Quick Response: Quantification of Research Benefits

FINAL REPORT

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16. Abstract

Quantifying research benefits and evaluating economic effectiveness of research projects are becoming increasingly important to agencies. The six States comprising the New England Transportation Consortium (NETC) were interested in developing a consistent way to evaluate and quantify the monetary benefits from research projects. This report documents the development of a research benefit quantitation tool for the NETC. The results are a five-step process of research benefit quantitation and a companion Excel-based tool for performing the calculation. The tool will help the NETC in evaluating and financially justifying its research projects.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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LIST OF ABBREVIATIONS

B/C	Benefit/Cost (ratio)
DOT	Department of Transportation
CTDOT	Connecticut Department of Transportation
CMF	Crash Modification Factor
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
MassDOT	Massachusetts Department of Transportation
MnDOT	Minnesota Department of Transportation
NETC	New England Transportation Consortium
QAQC	Quality assurance quality control
RFP	Request for Proposals
TAC	Technical Advisory Committee
TxDOT	Texas Department of Transportation
VTrans	Vermont Agency of Transportation
WIDOT	Wisconsin Department of Transportation

EXECUTIVE SUMMARY

More than ever, transportation agencies feel pressure to justify the economic effectiveness of their research programs and expenditures. With limited research funds, research engineers and other research staff must assess and evaluate the effectiveness of research projects' contributions to the agency and other stakeholders. Quantifying research benefits allows agencies to understand and improve the effectiveness of their research.

This project adapted the Minnesota Department of Transportation's (MnDOT) Excel-based benefit estimation tool to develop an updated and enhanced tool for the New England Transportation Consortium (NETC) and its member States. The updated tool was applied to two NETC projects selected by the Technical Advisory Committee (TAC) for the purpose of both demonstration and refinement of the tool.

Adapting the MnDOT benefit estimation tool to fit the needs of the NETC requires identifying the appropriate benefit categories of the research project that include:

- Engineering/administrative costs;
- Construction/installation costs;
- Operation and maintenance costs;
- Lifecycle costs;
- Environmental aspects;
- Safety costs;
- User benefits;
- Insurance/risk management; and,
- All other costs

The benefit estimation tool will help provide a consistent way for the NETC to evaluate and quantify the monetary benefits from many of its research projects. The development of this tool also provides information that can help NETC with more detailed research questions for its future requests for proposals (RFP).

CHAPTER 1. INTRODUCTION

Transportation programs are more aggressive in their performance targets, requiring greater fiscal responsibility and stewardship to achieve an agency's mission and goals. Program and project managers routinely assess and prioritize projects within programs and compare against projects. The same is true for research. With limited research funds, research engineers and other research staff must assess and evaluate the effectiveness of research projects' contributions to the agency and other stakeholders. State DOT research enhances the capabilities of the agency and other stakeholders, improves the materials they use, and increases the efficiency of their procedures. Quantifying research benefits can allow agencies to understand and improve the effectiveness of their research.

It is important to have a tool that can analyze transportation research projects and quantify their benefits in comparable financial terms. The six States comprising the NETC were interested in developing a consistent way to evaluate and quantify the monetary benefits from research projects. Having all New England States use the same estimation tool will allow the NETC to better collaborate and coordinate joint research projects. Using MnDOT's benefit estimation tool *(1,2,3)*, this project aimed to develop updated guidelines and an enhanced calculation tool that fits the NETC's needs.

This report documents the process of evaluating and adapting the MNDOT benefit estimation tool and provides guidelines for quantifying the benefits of NETC research projects. It also serves as a quick user's guide, illustrating two example projects selected by the TAC.

This document is organized as the following:

Chapter 1 introduces the objective and the purpose of the project.

Chapter 2 summarizes the review and assessment of MnDOT's tool.

Chapter 3 provides an outline for the process of quantifying research benefits.

Chapter 4 provides additional information on gathering and entering inputs.

Chapter 5 provides a summary and discusses the recommendations.

Appendix A provides more detailed description of the Excel Benefit Estimation tool with all necessary inputs and outputs. It serves as a user's guide for the tool. **Appendix B** and **Appendix C** summarize the process of quantifying the benefits of two NETC research projects:

1) NETC 9-03 Advanced Composite Materials in New England's Transportation *(4)* Infrastructure: Design, Fabrication, and Installation of ACM Bridge Drain System.
2) NETC 9-02 Effective Establishment of Native Grasses on Roadsides in New England. *(5)*

CHAPTER 2. ASSESSMENT OF THE MnDOT TOOL

This chapter provides a summary of the project team's in-depth review and assessment of the MnDOT tool. This review allowed the team to demonstrate the feasibility of using the MnDOT tool and how to adapt it to fit the needs of the NETC. The assessment also helps identify potential changes to enhance the tool. The following sections present a brief overview of the MnDOT benefit estimation tool, the underlying process and structure of quantifying research benefits, and the underlying formula and user's interface of the Excel-based tool. The last section discusses our assessment and recommended improvements in adapting the MnDOT tool for NETC projects.

