by State

The **Solution by State**, shown in Figure A-14, contains the results for the model after all the parameters have been entered and the model has been solved using the *Solve Model* button at the top of the screen. For each combination of O&M Condition Level and Safety/Mobility Risk, the table

shows which treatment is recommended, the discounted long-term cost of performing the treatment (and then performing subsequent optimal treatments), and the benefit of performing the recommended treatment. The benefit is the savings in agency and user costs per unit if the treatment is performed, relative to deferring treatment one year.

SOLUTION BY STATE

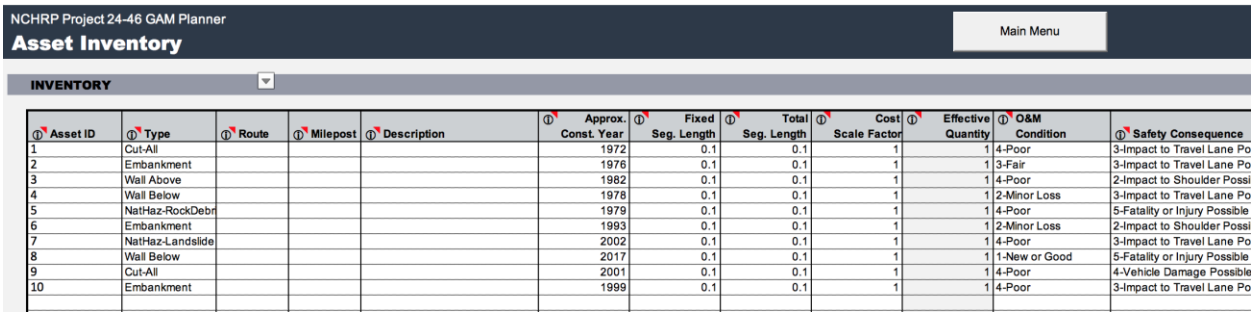
State	O&M Condition Level	Safety/Mobility Conseq. Level	Rec. Action	Desc.	Long-Term Cost	Benefit
1	1	1	1	Maintain	105,000	33,095
2	2	1	1	Maintain	105,000	185,976
3	3	1	1	Maintain	105,000	378,452
4	4	1	1	Maintain	105,000	1,904,762
5	5	1	4	Restore	1,230,000	0
6	1	2	1	Maintain	105,000	33,095
7	2	2	1	Maintain	105,000	185,976
8	3	2	1	Maintain	105,000	378,452
9	4	2	1	Maintain	105,000	1,904,762
10	5	2	4	Restore	1,230,000	0
11	1	3	1	Maintain	126,000	33,276
12	2	3	1	Maintain	126,000	186,881
13	3	3	1	Maintain	126,000	380,262
14	4	3	1	Maintain	126,000	1,913,810
15	5	3	4	Restore	1,270,000	0
16	1	4	1	Maintain	206,000	33,476
17	2	4	1	Maintain	206,000	187,881
18	3	4	1	Maintain	206,000	382,262
19	4	4	1	Maintain	206,000	1,923,810
20	5	4	4	Restore	1,375,000	0
21	1	5	1	Maintain	724,048	37,562
22	2	5	1	Maintain	724,048	208,312
23	3	5	1	Maintain	724,048	423,124
24	4	5	1	Maintain	724,048	2,128,118
25	5	5	4	Restore	2,244,048	0

Figure A-14. Solution by State

To revise the model, edit any of the model parameters in the sections described above, and click the *Solve* button. Once all edits are complete, click *Main Menu*.

INVENTORY WORKSHEET

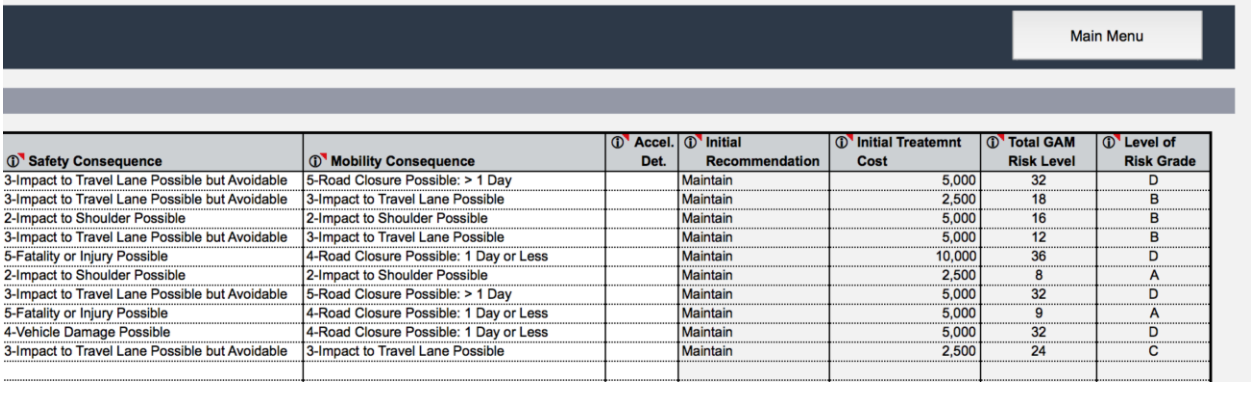
The **Inventory** worksheet contains the asset inventory data necessary for using the GAM Planner, including asset type, several fields describing the asset, several fields detailing the asset quantity, O&M condition level, safety consequence level, and mobility consequence level. There is also an option for accelerated deterioration. The system provides an initial work recommendation and calculates the initial cost of the treatment, the total GAM risk, and the level-of-risk grade. The following steps describe the process of entering assets into the GAM Planner. Partial views of the **Inventory** worksheet are shown in Figures A-15 and A-16.



Asset ID	Type	Route	Milepost	Description	Approx. Const. Year	Fixed Seg. Length	Total Seg. Length	Cost Scale Factor	Effective Quantity	O&M Condition	Safety Consequence
1	Cut-All				1972	0.1	0.1	1	1	4-Poor	3-Impact to Travel Lane Po
2	Embankment				1976	0.1	0.1	1	1	3-Fair	3-Impact to Travel Lane Po
3	Wall Above				1982	0.1	0.1	1	1	4-Poor	2-Impact to Shoulder Possi
4	Wall Below				1978	0.1	0.1	1	1	2-Minor Loss	3-Impact to Travel Lane Po
5	NatHaz-RockDebr				1979	0.1	0.1	1	1	4-Poor	5-Fatality or Injury Possible
6	Embankment				1993	0.1	0.1	1	1	2-Minor Loss	2-Impact to Shoulder Possi
7	NatHaz-Landslide				2002	0.1	0.1	1	1	4-Poor	3-Impact to Travel Lane Po
8	Wall Below				2017	0.1	0.1	1	1	1-New or Good	5-Fatality or Injury Possible
9	Cut-All				2001	0.1	0.1	1	1	4-Poor	4-Vehicle Damage Possible
10	Embankment				1999	0.1	0.1	1	1	4-Poor	3-Impact to Travel Lane Po

Figure A-15. Asset Inventory Worksheet, Part 1

1. Define the **Asset ID**. This is the unique identifier for the asset. The asset identification can be any alphanumeric characters or symbols.
2. Select the asset **Type** from the list of defined asset types. To add to the list first create a new asset model on the **Main Menu**.
3. Enter the **Route** along which the asset is located.
4. Enter the **Milepost** of the route along which the asset is located.
5. Enter a **Description** of the asset.
6. Enter the **Fixed Segment Length**. This is the length per fixed asset segment. Note: This length should correspond to that assumed in developing the asset model. Use a value of 0.1 miles if using default asset models.
7. Enter the **Total Segment Length** of the segment.
8. Enter a **Cost Scale Factor**. This is a multiplier for segment costs.
9. The **Effective Quantity** is calculated by dividing **Total Segment Length** by **Fixed Segment Length** and multiplying the result by the **Cost Scale Factor**. This is a calculated field and cannot be edited.
10. Select the **O&M Condition** from the list. This is the existing O&M condition level. There are four condition levels, with 1 being the best and 5 the worst.



Safety Consequence	Mobility Consequence	Accel. Det.	Initial Recommendation	Initial Treatemnt Cost	Total GAM Risk Level	Level of Risk Grade
3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day		Maintain	5,000	32	D
3-Impact to Travel Lane Possible but Avoidable	3-Impact to Travel Lane Possible		Maintain	2,500	18	B
2-Impact to Shoulder Possible	2-Impact to Shoulder Possible		Maintain	5,000	16	B
3-Impact to Travel Lane Possible but Avoidable	3-Impact to Travel Lane Possible		Maintain	5,000	12	B
5-Fatality or Injury Possible	4-Road Closure Possible: 1 Day or Less		Maintain	10,000	36	D
2-Impact to Shoulder Possible	2-Impact to Shoulder Possible		Maintain	2,500	8	A
3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day		Maintain	5,000	32	D
5-Fatality or Injury Possible	4-Road Closure Possible: 1 Day or Less		Maintain	5,000	9	A
4-Vehicle Damage Possible	4-Road Closure Possible: 1 Day or Less		Maintain	5,000	32	D
3-Impact to Travel Lane Possible but Avoidable	3-Impact to Travel Lane Possible		Maintain	2,500	24	C

Figure A-16. Asset Inventory Worksheet, Part 2

11. Select the **Safety Consequence** from the list. This is the risk level best representing potential safety consequences in the event of asset failure. There are five levels of safety consequences, with 1 having no safety impact and 5 causing possible fatality or injury.

12. Select the **Mobility Consequence** from the list. This is the risk level best representing potential mobility consequences in the event of asset failure. There are five levels of mobility consequences, with 1 having no mobility impact and 5 having possible road closures.
13. Choose whether to use **Accelerated Deterioration**. Enter "Yes" if the asset is expected to undergo accelerated deterioration relative to the default rate for the selected asset type.
14. The **Initial Recommendation** is the recommendation for the asset given its risk level and the selected asset type. This is a calculated field and cannot be edited.
15. The **Initial Treatment Cost** is the cost for the initial recommended action. Note: You can adjust the scale factor so that this matches a known cost if available. This is a calculated field and cannot be edited.
16. The **Total GAM Risk Level** is the total risk level on a scale of 2 to 50. This is a calculated field and cannot be edited.
17. The **Level-of-Risk Grade** is the letter grade (A-F) representing overall level of risk. This is a calculated field and cannot be edited.

To edit the inventory, enter data into any of the editable fields above. Once all edits are complete, click *Main Menu*.

SUMMARY RESULTS WORKSHEET

The **Summary Results** worksheet contains the summary outputs of the GAM Planner. It contains one summary table and three summary charts, each showing results by year: **Needs and Costs**, **O&M Condition Level,** and **Safety/Mobility Consequence Level**. Except for the first **Year** and the **Budget** fields for each year, the cells in this worksheet are all calculated from other input cells and should not be edited. The results automatically update when the input worksheets are edited.

At the top of the worksheet is an option to *Randomize Deterioration.* The deterioration models in the GAM Planner are probabilistic models, and deterioration is simulated by generating a set of random numbers. Clicking this button regenerates all of the random numbers in the tool, and may impact model results.

The **Summary Results** worksheet is shown in Figure A-17. Note that the following screenshots are presented using illustrative data.