Overview of MnDOT's Benefit Estimation Tool

The benefit estimation tool was developed for MnDOT to provide a consistent process of quantifying benefits of research projects in terms of dollars. The tool has two key components:

a) A seven-step process for benefit quantification based on potential cost savings; and
b) A set of Excel spreadsheet templates for calculation and presentation.

MnDOT's Seven-Step Process for Quantification of Research Benefits

The potential monetary cost savings and benefit/cost (B/C) ratio from the implementation of research results are quantified using the following 7-step process:

- Step 1. Determine Benefit Category
- Step 2. Build Benefit Estimation Tool
- Step 3. Collect Input Data
- Step 4. Document Implementation of Recommendations
- Step 5. Populate Benefit Estimation Tool
- Step 6. Determine Benefit
- Step 7. Compare Benefit to Cost

Figure 1 is the flowchart for the seven-step process developed for the MnDOT benefit estimation tool. The following section provides more details on each step of this procedure.

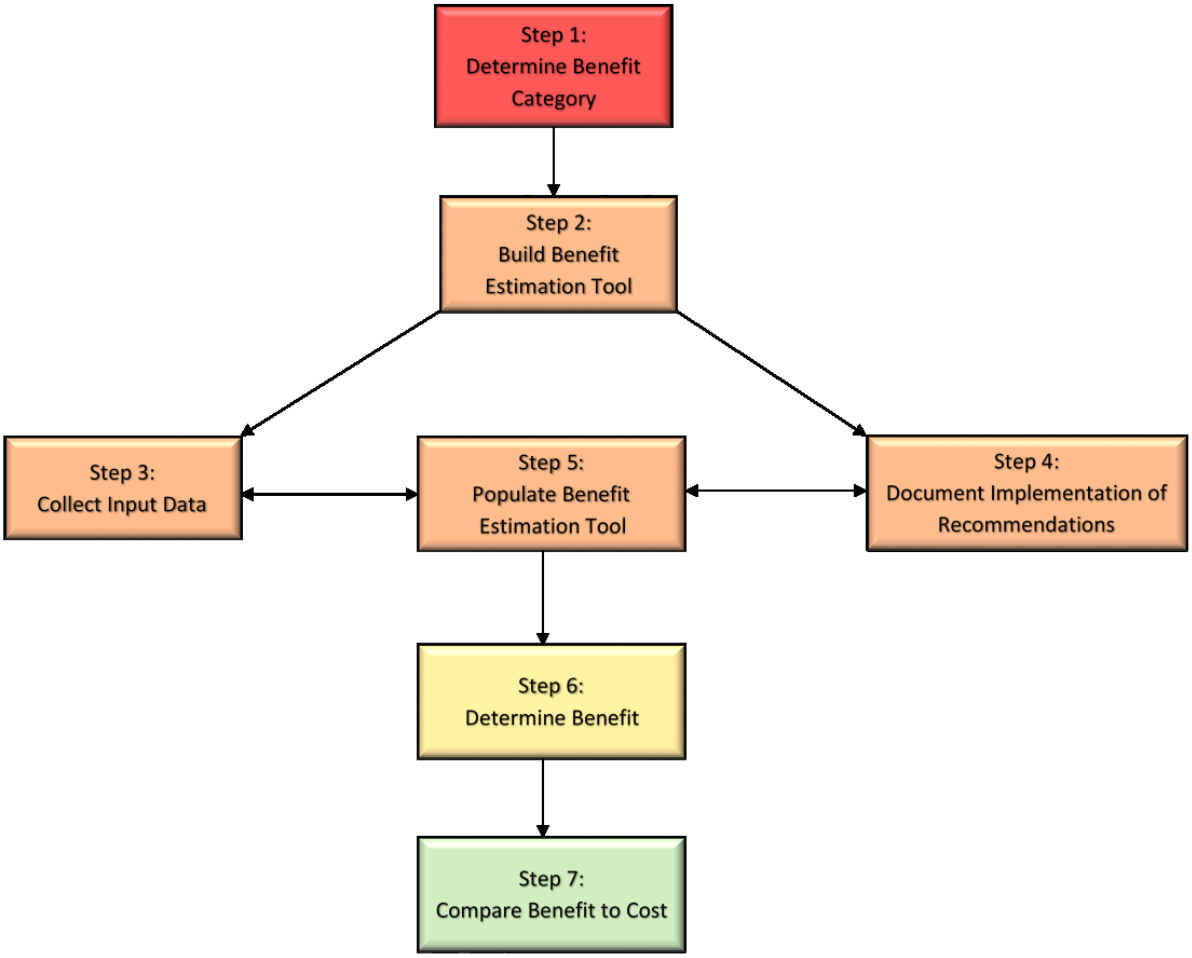


Figure 1. MnDOT's Benefit Quantification Flowchart. [1]

Step 1: Determine Benefit Category

The first step is to select the benefit categories applicable to the research for which benefits are evaluated and quantified. The MnDOT process includes a list of potential benefit categories and users can select appropriate benefits that fall into at least one of the following 9 categories:

- Construction Saving
- Decrease Engineering/Administrative Costs
- Decrease Lifecycle Costs
- Environmental Aspects
- Increase Lifecycle
- Operation and Maintenance Saving
- Safety
- User Benefits
- Risk Management

Step 2: Build Benefit Estimation Tool

This second step is to develop a set of Excel-based templates. In development of this tool, draft calculation spreadsheets for 11 research projects were first developed, then the commonalities among these spreadsheets were synthesized and combined into six templates for the benefit estimation tool. All nine benefit categories are captured in these six spreadsheet templates:

1. **Direct Labor Savings**: This template covers all cost savings from a decrease in total labor costs, often achieved by a reduction in labor hours as a result of implementing of research findings. The calculation relies on number of hours needed for the same tasks, before and after the research recommendations are implemented.
2. **Materials and Activities:** This template captures all cost savings related to reduction in materials and/or time. These savings can be from a reduction quantity of the same material, using lower-cost material, or a revised method of completing the same task that requires less time. The calculation relies on the quantity, price, or time before and after the research recommendations are implemented.
3. **Traffic Operations/User Benefits:** This template calculates benefits for both roadway users and transportation agencies. The benefits for roadway users are the monetary savings achieved by a reduction in travel time. As a result of the research implementation, the agencies might also achieve savings from reduced maintenance and/or savings in labor hours.
4. **Lifecycle:** The lifecycle template covers the cost savings from a product with a longer lifecycle, and therefore lower average annual costs for new purchase, construction, or installation.
5. **Safety:** The safety template captures the monetary benefits achieved by a reduction in the frequency and/or severity of crashes as a result of the improvements recommended by the research findings.
6. **Risk Management:** This template calculates the cost savings from a reduction in insurance premiums, tort liability, or fines as a result of implementing the research recommendations.

In this step, the users select the appropriate templates based on the benefit categories identified in Step 1 and modify them as necessary to allow more accurate calculation of the potential benefits.

Step 3: Collect Input Data

In this step, the users need to collect all input values required for the templates in the previous step to perform the benefit calculations. In general, all calculations require data (e.g., labor hours, prices, quantities) from the time periods before and after implementing the research results. The calculation procedure also requires the anticipated level of deployment or frequency of activity for estimating the savings. The Excel templates use color-coding schemes and additional guidance information to assist users with the input collection. Step 3 and Step 5 can take place simultaneously so that inputs can be entered as they are collected.

Step 4: Document Implementation of Recommendations

In this step of the process, the users collect and document the implementation rate of the research results. This is a key input since the total benefits are dependent upon the level of implementation. This might include information such as number of locations that received the improvement recommended by the research, and when the agency received this information. For some projects, numbers of crashes before and after the implementation date are required to estimate the safety benefits. This step could be performed simultaneously with Step 4 and Step 5, as a part of collecting and inputting data.

Step 5: Populate Benefit Estimation Tool

In this step, the users enter all input data collected in Step 3. The Excel templates use color coding in the cells to indicate to the user where input data is to be entered. Step 3, Step 4 and Step 5 can be performed simultaneously, allowing the user to enter inputs as they are collected.

Step 6: Determine Benefit

In this step, users might need to perform necessary modifications to the templates to sum up the benefits, which are calculated separately, to determine the total savings. The result is presented in present dollar value.

Step 7: Compare Benefit to Cost

In this step, the benefit is compared to the cost of research. The results can be used to assess the effectiveness of the research program in terms of both the magnitude of the benefit and the return on investment. The built-in formula calculates the B/C ratio by dividing the estimated cost savings (i.e., the benefit) by the cost of funding the research project. A B/C ratio less than 1.0 indicates the research cost is greater than the potential monetary benefits, where a B/C ratio greater than 1.0 indicates the potential benefits outweigh the research costs.