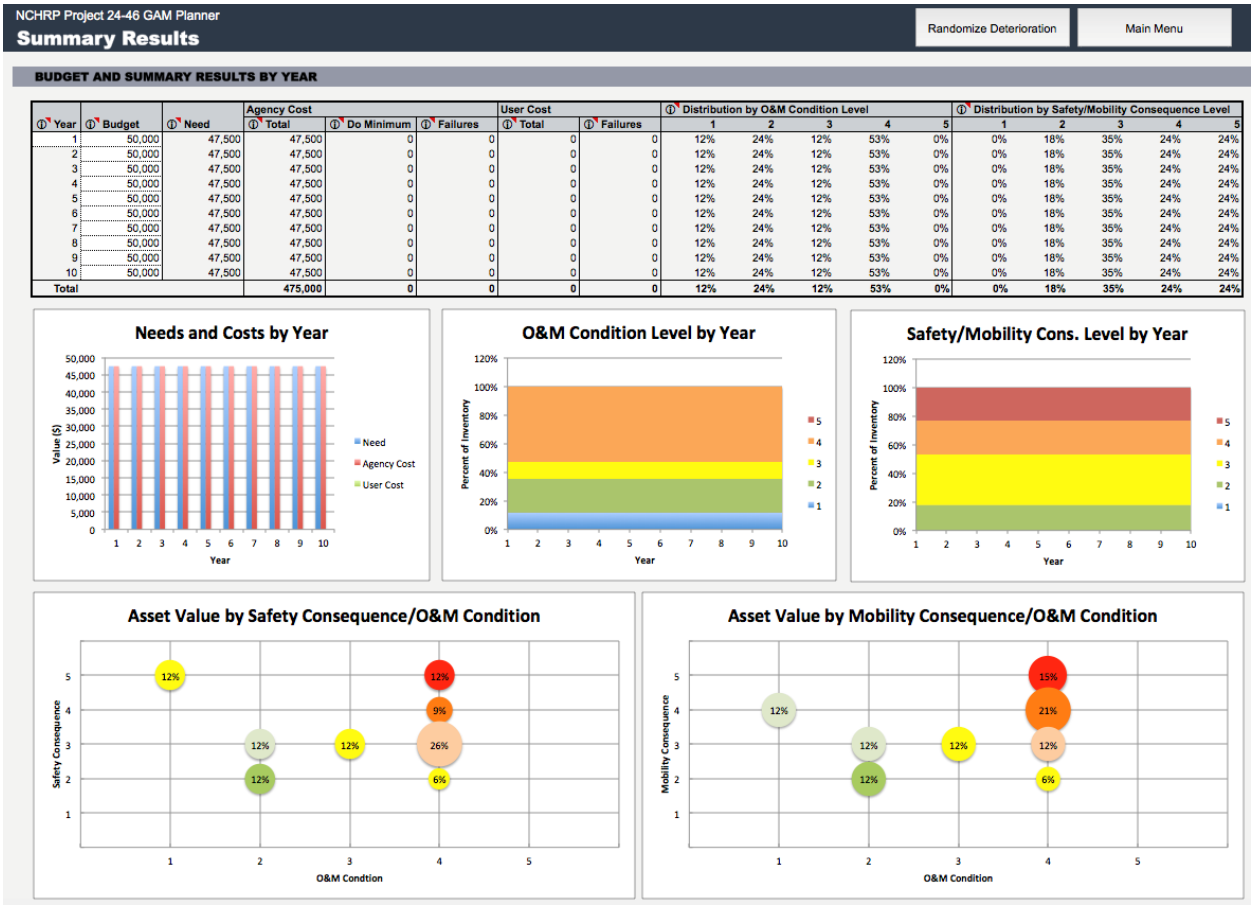


Figure A-17. Summary Results Worksheet

Budget and Summary Results by Year

The **Budget and Summary Results by Year** table shows the summary outputs of the GAM Planner. Except for the first **Year** field and the **Budget** fields, the cells in this worksheet are all calculated from other input cells and should not be edited. The results automatically update when the input worksheets are edited. The following are descriptions of the fields on this worksheet.

A view of the **Budget and Summary Results by Year** table is shown below in Figure A-18. Note that the following screenshot is presented using illustrative data.

BUDGET AND SUMMARY RESULTS BY YEAR

Year	Budget	Need	Agency Cost			User Cost		Distribution by O&M Condition Level					Distribution by Safety/Mobility Consequence Level				
			Total	Do Minimum	Failures	Total	Failures	1	2	3	4	5	1	2	3	4	5
1	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
2	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
3	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
4	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
5	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
6	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
7	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
8	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
9	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
10	50,000	47,500	47,500	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%
Total			475,000	0	0	0	0	12%	24%	12%	53%	0%	0%	18%	35%	24%	24%

Figure A-18. Budget and Summary Results by Year Table

1. **Year** is the program year. Note: You can enter the value for the first year here.
2. The **Budget** is the budget each year for GAM assets. Note: Agency costs may exceed this value as a result of do-minimum and/or failure costs that cannot be avoided.

- **Need** is the agency expenditure to support the least life-cycle cost recommendations by year. Note: Actual expenditures may exceed this amount as a result of do-minimum and/or failure costs.
- **Total** agency costs by year, including treatment costs, do-minimum costs, and failure costs.
- Agency "**Do Minimum"** cost by year.
- Agency "**Failures"** cost by year.
- **Total** user cost by year, including costs incurred by risk level and costs from failures.
- User "**Failures"** cost by year.
- **Distribution by O&M Condition Level** is the distribution of asset quantity by operations & maintenance condition level. Note: Assets are weighted by reconstruction value.
- **Distribution by Safety/Mobility Consequence Level** is the distribution of asset quantity by safety/mobility consequence level, the average of safety and mobility consequence levels. Note: Assets are weighted by reconstruction value.

Summary Results Charts

There are five summary charts. Three of these show results by year: **Needs and Costs**, **O&M Condition Level,** and **Safety/Mobility Consequence Level**. Views of the charts are shown in Figures A-19 through A-21.

The **Needs and Costs by Year** chart, shown in Figure A-19, shows the need, agency cost, and user cost in dollars for each year of the analysis. The **O&M Condition Level by Year** chart, shown in Figure A-20, shows the percent of asset inventory for each of the five operation and maintenance levels for each year of the analysis. The **Safety/Mobility Consequence Level by Year** chart, shown in Figure A-21, shows the percent of the asset inventory at each of the five safety/mobility consequence levels for each year in the analysis.

Note that the following screenshots are presented using illustrative data.

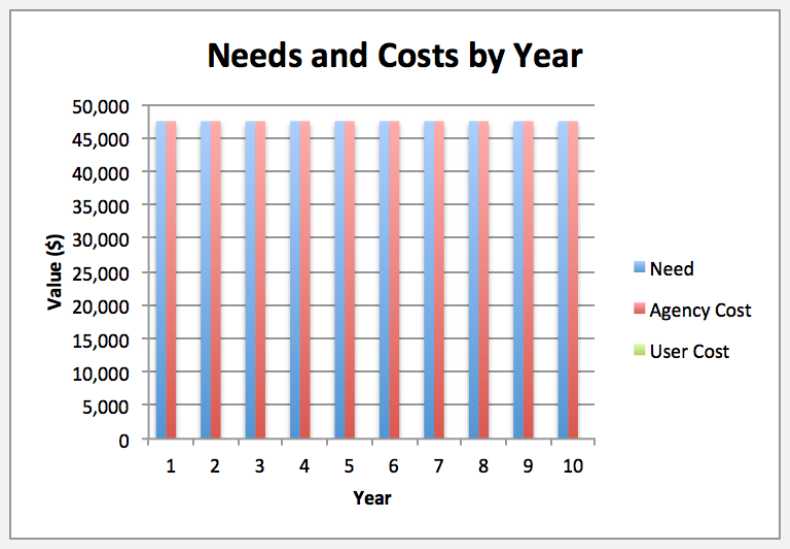


Figure A-19. Needs and Costs by Year

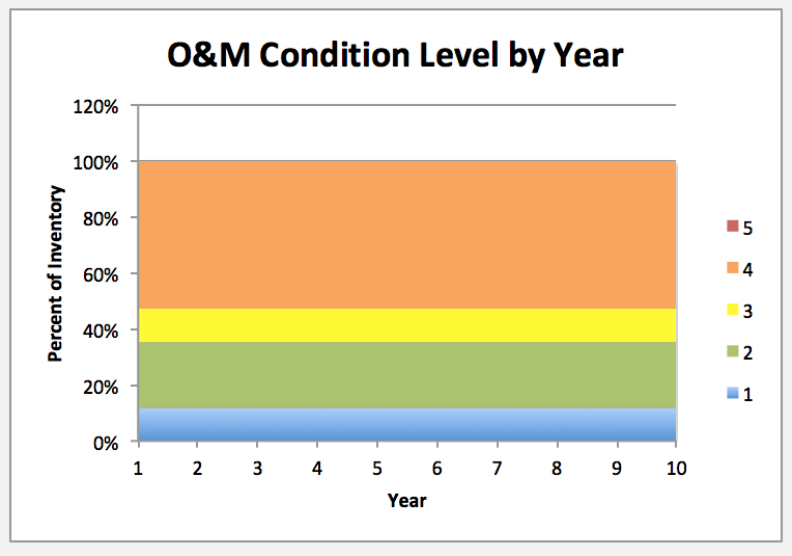


Figure A-20. O&M Condition Level by Year

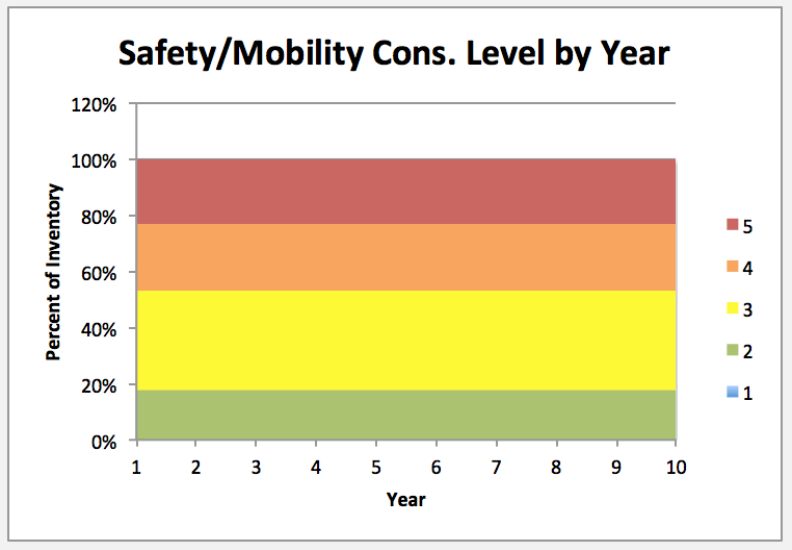


Figure A-21. Safety/Mobility Consequence Level by Year

Two additional charts show details on initial conditions of the inventory. The **Asset Value by Safety Consequence/O&M Condition** chart, shown in Figure A-22, shows the percentage of assets in the initial inventory at each combination of safety consequence and O&M condition level, weighted by asset reconstruction value. The **Asset Value by Mobility Consequence/O&M Condition** chart, shown in Figure A-23, shows the percentage of assets in the initial inventory at each combination of mobility consequence and O&M condition level.