Overview of MnDOT's Benefit Estimation Excel Spreadsheets

The Excel spreadsheets were designed to assist users with performing calculations for each applicable benefit category determined from the seven-step process. These Excel templates require users to follow the process to collect and input several layers of data for the periods before and after implementation of research results. There are necessary assumptions specific to the project to perform the calculation for a user-selected analysis timeframe. The MnDOT benefit estimation Excel-spreadsheet tool is organized into the following six calculation template sheets:

- Direct Labor Savings
- Materials and Activities
- Traffic Operations/User Benefits
- Lifecycle
- Safety
- Risk Management

These six spreadsheets come with six cover/guidance sheets to serve as a quick reference guide with information that assists users in understanding the layout, structure, input, and output for the calculation templates. The calculation templates, however, are not linked; they operate separately to cover all potential benefit categories. Also, the templates do not combine results from all applicable sheets to produce the total monetary benefit value. The users can take these steps manually by summing up the separate results to determine the total benefit and compare it to the total cost of research for the overall B/C ratio.

Adaptation of MnDOT's Benefit Estimation Tool and Improvement Recommendations

After reviewing and assessing the MnDOT benefit estimation tool and its supporting documents, the researchers recommend adapting this tool for NETC with some modifications and updates to enhance the clarity, consistency, and usability of the tool. The assessments and recommendations are summarized below for both the benefit quantification process and the Excel-based tool.

- The research team recommends adapting MnDOT's benefit quantification process for NETC with the following updates:
    - Consolidating the seven-step process into a five-step process: A new Excel-based tool will be adapted from MnDOT's tool. As such, Step 2 of MnDOT's tool (build benefit estimation tool) is no longer necessary. The adaptation of MnDOT's Excel-based tool will be discussed in a separate section. Step 3 and Step 4 can be combined since they are two separate types of inputs.
    - Revising some benefit category names and replacing "saving" or "savings" by "costs": This update is recommended to reflect the fact that research recommendations might lead to change in costs but do not always result in "savings". The total of these changes in all benefit categories might be a saving but the individual category might not always lower the cost.
    - Updating some other minor details to keep the new process consistent with the revised overall process.
- The research team also recommends adapting MnDOT's Excel tool for NETC with the following updates:
    - Developing one spreadsheet template for each benefit category: MnDOT's tool includes six calculation templates that covers all benefit categories. Each spreadsheet can be used to capture parts of several benefit categories and each benefit category is spread throughout several calculation sheets. The research team recommends changing the overall structure of the calculation spreadsheets to one separate template for each benefit category.
    - Linking all templates together and creating formulas to calculate the total benefit and B/C ratio: The calculation templates in MnDOT's tool do not work together and do not output the overall outcomes, which are the total benefit and overall B/C ratio. The research team recommends adding this feature to enhance the usability. This will also allow the user to quickly test different scenarios of assumptions and deployment schedule.

- Updating the user's interface and various features to enhance the data inputs, outputs, and overall usability of the tool.

CHAPTER 3. PROCEDURE FOR QUANTIFYING THE RESEARCH BENEFITS

This chapter documents the development of a procedure for quantifying the research benefits and provides detailed discussion on each step of the process. The core principle of the research benefit quantification process is to deconstruct and then rebuild. This is a general approach that can be applied to analyze complex systems. By deconstructing complex systems into smaller and simpler subsystems, they can usually be analyzed and understood, and in this case, quantified more easily. This allows the subsystems to be combined with one another and with the analysis results. MnDOT Benefit Estimation tool was developed based on this principle. The development of the updated research benefit quantification tool and process were largely based on MnDOT's tool with inputs from the TAC to meet the needs of the NETC and its member States. The updated NETC tool follows a five-step process and remains an Excel-based tool with updates to enhance the usability.

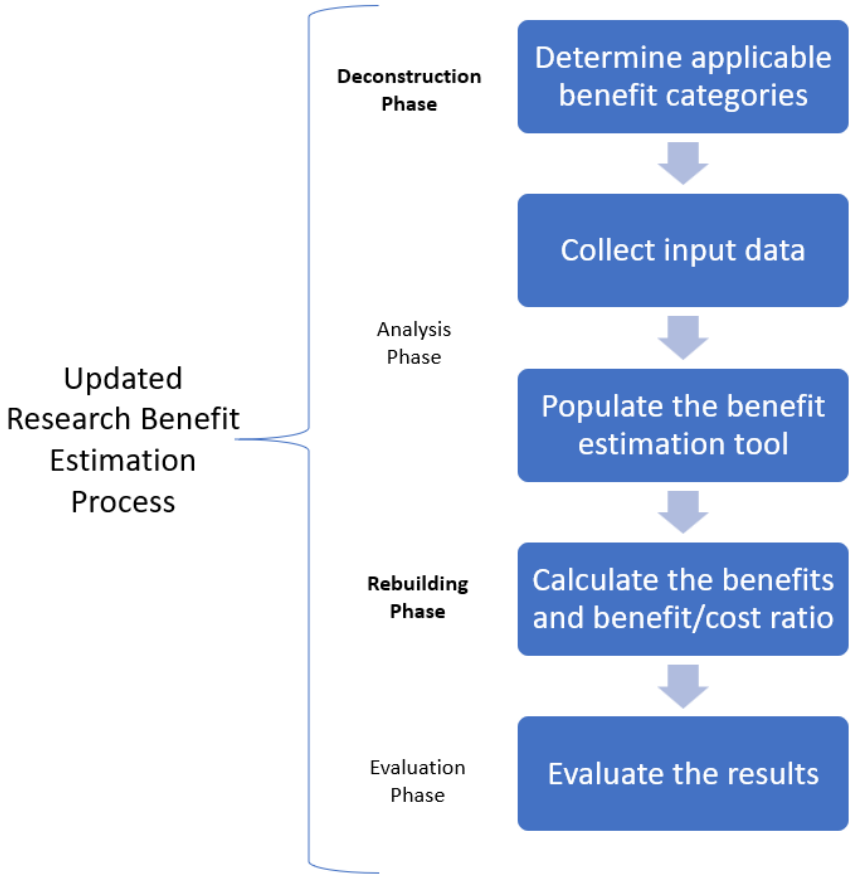


Figure 2 shows a flowchart for this five-step process. A more detailed discussion of each step and the Excel-based tool updates are provided throughout this chapter.

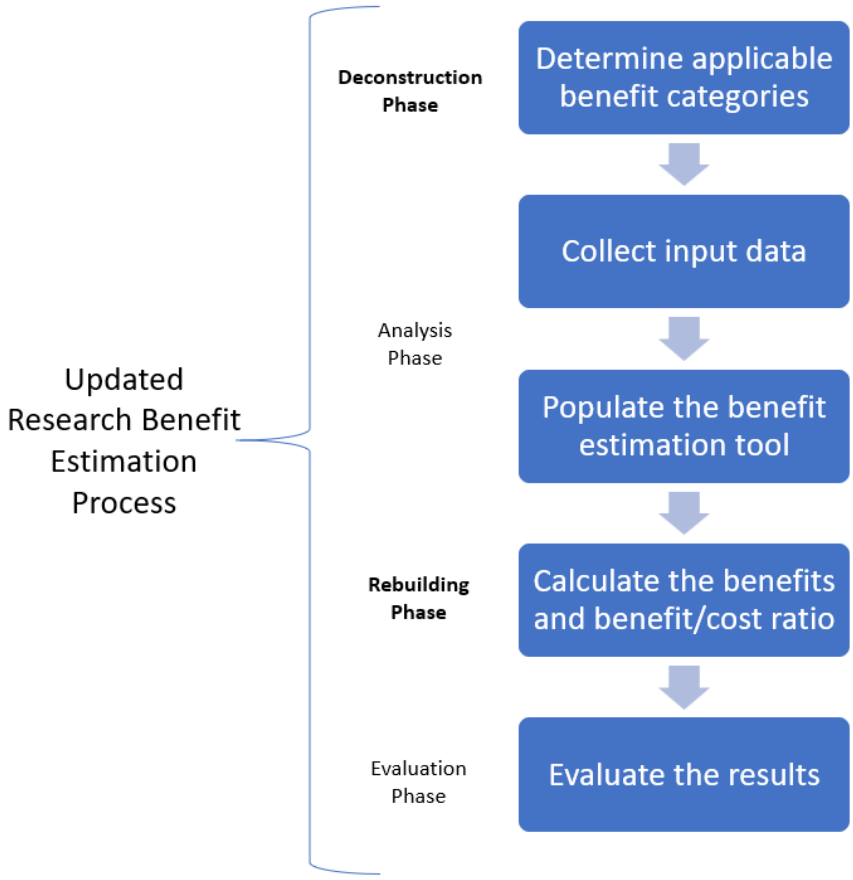


Figure 2. Five-Step Process Used to Update the Research Benefit Estimation Process.