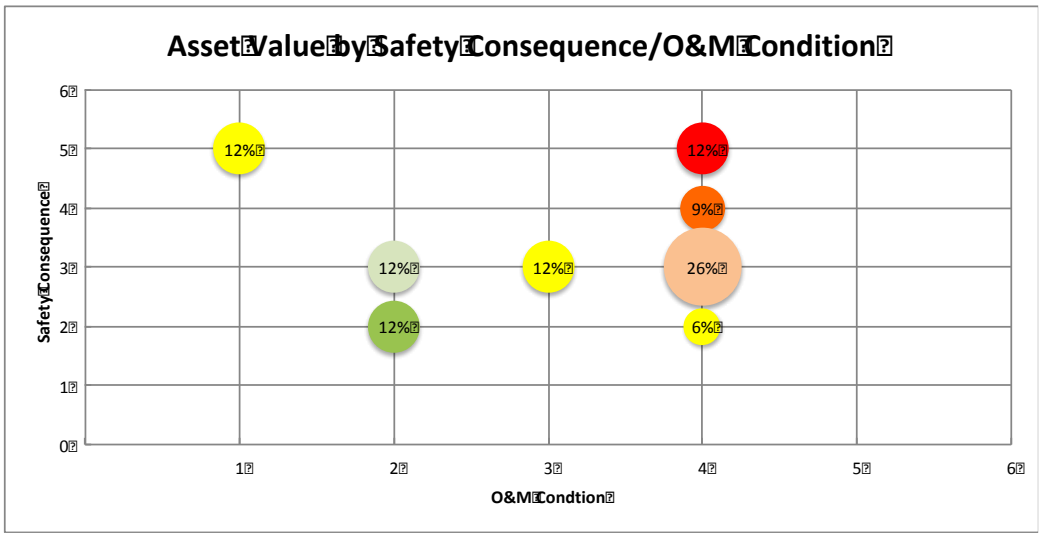


Figure A-22. Asset Value by Safety Consequence/O&M Condition

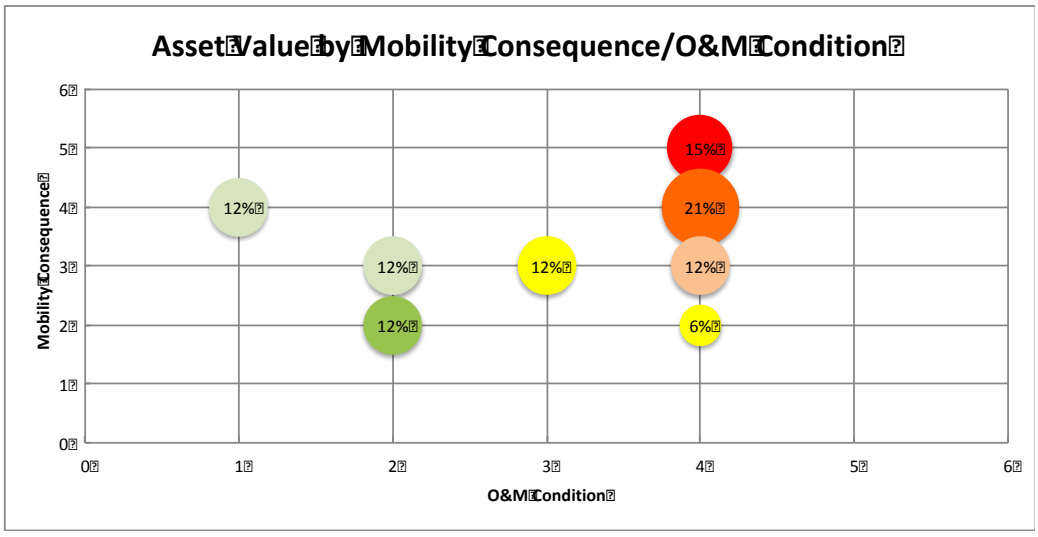


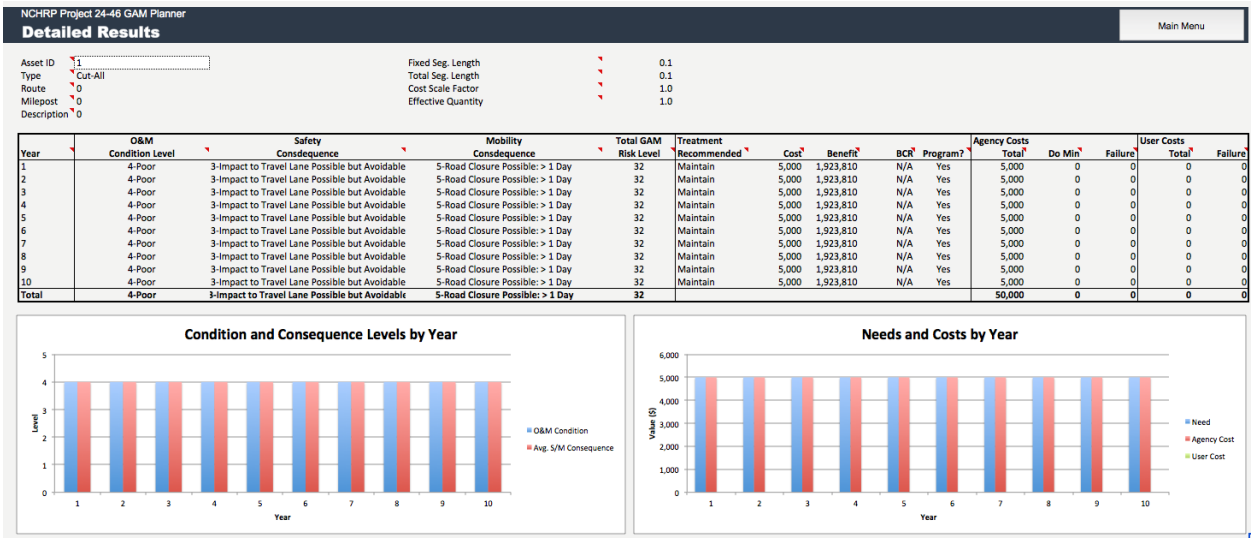
Figure A-23. Asset Value by Mobility Consequence/O&M Condition

DETAILED RESULTS WORKSHEET

The **Detailed Results** worksheet shows the detailed outputs of the GAM Planner for a single asset. At the top of this worksheet are descriptions of the asset from the **Inventory** worksheet, definitions for which can be found there. Following this are a summary results table and two summary charts showing, by year, **Needs and Costs** and **Risk Levels**. Except for the **Asset ID**, the cells in this worksheet are all calculated from other input cells and should not be edited. The results automatically update when the input worksheets are edited. The following are descriptions of the fields on this worksheet.

A partial view of the **Detailed Results** worksheet is shown in Figure A-24. The **Needs and Costs by Year** chart, shown in Figure A-25, shows the needs, agency costs, and user costs by year for the chosen asset. The **Risk Levels by Year** chart, shown in Figure A-26, shows the operation and

maintenance (O&M) condition level and safety/mobility (S/M) consequence level by year for the chosen asset. Note that the following screenshots are presented using illustrative data.



NCHRP Project 24-46 GAM Planner

Detailed Results

Main Menu

Asset ID	1	Fixed Seg. Length	0.1
Type	Cut-All	Total Seg. Length	0.1
Route	0	Cost Scale Factor	1.0
Milepost	0	Effective Quantity	1.0
Description	0		

Year	O&M Condition Level	Safety Consdequence	Mobility Consdequence	Total GAM Risk Level	Treatment Recommended	Cost	Benefit	BCR	Program?	Agency Costs Total	Do Min	Failure	User Costs Total	Failure
1	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
2	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
3	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
4	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
5	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
6	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
7	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
8	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
9	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
10	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32	Maintain	5,000	1,923,810	N/A	Yes	5,000	0	0	0	0
Total	4-Poor	3-Impact to Travel Lane Possible but Avoidable	5-Road Closure Possible: > 1 Day	32						50,000	0	0	0	0

Figure A-24. Detailed Results Worksheet

- **Year** is the program year.
- **O&M Condition Level** is the operations and maintenance condition level for the specified year.
- **Safety Consequence** is the safety consequence level for the specified year.
- **Mobility Consequence** is the mobility consequence level for the specified year.
- **Total GAM Risk Level** is the level of risk score, calculated by summing the safety and mobility consequences, and then multiplying this sum by the O&M condition level.
- **Treatment Recommended** is the recommended treatment for the asset.
- **Cost** is the agency cost of the recommended treatment.
- **Benefit** is the total agency and user benefit of the recommended treatment relative to deferring treatment one year.
- **BCR** is the benefit/cost ratio of the treatment. Note: A treatment that has the same life-cycle cost as "do minimum" has a benefit/cost ratio of 1.
- **Program** indicates whether sufficient budget is available to program the recommended treatment.
- **Agency Costs Total** is the total agency cost incurred for the asset in the specified year, including treatment, do-minimum, and failure costs.
- **Agency Costs Do Min** is the agency cost incurred for the asset in the specified year for the do-minimum treatment.
- **Agency Costs Failure** is the agency cost incurred for the asset in the specified year as a result of asset failure.
- **User Costs Total** is the total user costs incurred for the asset in the specified year.

- **User Costs Failure** is the user costs incurred for the asset in the specified year as a result of asset failure.

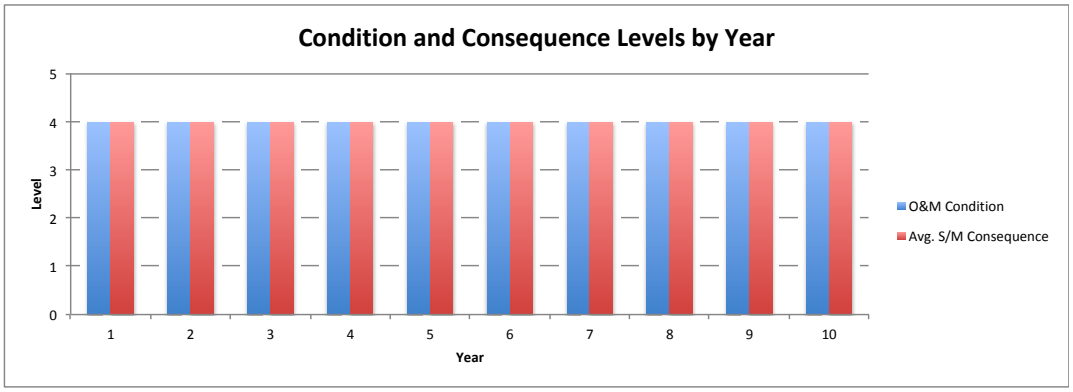


Figure A-25. Needs and Costs by Year

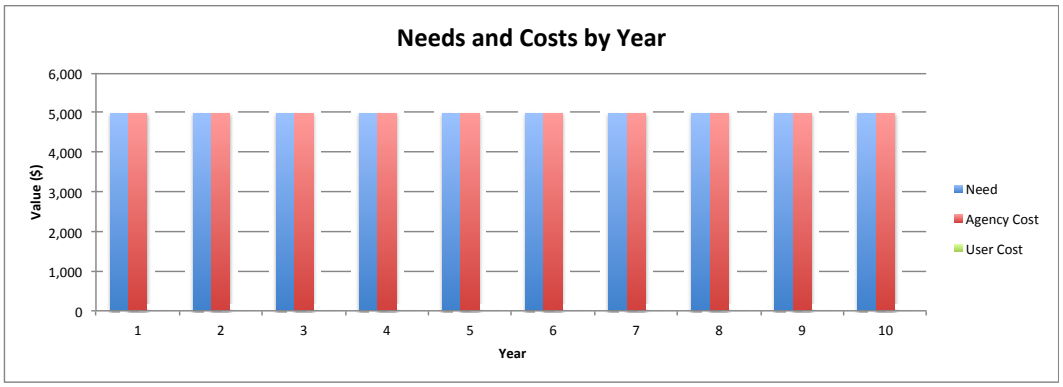


Figure A-26. Risk Levels by Year

Appendix B: GAM Inventory Start Example

INTRODUCTION

This appendix presents an example of a hypothetical inventory and assessment using the GAM Planner tool described in Chapter 2 and Appendix A of the *GAM Implementation Manual*. The following example demonstrates the initial steps an agency may follow to begin a GAM inventory for a corridor containing various geotechnical asset types.

STEP 1: SELECT EXAMPLE CORRIDOR AND IDENTIFY ASSETS FOR INVENTORY

Summary of example corridor: several reasonably performing cut and embankment assets. One wall with deterioration starting near middle and a problematic subgrade in an area with near surface

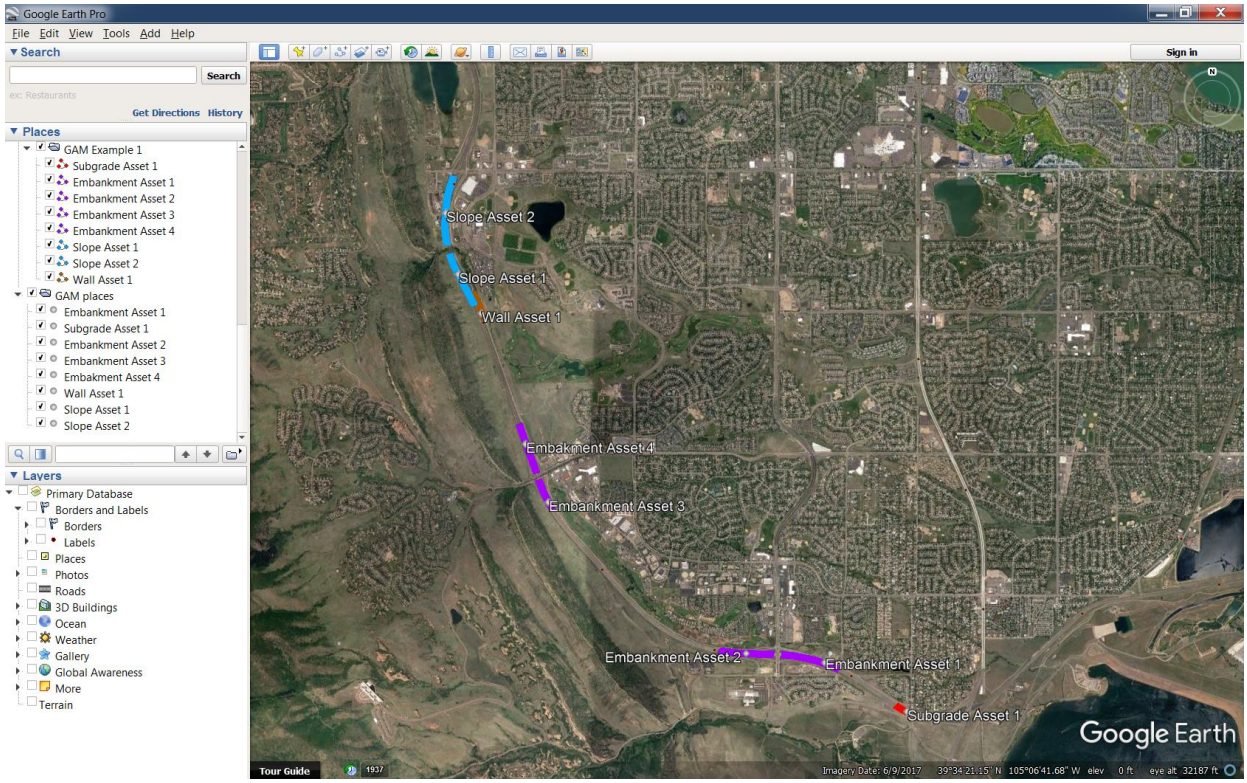


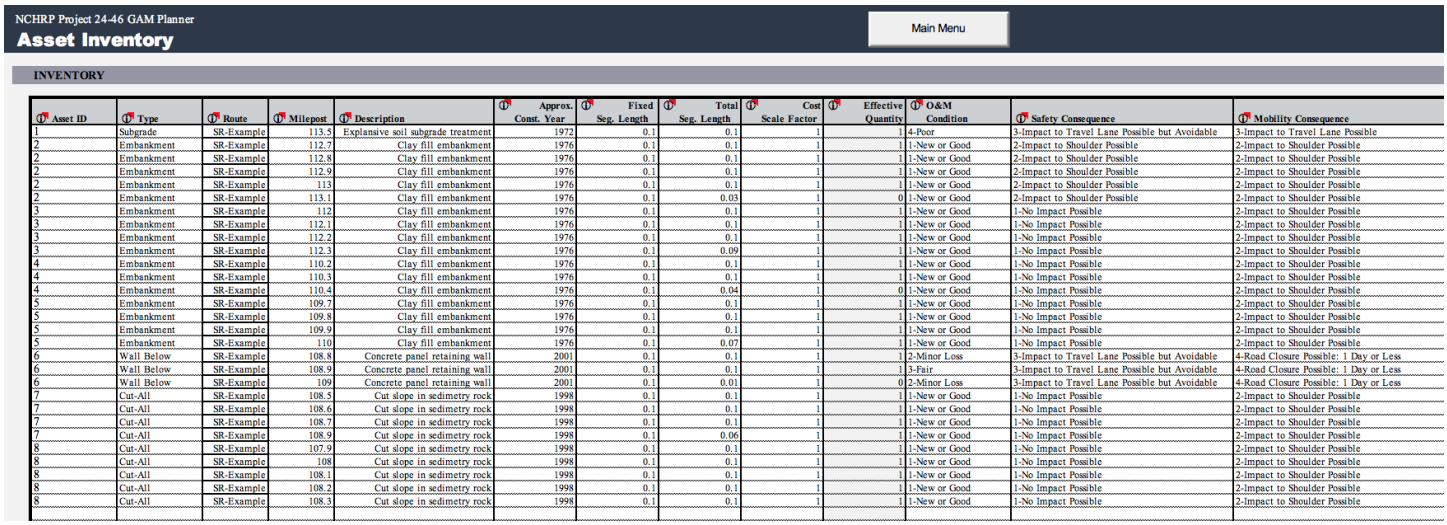
Figure B-1. Google Earth Annotated View of Example Corridor

The summary of assets is as follows.

Asset ID	Starting Milepoint (lower bound)	Length (mile)
Subgrade Asset 1	113.4	0.10
Embankment Asset 1	112.7	0.43
Embankment Asset 2	112.0	0.39
Embankment Asset 3	110.2	0.24
Embankment Asset 4	110.1	0.37
Wall Asset 1	109.0	0.21
Slope Asset 1	108.5	0.36
Slope Asset 2	108.4	0.50

STEP 2: BUILD GAM INVENTORY

Using default GAM Planner model settings, the inventory is constructed as shown in Figure B-2.


NCHRP Project 24-46 GAM Planner

Asset Inventory

Main Menu

INVENTORY

Asset ID	Type	Route	Milepost	Description	Approx. Const. Year	Fixed Seg. Length	Total Seg. Length	Cost Scale Factor	Effective Quantity	O&M Condition	Safety Consequence	Mobility Consequence
1	Subgrade	SR-Example	113.5	Explansive soil subgrade treatment	1972	0.1	0.1	1	1	4-Poor	3-Impact to Travel Lane Possible but Avoidable	3-Impact to Travel Lane Possible
2	Embankment	SR-Example	112.7	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	2-Impact to Shoulder Possible	2-Impact to Shoulder Possible
2	Embankment	SR-Example	112.8	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	2-Impact to Shoulder Possible	2-Impact to Shoulder Possible
2	Embankment	SR-Example	112.9	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	2-Impact to Shoulder Possible	2-Impact to Shoulder Possible
2	Embankment	SR-Example	113	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	2-Impact to Shoulder Possible	2-Impact to Shoulder Possible
2	Embankment	SR-Example	113.1	Clay fill embankment	1976	0.1	0.03	1	0	1-New or Good	2-Impact to Shoulder Possible	2-Impact to Shoulder Possible
3	Embankment	SR-Example	112	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
3	Embankment	SR-Example	112.1	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
3	Embankment	SR-Example	112.2	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
3	Embankment	SR-Example	112.3	Clay fill embankment	1976	0.1	0.09	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
4	Embankment	SR-Example	110.2	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
4	Embankment	SR-Example	110.3	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
4	Embankment	SR-Example	110.4	Clay fill embankment	1976	0.1	0.04	1	0	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
5	Embankment	SR-Example	109.7	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
5	Embankment	SR-Example	109.8	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
5	Embankment	SR-Example	109.9	Clay fill embankment	1976	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
5	Embankment	SR-Example	110	Clay fill embankment	1976	0.1	0.07	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
6	Wall Below	SR-Example	108.8	Concrete panel retaining wall	2001	0.1	0.1	1	1	2-Minor Loss	3-Impact to Travel Lane Possible but Avoidable	4-Road Closure Possible: 1 Day or Less
6	Wall Below	SR-Example	108.9	Concrete panel retaining wall	2001	0.1	0.1	1	1	3-Fair	3-Impact to Travel Lane Possible but Avoidable	4-Road Closure Possible: 1 Day or Less
6	Wall Below	SR-Example	109	Concrete panel retaining wall	2001	0.1	0.01	1	0	2-Minor Loss	3-Impact to Travel Lane Possible but Avoidable	4-Road Closure Possible: 1 Day or Less
7	Cut-All	SR-Example	108.5	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
7	Cut-All	SR-Example	108.6	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
7	Cut-All	SR-Example	108.7	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
7	Cut-All	SR-Example	108.9	Cut slope in sedimetry rock	1998	0.1	0.06	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
8	Cut-All	SR-Example	107.9	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
8	Cut-All	SR-Example	108	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
8	Cut-All	SR-Example	108.1	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
8	Cut-All	SR-Example	108.2	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible
8	Cut-All	SR-Example	108.3	Cut slope in sedimetry rock	1998	0.1	0.1	1	1	1-New or Good	1-No Impact Possible	2-Impact to Shoulder Possible

Figure B-2. Screen View of Example Inventory Entered into GAM Planner Tool

Example input notes:

- Assets shorter than default segment length noted by reduced length in asset segment length column.
- No assets judged to have accelerated deterioration criteria, such as a high quantity of metal elements or deteriorating drainage conditions that are degrading the geotechnical asset.

- Wall asset contains 3 segments, with the middle wall segment having a reduced visual condition score.

STEP 3: EVALUATE GAM PLANNER RESULTS

Once the corridor inventory is entered, the user can return to the Main Menu of the GAM Planner for an overview of the asset inventory summary, as shown in Figure B-4.

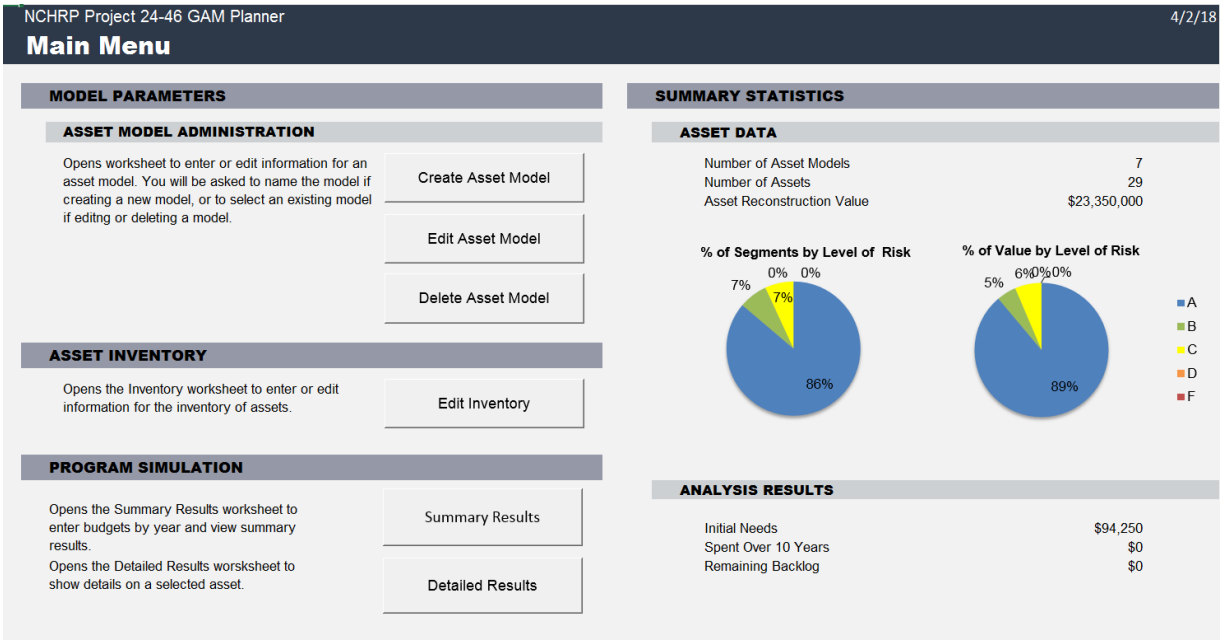


Figure B-3. Screen View of GAM Planner Tool Main Menu Page for Example Inventory

Reviewing Summary Statistics on Main Menu page:

1. There are 29 geotechnical asset segments (approximately 2.9 miles of geotechnical assets), with a reconstruction value of $23M.
    a. Check: Approximately $800K of replacement value per 500 feet of geotechnical asset.

2. Of the 29 assets, the Level of Risk (LOR) distribution is as follows:
   A – 25 asset segments
   B – 2 asset segments
   C – 2 asset segments
   No D or F segments

    a. Check: As there are no assets in the corridor creating major delay or safety threats, the LOR distribution and values are reasonable. The grades suggest the assets contribute relatively low TAM objective performance risk in their current condition.

The GAM Planner Summary Results Page (shown in Figure B-4 for this example corridor) provides additional temporal outcomes for the inventory assessment.

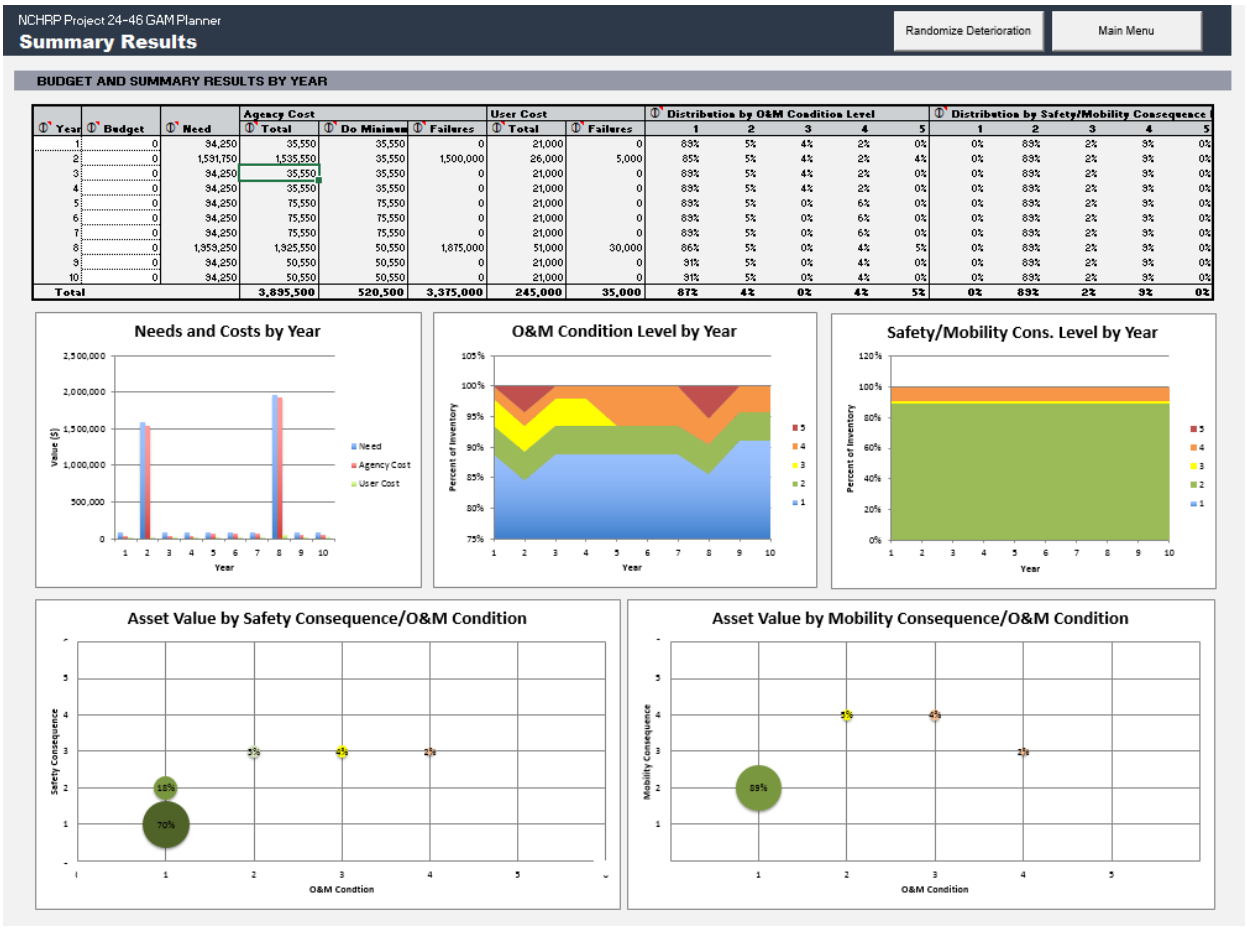


Figure B-4. Screen View of GAM Planner Tool Summary Results for Example Inventory

The geotechnical program for this agency does not have a budget for these assets. The budget is set to zero unless there is evidence of dedicated funding to other groups charged with management of these assets.