Step 1: Determine Applicable Benefit Categories

Quantification of the research benefit process begins with identifying the benefit categories that are applicable to the research project of interest. The following list contains research benefits that can be categorized as either one category, separate subcategories, or line items. The categories also list examples of how the category is broken down depending on data availability and format (discussed in Step 2):

- **Engineering/administrative costs:** This category includes all costs related to planning, design and managing the implementation of research results. The potential benefits under this category are the total savings as a result of the research. Engineering/administrative costs could be separated into the following sub-categories:
    - Direct labor costs
    - License/permitting costs
    - Other engineering/administrative related costs

- **Construction/installation costs:** This category includes all costs related to fabrication, manufacture, installation, construction, establishment as a part of the implementation of research results. Construction/installation costs can be separated into the following sub-categories:
    - Direct labor costs
    - Material, equipment, and activity costs
- **Operation and maintenance costs.** This category includes all costs related to operation and maintenance as a part of the implementation of research results. Operation and maintenance costs can be separated into the following sub-categories:
    - Direct labor costs
    - Material, Equipment, & Activity costs
- **Road user costs:** This category includes all costs related to road users in terms of time and monetary values as a result of the research implementation (e.g., the research implementation lowers travel time, saves fuel). Road user costs can be separated into the following sub-categories:
    - Road user's time costs
    - Road user's fuel costs
    - Road user's wear and tear costs
    - Other road user's costs
- **Environmental costs:** This category includes all costs related to environmental aspects (e.g., emissions, pollution, hazardous wastes and materials, recycling) of the implementation of research results. Environmental costs can be separated into the following sub-categories:
    - Direct labor costs
    - Material, equipment, and activity costs
    - Emission and pollution costs

Other quantifiable benefits categories include:

- **Lifecycle costs:** This category includes all costs related to the change in lifecycle as a result of the research implementation (e.g., the new material lasts twice as long therefore lowering the average cost per year throughout its lifecycle).
- **Safety costs:** This category includes all societal costs related to reduction of crash frequency and severity in monetary terms as a result of the research implementation (e.g., the research implementation lowers severity of crashes and saves overall crash costs).
- **Risk management costs:** This category includes all costs related to change in tort liability, insurance premiums, potential fines, or other risks to agencies as a result of the research implementation. The data availability and format (discussed in Step 2) might dictate how the category is broken down.
- **Others:** This category includes all other costs that cannot be included in one of the above categories.

The research team made the decision to use the same benefit categories, listed above, after a thorough review of MnDOT's tool and consultation with the TAC. The benefit categories were adopted from the list developed for MnDOT's benefit estimation tool, with a minor change to each category name. All category names now include the word "costs" instead of "savings" to reflect the fact that research recommendations might lead to a change in costs but do not always result in "savings" for every applicable benefit category.

In determining the applicable benefit categories, users first review the research report and recommendations to identify all potential benefits of the research and align them with the above list of benefit categories. One category might be applicable to various stages of the project implementation (i.e., Planning/Design, Construction/Installation, Operation/Maintenance); therefore, it is important to identify all applicable stages to avoid miscounting the potential benefits. For example, the environment costs for one research project might be applicable to both the installation/construction phase (e.g., new method that reduces emissions during manufacture and installation) and the operation/maintenance phase (e.g., the research recommends a new maintenance method that reduces toxic waste). In this case, the environment costs category is applicable to both stages. If these categories are broken into smaller sub-categories or items, it should be determined if each of those categories are applicable.

After the benefit categories and sub-categories have been identified, the users could consider adding a brief description of how the associated costs of categories might change (i.e., increase, decrease, or no change). Users should also consider developing and using a checklist in this step, which will help add clarity and might be useful throughout the entire process. An example of a benefit category identification checklist with descriptions is shown in Table 1. The first three columns indicate stages that are applicable to a category or sub-category. The fourth column (Benefit Category) shows all benefit categories developed for this process and should not change. The fifth column (Sub-Category/Item) shows all the breakdown sub-categories and/or items for each main benefit category. Users can add or change this column depending on how each main benefit category is broken down. The last column (Description of Cost Change) is for users to enter some brief descriptions/notes of how costs would change for each of the benefit categories and sub-categories/items.

It is important to note that benefit categories can have overlaps and users should take extra consideration to avoid double counting.

Table 1. Example of Checklist for Identifying Benefit Categories and Sub-Categories.