The model indicates the agency is incurring about $35,000 in annual costs for the current management strategy on this corridor, in addition to the costs related to the periodic failures of the poorly performing subgrade asset, which exceed $1M. By deferring treatment of geotechnical assets, the department is incurring an estimated 10-year life-cycle cost of $3.9M, based on a program/network level analysis.

STEP 4: EVALUATE INVESTMENT STRATEGIES

Once the inventory process for geotechnical assets has started, the asset manager can start developing investment strategies that can be used to inform decision makers of beneficial investment opportunities and project development. An example is presented in the next section.

Investment Scenario 1:

By obtaining an initial investment of $115K in the first year of the model and returning to a zero-budget program, the agency is able to address a problematic asset, thus reducing a future failure potential. The 10-year life-cycle cost estimate for this scenario is approximately $2.5M, or $1.4M less than the current 10-year estimate without treatment.

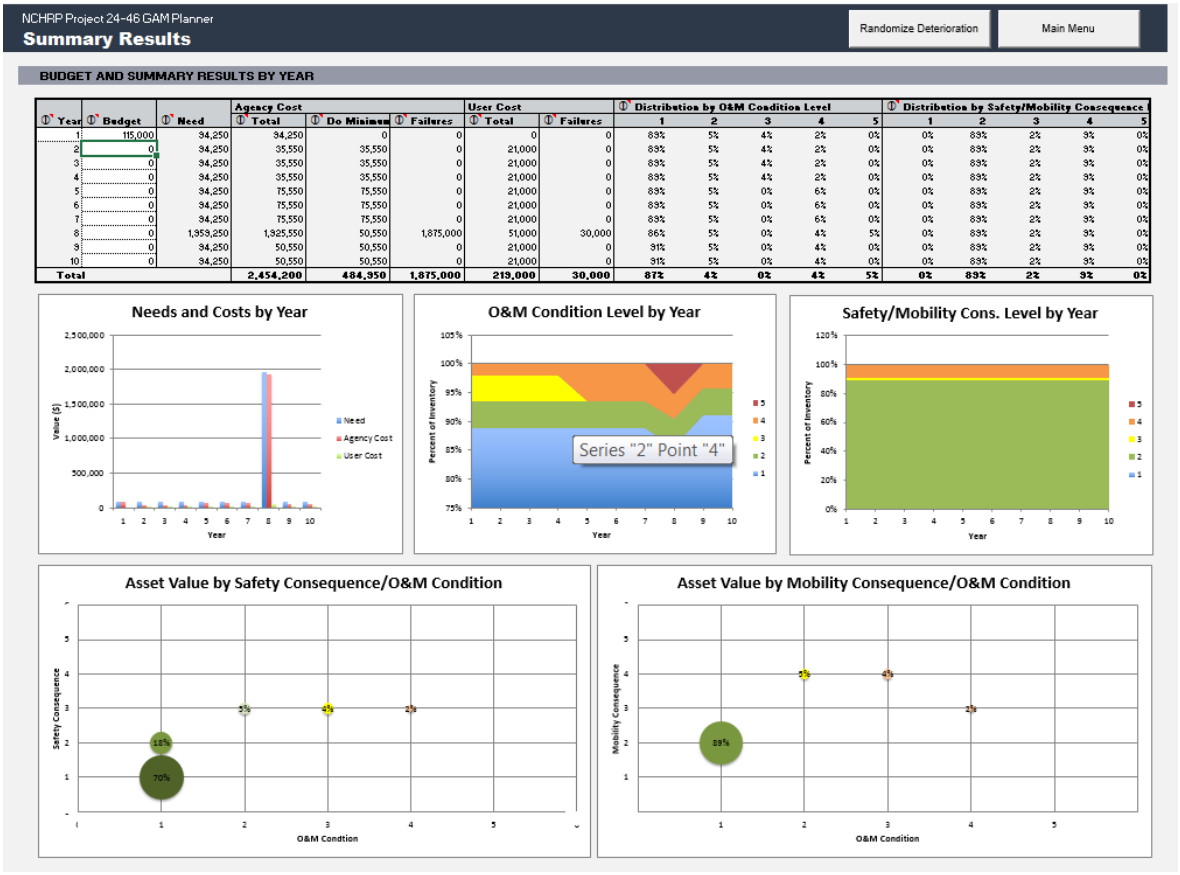


Figure B-5. Screen View of GAM Planner Tool Summary Results for Budget Scenario Planning on Example Inventory

Other scenarios can be proposed to evaluate further life-cycle cost reductions or based on likely funding scenarios.

In addition, should Investment Scenario 1 be advanced, the costs and treatment options for the subgrade treatment investment should be optimized at the project level using a life-cycle cost analysis (e.g., the net present value framework discussed in the *GAM Implementation Manual,* Chapter 8, and presented in Appendix E).

Appendix C: GAM Model Formulation

INTRODUCTION

This appendix details the formulation of the asset models used in the GAM Planner. As described below, the basic approach used in the tool is to model assets using a Markov Decision Process. This approach has been used previously in various pavement and bridge management systems, as well as in other asset management systems. The following sections present the model formulation and provide details on how the model has been implemented in the GAM Planner.

MODEL FORMULATION

The GAM model is a condition-based model that recommends the optimal treatment to perform for each of a number of discrete condition states to minimize life-cycle costs of maintaining the asset. This approach has been applied previously to a number of asset types, as described in *TCRP Report 157*: *State of Good Repair: Prioritizing the Rehabilitation and Replacement of Existing Capital Assets and Evaluating the Implications for Transit.* The basic inputs to the model are the:

- Set of states defined for the asset.
- Set of treatments that can be performed in each state, including a "do-minimum" treatment.
- Treatment costs and effects. Treatment effects are described through a transition probability matrix detailing the probability of transition from one state to every other state given performance of a specific treatment. The deterioration of the asset is described through the effects of the do-minimum treatment.
- Discount rate.

Once a Markov Decision Process has been defined, a linear program can be formulated and solved to determine what actions, if taken, will minimize asset costs over time. The output of the model is the recommended treatment policy specifying what treatment to perform based on the condition of the asset. The model also predicts the future life-cycle cost for each state/treatment combination if a given action is performed within the next decision period and the optimal policy is followed subsequently. The benefit of performing a treatment is the savings that will result from performing the action relative to deferring action for one year (performing the "do-minimum" action). If this difference is non-zero, it will be more cost effective to perform the action than to defer the work. The priority of performing a treatment is calculated by dividing this benefit by the treatment cost.

To formulate the problem, it is necessary to describe the optimal stationary policy for the asset (that is, the optimal set of actions to take in each condition state) using Bellman's optimality equation:

$$LCC^{*}(x) = \min_{a} \left(C_{x,a} + \frac{1}{1+i} \sum_{y} P_{x,y}^{a} LCC^{*}(y) \right) \qquad (1)$$

where

$LCC^{*}(x)$	minimum life-cycle cost for asset in state x
a	optimal treatment to perform in state x
$C_{x,a}$	cost of taking treatment a in state x
$P_{x,y}^{a}$	probability of transition from state x to state y given treatment a is performed

Although Equation (*1*) is a dynamic equation, it can be formulated and solved as a linear program. Once the optimal policy has been determined, the life-cycle cost for an asset in state *x* given that treatment *a* is performed within the next period can be specified as follows:

$$LCC(x \mid a) = C_{x,a} + \frac{1}{1+i}\sum_{y} P_{x,y}^{a} LCC^{*}(y) \qquad (2)$$

Note: This equation assumes that the optimal policy is followed within the next decision period and thereafter. Thus, the difference between $LCC(x|a)$ and $LCC^{*}(x)$ represents the additional costs incurred if treatment *a* is followed rather than the optimal treatment. Likewise, the benefit *B* of performing a treatment relative to deferring action for one decision period (typically one year) is the difference between the life-cycle cost for the do-minimum treatment and the selected treatment.

MODEL IMPLEMENTATION

It is necessary to define discrete states to use the modeling approach. In the GAM Planner asset models, 25 discrete states are defined, representing each combination of O&M condition level and safety/mobility consequence level. These include:

- 1-5: Maintenance consequence levels 1 to 5 for a safety/mobility consequence level of 1.
- 6-10: Maintenance consequence levels 1 to 5 for a safety/mobility consequence level of 2.
- 11-15: Maintenance consequence levels 1 to 5 for a safety/mobility consequence level of 3.
- 16-20: Maintenance consequence levels 1 to 5 for a safety/mobility consequence level of 4.
- 21-25: Maintenance consequence levels 1 to 5 for a safety/mobility consequence level of 5.

In the model, the following treatments may be defined:

- **Do Minimum.** When the "do-minimum" treatment is performed, the asset may stay in the same state, deteriorate, or fail. Failure probabilities are specified by O&M condition and safety/mobility consequence. These probabilities are assumed to be independent. Thus, the overall failure probability for each state given application of the do-minimum treatment is calculated by combining them. Likewise, the agency and user costs of this treatment are calculated by adding the costs for the corresponding O&M condition and safety/mobility consequence levels.
- **Maintenance.** This treatment has the effect of maintaining the asset in its current state. An agency cost is specified for this treatment. If this treatment is applied, the do-minimum costs specified by O&M condition level are <u>not</u> applied, but the agency and user costs by safety/mobility consequence level <u>are</u> applied. In addition, the failure probability specified by safety/mobility consequence level is applied for this treatment.
- **Rehab.** This treatment has a user-specified effect on O&M condition level. An agency cost is specified for this treatment. If this treatment is applied, the do-minimum costs specified by O&M condition level are <u>not</u> applied, but the agency and user costs by safety/mobility consequence level <u>are</u> applied. In addition, the failure probability specified by safety/mobility consequence level is applied for this treatment.
- **Reconstruction.** This treatment restores the asset to "State 1" (best O&M condition, lowest safety/mobility risk). An agency cost is specified for this treatment. If this treatment is

applied, the do-minimum costs specified by O&M condition level are not applied, but the agency and user costs by safety/mobility consequence level are applied.

- **Restore.** This action is triggered in the event an asset fails, or reaches an O&M condition level of 5. The user specifies the resulting state in the event this treatment is triggered, as well as the agency and user costs of the treatment. The user may set these parameters to define what constitutes "failure" for a given asset type.

In Excel the asset model is formulated as a linear program and solved using the Excel Solver. When the asset model is applied in the simulation model, the entire asset quantity is assumed to be in the same discrete state. Random numbers from 0 to 1 are generated for each asset and year to determine the effect of performing the selected treatment. For instance, if the failure probability for a given state is 1 percent and the deterioration probability is 5 percent, the asset is modeled as failing if the random number is 0.01 or less, and simulated as deteriorating if the random number is between 0.01 and 0.06. If accelerated asset deterioration is assumed, the random numbers generated for a given asset are halved, doubling the likelihood of failure or deterioration.

Appendix D: Geotechnical Asset Condition and Level-of-Risk Examples

Embankment Condition Examples

	**New or Good Condition** No work recommended or agency costs (<1% chance of adverse event in assessment year)
	**Minor Condition Loss Occurring** Incidental annual maintenance needs of a few hours of staff time or <$500 of other costs
	**Fair Condition** Deterioration and repair needs evident Agency annual costs estimated to be <$5,000 or up to about 1 week of labor for asset maintenance (<1% chance of adverse event in assessment year)
	**Poor Condition** Significant deterioration present Regular agency staff involvement required and/or department expenses may be up to $100,000 per year for asset
	**Failed Condition** Failed or nearly failed asset causing other assets to be out of service with corrective action required or imminent

Slope Condition Examples

	**New or Good Condition** No work recommended or agency costs (<1% chance of adverse event in assessment year)
	**Minor Condition Loss Occurring** Incidental annual maintenance needs of a few hours of staff time or <$500 of other costs
	**Fair Condition** Deterioration and repair needs evident Agency annual costs estimated to be <$5,000 or up to about 1 week of labor for asset maintenance (<1% chance of adverse event in assessment year)
	**Poor Condition** Significant deterioration present Regular agency staff involvement required and/or department expenses may be up to $100,000 per year for asset
	**Failed Condition** Failed or nearly failed asset causing other assets to be out of service with corrective action required or imminent

Wall Condition Examples

	**New or Good Condition** No work recommended or agency costs (<1% chance of adverse event in assessment year)
	**Minor Condition Loss Occurring** Incidental annual maintenance needs of a few hours of staff time or <$500 of other costs
	**Fair Condition** Deterioration and repair needs evident Agency annual costs estimated to be <$5,000 or up to about 1 week of labor for asset maintenance (<1% chance of adverse event in assessment year)
	**Poor Condition** Significant deterioration present Regular agency staff involvement required and/or department expenses may be up to $100,000 per year for asset
	**Failed Condition** Failed or nearly failed asset causing other assets to be out of service with corrective action required or imminent

Subgrade Condition Examples

	**New or Good Condition** No work recommended or agency costs (<1% chance of adverse event in assessment year)
	**Minor Condition Loss Occurring** Incidental annual maintenance needs of a few hours of staff time or <$500 of other costs
	**Fair Condition** Deterioration and repair needs evident Agency annual costs estimated to be <$5,000 or up to about 1 week of labor for asset maintenance (<1% chance of adverse event in assessment year)
	**Poor Condition** Significant deterioration present Regular agency staff involvement required and/or department expenses may be up to $100,000 per year for asset
	**Failed Condition** Failed or nearly failed asset causing other assets to be out of service with corrective action required or imminent

Level-of-Risk Examples

LEVEL OF RISK

A = < 10

Maintenance Condition	1
Safety Consequence	1
Mobility/Economic Conseq.	2
Safety Risk Score	1
Mobility/Econ. Risk Score	2
GAM Level of Risk	**3**

Maintenance Condition	2
Safety Consequence	1
Mobility/Economic Conseq.	2
Safety Risk Score	2
Mobility/Econ. Risk Score	4
GAM Level of Risk	**6**

B = 10 - 20

Maintenance Condition	2
Safety Consequence	3
Mobility/Economic Conseq.	5
Safety Risk Score	6
Mobility/Econ. Risk Score	10
GAM Level of Risk	**16**

Maintenance Condition	2
Safety Consequence	4
Mobility/Economic Conseq.	3
Safety Risk Score	8
Mobility/Econ. Risk Score	6
GAM Level of Risk	**14**

C = 20 - 30

Maintenance Condition	4
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	12
Mobility/Econ. Risk Score	16
GAM Level of Risk	**28**

Maintenance Condition	3
Safety Consequence	4
Mobility/Economic Conseq.	3
Safety Risk Score	12
Mobility/Econ. Risk Score	9
GAM Level of Risk	**21**

D = 30 - 40

Maintenance Condition	5
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	15
Mobility/Econ. Risk Score	20
GAM Level of Risk	**35**

Maintenance Condition	4
Safety Consequence	5
Mobility/Economic Conseq.	4
Safety Risk Score	20
Mobility/Econ. Risk Score	16
GAM Level of Risk	**36**

F = > 40

Maintenance Condition	5
Safety Consequence	4
Mobility/Economic Conseq.	5
Safety Risk Score	20
Mobility/Econ. Risk Score	25
GAM Level of Risk	**45**

Maintenance Condition	5
Safety Consequence	5
Mobility/Economic Conseq.	4
Safety Risk Score	25
Mobility/Econ. Risk Score	20
GAM Level of Risk	**45**

Level-of-Risk Examples

LEVEL OF RISK

A = < 10

Maintenance Condition	1
Safety Consequence	2
Mobility/Economic Conseq.	2
Safety Risk Score	2
Mobility/Econ. Risk Score	2
GAM Level of Risk	**4**

Maintenance Condition	2
Safety Consequence	2
Mobility/Economic Conseq.	2
Safety Risk Score	4
Mobility/Econ. Risk Score	4
GAM Level of Risk	**8**

B = 10 - 20

Maintenance Condition	2
Safety Consequence	3
Mobility/Economic Conseq.	3
Safety Risk Score	6
Mobility/Econ. Risk Score	6
GAM Level of Risk	**12**

Maintenance Condition	2
Safety Consequence	5
Mobility/Economic Conseq.	4
Safety Risk Score	10
Mobility/Econ. Risk Score	8
GAM Level of Risk	**18**

C = 20 - 30

Maintenance Condition	4
Safety Consequence	3
Mobility/Economic Conseq.	3
Safety Risk Score	12
Mobility/Econ. Risk Score	12
GAM Level of Risk	**24**

Maintenance Condition	3
Safety Consequence	4
Mobility/Economic Conseq.	3
Safety Risk Score	12
Mobility/Econ. Risk Score	9
GAM Level of Risk	**21**

D = 30 - 40

Maintenance Condition	5
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	15
Mobility/Econ. Risk Score	20
GAM Level of Risk	**35**

Maintenance Condition	5
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	15
Mobility/Econ. Risk Score	20
GAM Level of Risk	**35**

F = > 40

Maintenance Condition	5
Safety Consequence	3
Mobility/Economic Conseq.	5
Safety Risk Score	15
Mobility/Econ. Risk Score	25
GAM Level of Risk	**40**

Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

Level-of-Risk Examples

LEVEL OF RISK

A = < 10

Maintenance Condition	1
Safety Consequence	3
Mobility/Economic Conseq.	3
Safety Risk Score	3
Mobility/Econ. Risk Score	3
GAM Level of Risk	**6**

Maintenance Condition	1
Safety Consequence	1
Mobility/Economic Conseq.	2
Safety Risk Score	1
Mobility/Econ. Risk Score	2
GAM Level of Risk	**3**

B = 10 - 20

Maintenance Condition	2
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	6
Mobility/Econ. Risk Score	8
GAM Level of Risk	**14**

Maintenance Condition	4
Safety Consequence	2
Mobility/Economic Conseq.	2
Safety Risk Score	8
Mobility/Econ. Risk Score	8
GAM Level of Risk	**16**

C = 20 - 30

Maintenance Condition	3
Safety Consequence	4
Mobility/Economic Conseq.	3
Safety Risk Score	12
Mobility/Econ. Risk Score	9
GAM Level of Risk	**21**

Maintenance Condition	4
Safety Consequence	3
Mobility/Economic Conseq.	3
Safety Risk Score	12
Mobility/Econ. Risk Score	12
GAM Level of Risk	**24**

D = 30 - 40

Private Property and Utility Impacts

Maintenance Condition	4
Safety Consequence	3
Mobility/Economic Conseq.	5
Safety Risk Score	12
Mobility/Econ. Risk Score	20
GAM Level of Risk	**32**

Maintenance Condition	5
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	15
Mobility/Econ. Risk Score	20
GAM Level of Risk	**35**

F = > 40

Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

Level-of-Risk Examples

LEVEL OF RISK

A = < 10

Maintenance Condition	3
Safety Consequence	1
Mobility/Economic Conseq.	1
Safety Risk Score	3
Mobility/Econ. Risk Score	3
GAM Level of Risk	**6**

Maintenance Condition	3
Safety Consequence	1
Mobility/Economic Conseq.	1
Safety Risk Score	
Mobility/Econ. Risk Score	3
GAM Level of Risk	**3**

B = 10 - 20

Maintenance Condition	4
Safety Consequence	2
Mobility/Economic Conseq.	2
Safety Risk Score	8
Mobility/Econ. Risk Score	8
GAM Level of Risk	**16**

Maintenance Condition	2
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	6
Mobility/Econ. Risk Score	8
GAM Level of Risk	**14**

C = 20 - 30

Maintenance Condition	4
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	12
Mobility/Econ. Risk Score	16
GAM Level of Risk	**28**

Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

D = 30 - 40

Maintenance Condition	5
Safety Consequence	3
Mobility/Economic Conseq.	4
Safety Risk Score	15
Mobility/Econ. Risk Score	20
GAM Level of Risk	**35**

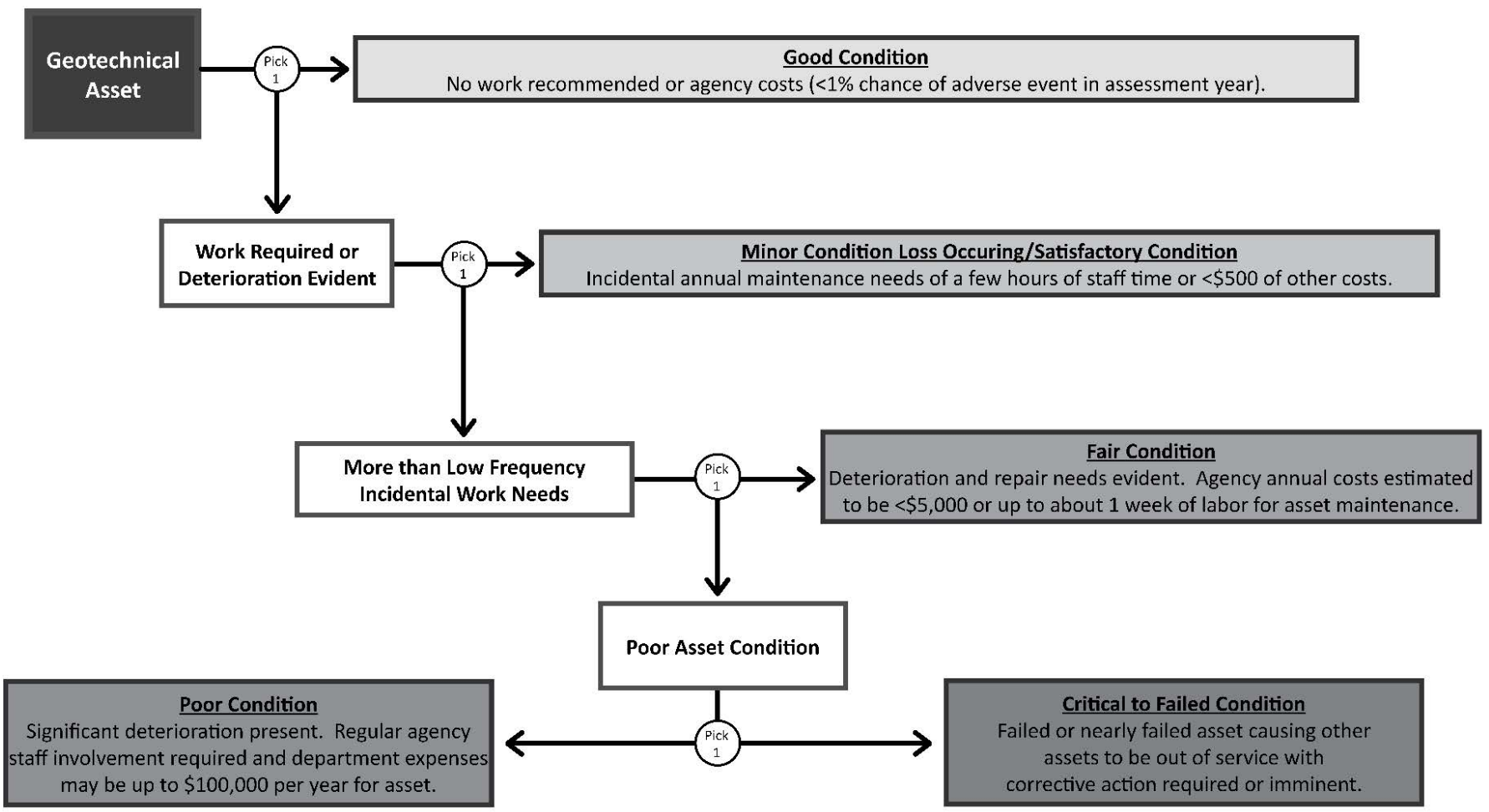
Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

F = > 40

Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

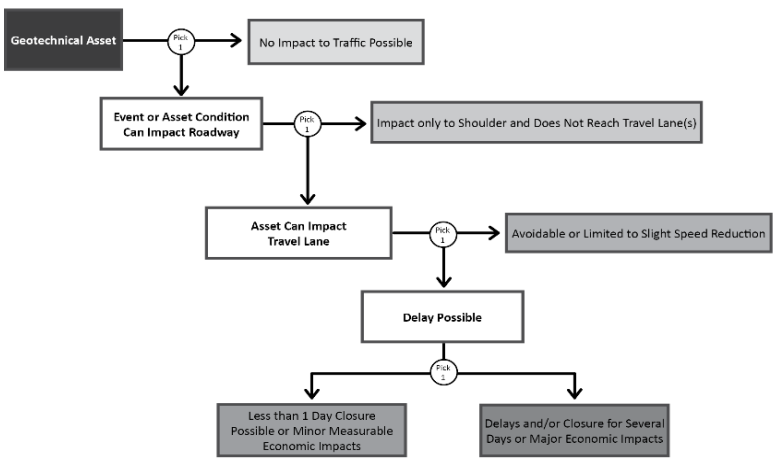
Maintenance Condition	
Safety Consequence	
Mobility/Economic Conseq.	
Safety Risk Score	0
Mobility/Econ. Risk Score	0
GAM Level of Risk	**0**

Asset Operation and Maintenance Condition Tree

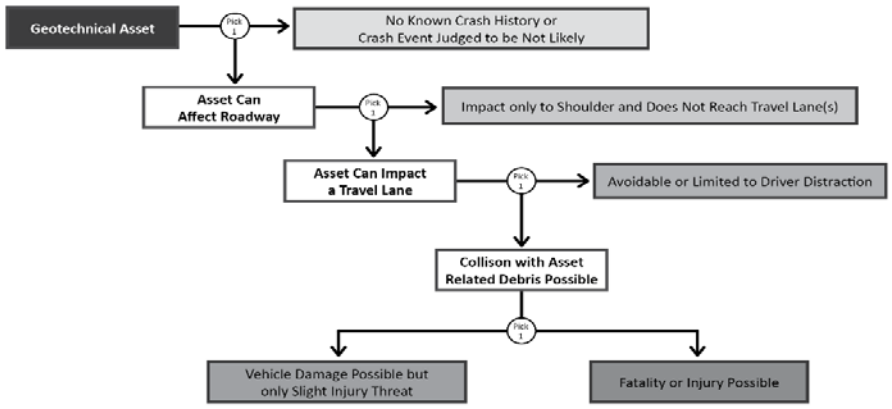


Mobility and Economic Consequence Tree

(select most applicable box on the right as outcome for adverse asset performance)



Safety Consequence Tree



Appendix E: GAM Asset-Level Net Present Value Framework Worksheet

INTRODUCTION

The Net Present Value (NPV) worksheet template is intended to be a life-cycle cost investment analysis tool to support the project-level treatment alternative selection process. The template can be used for investment-based treatment alternative analysis that considers the project (not necessarily the asset) life-cycle costs, including design, O&M, and any potential rehabilitation or reconstruction treatments.