Stage			Benefit Category	Sub-Category/Item	Description of Cost Change	Potential sources of data
1	*2*	*3*				
			Engineering & Admin costs	Engineering & admin costs		
			Construction costs	Direct labor costs		
				Material, equipment, & activity costs		
			Operation & Maintenance costs	Direct labor costs		
				Material, equipment, & activity costs		
			Lifecycle costs	Lifecycle costs		
			Road user costs	Road user costs		
			Safety costs	Safety costs		
			Environmental costs	Direct labor costs		
				Material, equipment, & activity costs		
				Emission & pollution costs		
			Risk management costs	Risk management costs		
			Others	Others		

Note: Stage 1: Planning and Design; Stage 2: Installation/Construction; Stage 3: Operation and Maintenance.

Ideally, the potential benefits are included in the research report. Although it is not unrealistic to expect the benefits to be organized in a list of benefit categories or sub-categories, research reports may have discussions related to the potential improvements, especially those research topics on new materials, methods, or activities. While this kind of information might not always fit perfectly into one or some of the above benefit categories, some further assessment of the information will help put it in the right place. There are circumstances where one benefit discussed in the research report might be placed in multiple categories or sub-categories; generally, it is not important which category it is placed in, as long as this is recorded to avoid the benefit being double counted.

The users could also consult and discuss with experts in the subject matters. These could be the authors of the research report, State DOT's personnel and local agency's representative in charge of the subject matters, industry's representatives, or some other experts with extensive knowledge of the subject.

Step 2: Collect Input Data

After determining the applicable benefit categories in Step 1, users need to collect all input values required for the templates to perform the benefit calculations. In general, all calculations require two types of data:

- Input values for quantifiable changes in labor hours, prices, quantities etc., from before and after implementing the research results.
- The anticipated level of deployment or frequency of activity.

For the first type of data, users can collect change in component, module, or package costs (e.g., cost of purchase, contract price per fully constructed units), or change in labor hours, quantities, and unit prices from before and after implementing the research results. The availability of data will dictate how this step is performed. Also, if applicable, numbers of crashes before and after the implementation date are required to estimate the safety benefits of this category. The Excel templates use a color-coding scheme and provide additional guidance to assist users with the data collection input.

The users collect and document the second type of data which is the anticipated rate of implementing the research results. This is a key input since the total benefits are dependent upon the level of implementation, and this might include information such as number of locations that received the improvement recommended by the research, and when they received such improvements.

The ideal scenario is that necessary data for potential benefit estimation is included in the research report. If this is not the case, the user should pursue the data through other channels and resources:

- Published resources and databases at either the State and/or national levels.
- State DOT's personnel and local agency's representative in charge of the subject matters.
- Suppliers and contractors.
- Other subject matter experts.

If these resources are not fruitful, then relevant and reasonable assumptions could be made to substitute the actual data.

Step 3: Populate Benefit Estimation Tool

In this step, the users enter all input data collected in step 2. The Excel templates are color-coded to assist users with entering the data. Users can modify the templates to fit their needs based on sub-categories and breakdown items determined in Step 1 and input data collected in Step 2. Modifications are relatively easy as they involve simple tasks such as inserting new rows and columns, copying Excel formulas, and expanding/contracting the range of calculation. Users with average Excel skills should be able to perform these modifications.

Steps 2 and 3 can take place simultaneously where the user can enter inputs as they are collected.

Step 4: Calculate the Benefits and B/C Ratio

This step is largely automated with built-in Excel formulas that link the individual categories and sub-categories and calculate the overall benefits and B/C ratio. The users should always perform a quality assurance and quality control (QAQC) to make sure that all references are correct, all links work, and no accidental changes have been made to the built-in formulas.

Step 5: Evaluate the Results

In this step, users can evaluate the results and use them as a key piece of input for assessing the effectiveness of the research program. The key outputs include the total monetary benefit in current dollars and B/C ratio. A B/C ratio less than 1.0 indicates the research cost is greater than the potential monetary benefits, where a B/C ratio greater than 1.0 indicates the potential benefits outweigh the research costs. Users could also test different scenarios with respect to important assumptions or anticipated deployment schedules; however, these could drastically change the total benefits. Testing different scenarios of deployments could help agencies make informed decisions in allocating budgets for implementation of the research results. The results can also help agencies make informed decisions to implement or not implement research recommendations. It is worth noting that the monetarized benefit is only one of the inputs for this decision-making process or for judging the effectiveness of a research program.

CHAPTER 4. INFORMATION FOR GATHERING AND ENTERING INPUTS

This chapter provides additional information on inputs needed for the Excel Benefit Estimation tool and some direction on the potential resources to gather inputs for performing the calculation. This chapter primarily focuses on assisting users with more information on Step 2 (Collect Input Data) and Step 3 (Populate the Benefit Estimation Tool), discussed in Chapter 2. The organization of this chapter follows the structure of the Excel Benefit Estimation tool, with one section for each spreadsheet.