The accompanying Microsoft Excel file, "NR903_NPV_Template.xlsx" is an unlocked worksheet that can be used and modified by the user. Three tabs are visible at the bottom of the worksheet: "Instructions," "NPV Worksheet," and "NPV Options Chart."

WORKSHEET TEMPLATE

Figure E-1 shows a partial-screen view of the data entry portion of the worksheet template. (Note: The areas highlighted in the screen-shot show data from an example that comes pre-loaded on the worksheet. For each new analysis, users will simply key in the new data to replace/over-write the content in the highlighted areas.)

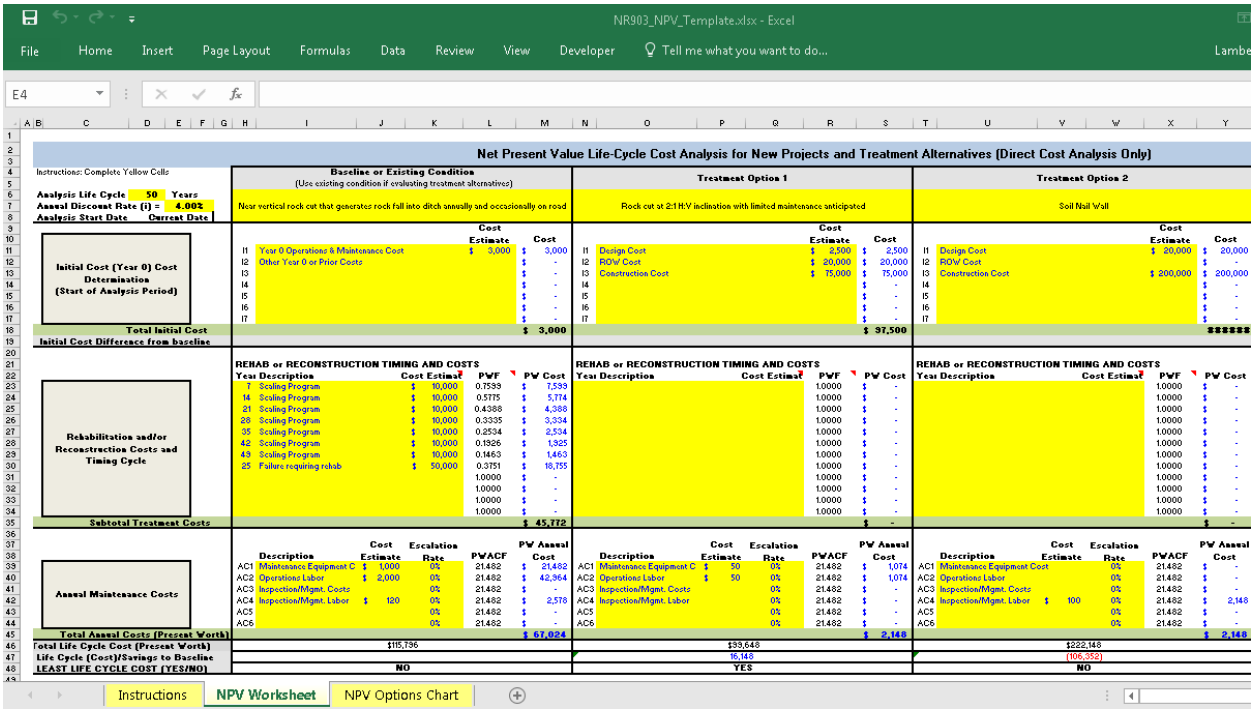


Figure E-1. Screen view of NPV worksheet.

WORKSHEET USE EXAMPLE

Additional details (based on the sample data and output in the pre-loaded example) can be seen in Figures E-2 and E-3. This example assumes the investment outcomes for different hypothetical slope treatment options.

Net Present Value Life-Cycle Cost Analysis for New Projects and Treatme

Instructions: Complete Yellow Cells

Analysis Life Cycle: 50 Years
Annual Discount Rate (i) = 4.00%
Analysis Start Date = Current Date

	Baseline or Existing Conditon (Use existing condition if evaluating treatment alternatives)			Treatment Option 1		
	Near vertical rock cut that generates rockfall into ditch annually and occassionally on road			Rock cut at 2:1 H:V inclination with limited maintenance anticipated		
Initial cost (year 0) cost determination (start of analysis period)		Cost Estimate	Cost		Cost Estimate	Cost
I1	Year 0 Operations & Maintenance Cost	$ 3,000	$ 3,000	Design Cost	$ 2,500	$ 2,500
I2	Other Year 0 or Prior Costs		$ -	ROW Cost	$ 20,000	$ 20,000
I3			$ -	Construction Cost	$ 75,000	$ 75,000
I4			$ -			$ -
I5			$ -			$ -
I6			$ -			$ -
I7			$ -			$ -
Total Initial Cost			$ 3,000			$ 97,500
Initial Cost Difference from baseline						

Rehabilitation and/or Reconstruction Costs and Timing Cycle	REHAB or RECONSTRUCTION TIMING AND COSTS					REHAB or RECONSTRUCTION TIMING AND COSTS			
	Year	Description	Cost Estimate	PWF	PW Cost	Year	Description	Cost Estimate	PWF	PW Cost
	7	Scaling Program	$ 10,000	0.7599	$ 7,599				1.0000	$ -
	14	Scaling Program	$ 10,000	0.5775	$ 5,774				1.0000	$ -
	21	Scaling Program	$ 10,000	0.4388	$ 4,388				1.0000	$ -
	28	Scaling Program	$ 10,000	0.3335	$ 3,334				1.0000	$ -
	35	Scaling Program	$ 10,000	0.2534	$ 2,534				1.0000	$ -
	42	Scaling Program	$ 10,000	0.1926	$ 1,925				1.0000	$ -
	49	Scaling Program	$ 10,000	0.1463	$ 1,463				1.0000	$ -
	25	Failure requiring rehab	$ 50,000	0.3751	$ 18,755				1.0000	$ -
				1.0000	$ -				1.0000	$ -
				1.0000	$ -				1.0000	$ -
				1.0000	$ -				1.0000	$ -
				1.0000	$ -				1.0000	$ -
Subtotal Treatment Costs					$ 45,772					$ -

Annual Maintenance Costs		Decription	Cost Estimate	Escalation Rate	PWACF	PW Annual Cost		Decription	Cost Estimate	Escalation Rate	PWACF	PW Annual Cost
	AC1	Maintenance Equipment C	$ 1,000	0%	21.482	$ 21,482	AC1	Maintenance Equipment C	$ 50	0%	21.482	$ 1,074
	AC2	Operations Labor	$ 2,000	0%	21.482	$ 42,964	AC2	Operations Labor	$ 50	0%	21.482	$ 1,074
	AC3	Inspection/Mgmt Costs		0%	21.482	$ -	AC3	Inspection/Mgmt Costs		0%	21.482	$ -
	AC4	Inspection/Mgmt Labor	$ 120	0%	21.482	$ 2,578	AC4	Inspection/Mgmt Labor		0%	21.482	$ -
	AC5			0%	21.482	$ -	AC5			0%	21.482	$ -
	AC6			0%	21.482	$ -	AC6			0%	21.482	$ -
Total Annual Costs (Present Worth)						$ 67,024						$ 2,148

Total Life Cycle Cost (Present Worth)	$115,796	$99,648
Life Cycle (Cost)/Savings to Baseline		16,148
LEAST LIFE CYCLE COST (YES/NO)	NO	YES

Figure E-2 (left). Screen view of example completed NPV analysis for a slope treatment investment alternative analysis.

ent Alternatives (Direct Cost Analysis Only)

Treatment Option 2				Treatment Option 3			
Soil Nail Wall				Rock cut with 0.5:1 H:V slope inclination and regular clean up needs			
		Cost Estimate	Cost			Cost Estimate	Cost
I1	Design Cost	$ 20,000	$ 20,000	I1	Design Cost	$ 10,000	$ 10,000
I2	ROW Cost		$ -	I2	ROW Cost		$ -
I3	Construction Cost	$ 200,000	$ 200,000	I3	Construction Cost	$ 50,000	$ 50,000
I4			$ -	I4			$ -
I5			$ -	I5			$ -
I6			$ -	I6			$ -
I7			$ -	I7			$ -
			$ 220,000				$ 60,000

REHAB or RECONSTRUCTION TIMING AND COSTS

Year	Description	Cost Estimate	PWF	PW Cost	Year	Description	Cost Estimate	PWF	PW Cost
			1.0000	$ -	25	Failure Requiring Rehab	$ 50,000	0.3751	$ 18,755
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
			1.0000	$ -				1.0000	$ -
				$ -					$ 18,755

	Decription	Cost Estimate	Escalation Rate	PWACF	PW Annual Cost		Decription	Cost Estimate	Escalation Rate	PWACF	PW Annual Cost
AC1	Maintenance Equipment Cost		0%	21.482	$ -	AC1	Maintenance Equipment C	$ 500	1%	21.482	$ 10,741
AC2	Operations Labor		0%	21.482	$ -	AC2	Operations Labor	$ 500	0%	21.482	$ 10,741
AC3	Inspection/Mgmt Costs		0%	21.482	$ -	AC3	Inspection/Mgmt Costs		0%	21.482	$ -
AC4	Inspection/Mgmt Labor	$ 100	0%	21.482	$ 2,148	AC4	Inspection/Mgmt Labor	$ 120	0%	21.482	$ 2,578
AC5			0%	21.482	$ -	AC5			0%	21.482	$ -
AC6			0%	21.482	$ -	AC6			0%	21.482	$ -
					$ 2,148						$ 24,060
		$222,148						$102,815			
		(106,352)						12,981			
		NO						NO			

Figure E-2 (right). Screen view of example completed NPV analysis for a slope treatment investment alternative analysis.

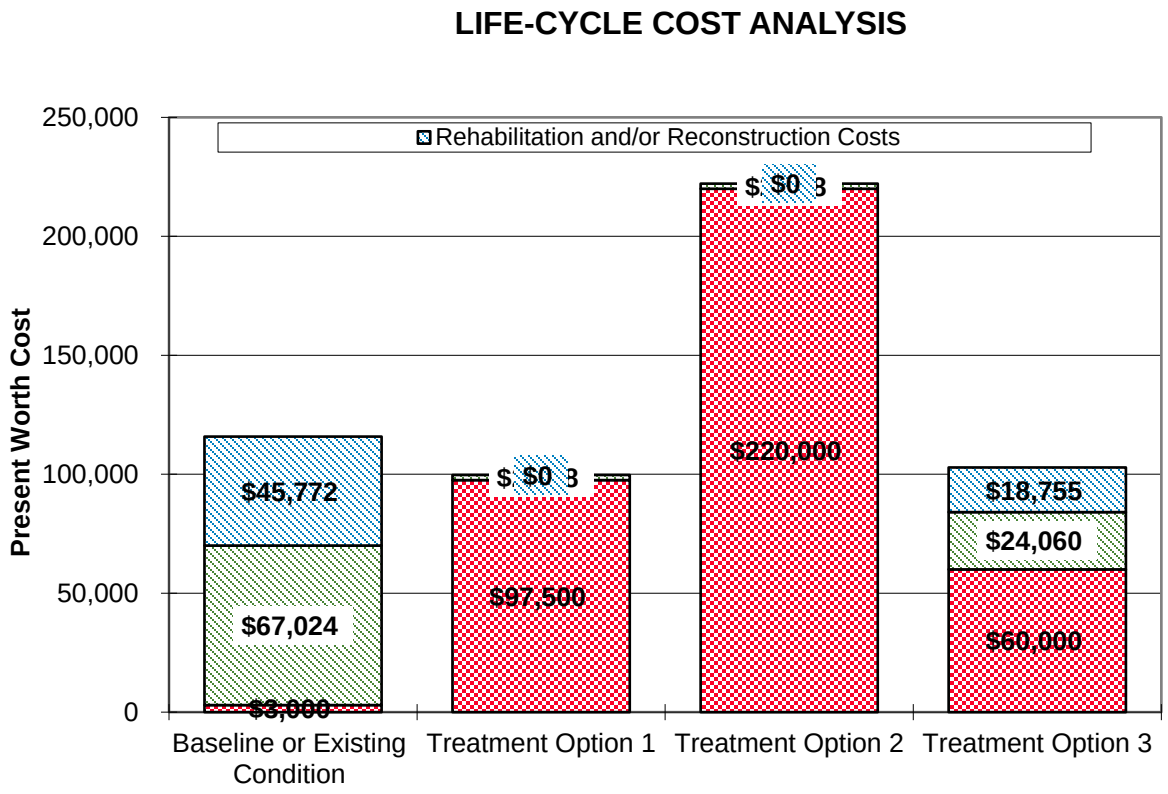


Figure E-3. Screen view of completed NPV analysis illustrating distribution in costs across asset life-cycle phase.

Appendix F: GAM Plan Outline

INTRODUCTION

The annotated outline presented in this appendix is provided as a guidance framework for an agency implementing GAM and authoring the initial GAM Plan document. The GAM Plan outline provided is intended to support implementation at a simple maturity level and with a low initial resource commitment level.

Once created, revisions to the GAM Plan document should be anticipated in future years based on stakeholder feedback and implementation results that direct the asset management strategy and tactics specific to the agency.

In the outline, items shown in bold are highly recommended for any GAM Plan, whereas other items are recommended for inclusion as feasible. In the body of the outline, cross-references to chapter text and to tables and figures refer to content in *NCHRP Research Report 903: Geotechnical Asset Management for Transportation Agencies, Volume 2: Implementation Manual* (the *GAM Implementation Manual*. Some cross-references mention companion tools, such as the GAM Planner, which are available for download from the *NCHRP Report 903* web page).

ANNOTATED GAM PLAN OUTLINE

Chapter 1. Plan Purpose and Objectives

A. Asset Definitions: Introduce what are geotechnical assets with example images or photographs to quickly communicate the definitions and taxonomy to non-geotechnical staff (similar to Figures 2-2 through 2-6 and/or Tables 3-2 through 3-6 in the *GAM Implementation Manual*).

B. GAM Purpose: Summarize the high-level purpose of GAM, using language comparable to the bulleted copy listed under "Why Implement Geotechnical Asset Management?" in Chapter 1 of the *GAM Implementation Manual*.

C. GAM Objectives: Inform the stakeholders of the GAM objectives that will connect to executive or agency strategic performance areas of interest, such as safety, mobility, and economic vitality, and to asset condition (when using the GAM Planner spreadsheet tool). See "Plan Objectives and Measures" in Chapter 8 of the *GAM Implementation Manual* for example objectives and measures.

Chapter 2. Asset Inventory

A. Prioritizing Assets based on Risk: Introduce the concept that sources of risk to performance objectives come from either **physical failure/deterioration** of constructed geotechnical assets within the ROW/agency boundary or from **natural hazards** at regional scale or originating beyond the ROW features (see discussion in Chapter 7 and Figures 7-1 and 7-6 in the *GAM Implementation Manual*). In the development of this section, the asset manager can simply introduce the differentiation in risk sources or can engage with executives and other asset managers about inclusion approaches for natural hazard risk sources in the GAM Plan, as natural hazards may have different management approaches in the agency.

B. Inventory Development: Present the means of starting inventory development, such as historical agency records, maintenance staff reporting, bridge inspection data, or visual observations. Present a feasible plan for ongoing data collection and identify future process improvements that may exist based on agency data sources. (Refer to Chapter 5 and Table 5-3 in the *GAM Implementation Manual*.)

C. Geotechnical Asset Summary: Present a summary of the existing asset inventory, such as quantity and distribution of geotechnical asset segments and asset types, O&M conditions, and mobility and safety consequence asset statistics. Depending on data geo-referencing resources within an agency, information also can be presented graphically in a mapped environment to illustrate locations and the distribution of asset performance data. (Review data sections in Chapter 5 in the *GAM Implementation Manual*.)

Chapter 3. Performance Assessment

A. Historic Performance: document existing performance where data exist or provide agency specific examples that indicate potential consequences and risks that exist. Summarize agency approaches to geotechnical asset treatments in the context of categories for do minimum, maintain, rehabilitation, and reconstruct. Where data exist, summarize existing measurable economic consequences (similar to concepts illustrated in Figure 7-3 in the *GAM Implementation Manual*).

B. Gap Assessment: Document the existing level of performance, projected future performance, the desired level of performance, and the gaps between these levels. Document the outcomes of executive and planning input toward performance targets and performance relative to targets, if feasible. If this is not feasible at the start of implementation, indicate that this is an area for process improvement as the plan and data mature. Note that the GAM Planner tool may be used to support analysis of future conditions (see Chapter 2 and Appendix A of the *GAM Implementation Manual*).

C. Strategies to Address Gaps: Recommend and document actions to address performance gaps. For an agency starting GAM, implementation gaps may relate to the need to complete inventory, improve communication with stakeholders, and incorporate data management practices. (See "Performance Gaps" in Chapter 4, and "Gap Analysis" in Chapter 8. Additional references to information, data, and performance gaps also occur in other chapters of the *GAM Implementation Manual.)*

Chapter 4. Life-Cycle Planning and Risk Management

A. Life-Cycle Planning: Summarize the program-level plan, including projected deterioration, feasible treatments, and treatment strategy. Note: These topics may be addressed through use of the GAM Planner (the spreadsheet tool). Additionally, present options for project-level life-cycle cost analysis, such as the framework worksheet presented in Appendix E.

B. Risk Management: Summarize legacy management approaches and the known risk exposures that result. For example, some agencies may accept all risks from geotechnical assets through reactionary treatments and use of contingency funds for a "do minimum" treatment strategy. This section of the GAM Plan can be an opportunity to inform stakeholders of the range of

accepted risk, including high frequency, low consequence occurrences and lower frequency but higher consequence adverse events originating from geotechnical assets. Discuss options for incorporating consideration of risk in decision-making and/or reducing risk. (Refer to "Implementing Risk-Informed GAM Prioritization Decision Options" in Chapter 8 of the *GAM Implementation Manual*).

E. Cross-asset risk-management opportunities: Identify any options that may exist within the agency for cross-asset management approaches that increase benefits across asset types, such as rinsing of bridge, tunnel, and wall assets or roadway drainage treatments that enable desired life-cycle durations to occur for both pavement and geotechnical assets.

Chapter 5. Financial Plan and Investment Strategies

A. Sources and Uses of Funding: Summarize sources of GAM funding and expected uses. These data may exist, but they also can be fragmented among programs. Identify process improvements that may exist within agency systems to support completion of funding analyses for geotechnical assets.

B. Asset Valuation: Present a conceptual valuation of known inventory. (This suggestion is optional and is provided pending a forthcoming report from NCHRP Project 19-12.)

C. Investment Strategies: Describe approaches to managing geotechnical assets to minimize the gap between desired and expected performance.

D. Alignment with Other Department Plans and Policies: Identify and propose strategies for investment that align with other asset groups (cross-asset management), such as timing or joint treatment approaches among several asset types, and utilization of alternate funds such as emergency recovery funds for geotechnical features (natural hazard risk sources) beyond the right-of-way. (Refer to "Incorporating Risk into the Prioritization Process" discussion in Chapter 8 of the *GAM Implementation Manual*).

The framework presented in this appendix can guide development of a GAM Plan document that presents the plan in a context that connects with the agency's TAM plan and with performance objectives that are important to agency executives. At the start of implementation, comprehensive discussion of the topics in Chapter 5 of the GAM Plan may not be feasible, and this chapter may be reduced or include comments that indicate future versions of the plan will expand discussion as data become available.

Appendix G: GAM Implementation Barrier Mitigation Strategy Matrix

Appendix G
GAM Implementation Barrier Mitigation
Strategy Matrix

Perceived Implementation Barrier	Mitigation Strategy Suggestions
Absence of State or Federal Authorization or FHWA Requirements	Direct implementation at agency/organization strategic objectives and performance goals. GAM Planner is directed at objectives for safety, mobility and economic vitality, and O&M conditions.
	Inform executive, TAM, Maintenance, and other stakeholder staff about the definitions of geotechnical assets and the opportunity for making informed life-cycle investment decisions.
	Indicate GAM implementation can benefit from established programs with more than 15 years of implementation experience that now exist on the basis of business cases.
	Communicate risk exposures across department with respect to high level objectives and measures
	Advocate on basis of business case benefits rather than regulatory case. Note many other programs can exist within an organization without needing regulatory requirements.
Limited Budget for Starting Implementation	Advocate on potential for improved performance at same programmatic cost with GAM plan
	Utilize existing legacy geotechnical and event records to start inventory around known assets.
	Start with a small inventory to start communication versus waiting to complete full inventory
	Be able to answer question: "what can be done if given $XXX,XXX?"
	conditions when addressing natural hazard risk sources compared to physical deterioration risk sources for assets within ROW.
	Present decision options with a favorable business case that demonstrates good stewardship of taxpayer provided funds.
	Illustrate the cost of not implementing through increased life-cycle costs and performance impacts
Limited Staff Availability	Use the GAM Planner as time allows, and develop inventory in small blocks of time (e.g., inventory 10-20 assets at a time)
	Incorporate TAM, maintenance, bridge inspection, or other technical staff to assist in inventory development.
	Indicate implementation can provide cost savings that can be used to implement financially justified process and performance improvements
Undefined Agency Goals/Metrics	Use default safety, O&M, mobility, and economic vitality objectives within the risk-based GAM Planner.
	Identify design and maintenance practices for other assets that differentiate between natural hazards and physical failure. Illustrate how performance considerations likely already exist for other assets that are associated with natural hazards.
	Meet with executive stakeholders to discuss risk management concepts for geotechnical assets.
	Develop agency policy or guidance on differentiating investments between natural hazard features beyond the ROW/boundary and constructed geotechnical assets within ROW.
	Maintain emphasis on metrics that connect to strategic performance.
TAM and/or GAM Expertise	Utilize FHWA, AASHTO, and NCHRP training documents and web-based material.
	Seek to attend formal training opportunities (e.g., from NHI).
Executive Staff Interest/Motivation	Illustrate impacts to safety, direct costs, economic impacts, and mobility/delays.
	Focus on executive topics such as risk, performance, life-cycle, and benefit-cost outcomes.
	Indicate the potential for new/different financial investment strategies that consider risk and performance.
	Avoid the perception of needing to fund a new program, and emphasize business process improvement opportunities first.
	Include all risk treatment options in discussions (e.g., treat, transfer, tolerate/accept, and so forth).
	Illustrate potential financial benefits from preventative maintenance.
Transportation Asset Management Staff Interest/Motivation	Illustrate with examples of how geotechnical assets influence TAM performance reporting.
	Summarize roles and responsibilities using the GAM workflow figure (Figure 2.1) in the *GAM Implementation Manual.*
	Propose GAM outcome measures such as LOR targets and means to prioritize investments as discussed in Chapter 8.
	Discuss guidance from FHWA Division offices that will not "punish" for GAM performance.
	Provide references to *GAM Implementation Manual* and mature GAM programs (e.g., Highways England and Network Rail).
	Advocate for inclusion of geotechnical assets in planning, but accept that geotechnical assets do not need to be part of the state TAM Plan for realization of benefits. GAM can be a process that exists outside of the TAMP.
Geotechnical Staff Interest/ Motivation/Skepticism	Define and demonstrate benefits of GAM without using asset management jargon. The GAM Planner O&M condition and safety and mobility consequence trees were developed to be used by staff with various backgrounds and without needing asset management training.
	Leverage other assets for sharing/cross-asset benefits (e.g. culverts, pavements, structures).
	Reference common taxonomy for slopes, walls, embankments, and subgrades with modifications/elements.
	Start simply (i.e., with a simple maturity level GAM program).
	Discuss guidance for mitigating liability concerns from professional licensure.
	Provide opportunities for GIS, risk, TAM, and financial training.
	Incorporate GAM into staff development and training plans.
Agency Politics or Conflicting Processes	Build relationships with maintenance staff and other stakeholders that will see benefits (advocacy).
	Maintain emphasis on risk and performance management benefits from GAM.
Data for Inventory	Utilize existing sources (e.g., NBI data, maintenance records, traffic reports, enterprise accounting data, and legacy data archives).
	Meet with agency data management staff to present GAM approach and seek to find opportunities within existing systems.
	Use spreadsheet-based GAM Planner and other standard software where asset management systems can not support GAM.
	Utilize agency GIS system and staff, Google Maps, or other available software for geo-referencing asset locations at a minimum.