- **General Sheet:** This sheet provides the general information on the research project of which benefits are being quantified, and sections for general inputs and key outputs. The user only needs to gather and enter inputs under "Project Information" and "Input for Analysis" sections.
    - Inputs: general information of the research project of which benefits are being quantified and some essential inputs for the analysis.
    - Potential resources: all project-related information is available in the research report. Inflation rate is widely available through government source *(6)* (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Benefit Category Sheet**: This sheet was developed to assist users in the identification of potential benefit categories. The research benefits may be broken down further into separate subcategories, or line items, depending on data availability and format. Users should take extra steps to avoid double counting overlapped benefit categories. Please refer to Chapter 3 for discussion on how to identify the applicable benefit categories and sub-category breakdown.
    - Inputs: Benefit categories and sub-categories or line items applicable to the research project of which benefits are being quantified; narrative of cost benefits; potential data sources and other notes.
    - Potential resources: review of the research report and consultation with the research authors and/or subject matter experts.
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Input and Assumption sheet:** This sheet assists users in gathering data, making key assumptions and calculating key quantity inputs that are necessary for all cost/benefit estimations. The inputs can vary vastly, depending on the project type. Therefore, this sheet is not meant to be a template but a suggestion for the user to gather the information. The goal is to gather and prepare the necessary quantity data for all other calculation sheets. The user will have to make the decision to gather and process the inputs as they see fit for the research project of which benefits are being quantified.
    - Inputs: raw quantity inputs (these can be mileage of roads, number of bridges, area of land etc.); key assumptions.
    - Potential resources: review of the research report, publicly available resources and web search (e.g. State DOT, FHWA, other research reports in related topics), and consultation with the research authors and/or subject matter experts at the state DOTs, suppliers, or contractors with experience in the same areas of expertise.

    - Please refer to Appendix B and Appendix C for examples of these inputs from two example projects.
    - Please refer to Appendix A for a more detailed description of each section in this spreadsheet.
- **Deployment/Implementation Schedule:** This sheet was developed to assist users in gathering and entering the anticipated level of deployment or frequency of activities. It is probably unfeasible for states to implement the research findings at once (e.g. replace all traffic signs with a new type recommended by research in one year). Therefore, the schedule of implementation is key to all calculations. This might include information such as the number of locations that received the improvement recommended by the research, and when they received such improvements.
    - Inputs: implementation schedule in terms of raw quantity or percentage of statewide totals, by year for each state.
    - Potential resources: consultation with State DOT subject matter experts and/or decision makers.
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Engineering and Administration Cost Analysis Sheet:** This sheet was developed to assist users in gathering inputs and calculating all costs related to planning, design and managing the implementation of research findings. Three sections were designed to capture a wide variety of input data, depending on the makeup of the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
    - Inputs:
        - Direct labor: loaded labor rate for each labor category, number of labor hours required for one task or activity before and after the implementation of the research findings.
        - License/permitting: unit costs and quantities for each applicable license or permit before and after the implementation of the research findings.
        - Other engineering/administrative related costs: unit costs and quantities for all other applicable engineering/administrative related costs before and after the implementation of the research findings.
    - Potential resources: consultation with subject matter experts within relevant state agencies and/or outside organizations; published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Construction/Installation Cost Analysis:** This sheet was developed to assist users in gathering inputs and calculating all costs related to fabrication, manufacture, installation, construction, and establishment as a part of the implementation of research results. Two sections were designed to capture a wide variety of input data, depending on the makeup of the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
    - Inputs:

        - Direct labor: loaded labor rate for each labor category, number of labor hours required for one task or activity before and after the implementation of the research findings.
        - Material, equipment, and activity: unit costs and quantities for each applicable material, equipment and activity before and after the implementation of the research findings.
    - Potential resources: consultation with subject matter experts within the state DOT and/or outside organizations, suppliers and contractors; published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Operation and Maintenance Cost Analysis Sheet:** This sheet assists users in gathering inputs and calculating all costs related to operation and maintenance as a part of the implementation of research results. Two sections were designed to capture a wide variety of input data, depending on the makeup of the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
    - Inputs:
        - Direct labor: loaded labor rate for each labor category, number of labor hours required for one task or activity before and after the implementation of the research findings.
        - Material, equipment, and activity: unit costs and quantities for each applicable material, equipment and activity before and after the implementation of the research findings.
    - Potential resources: consultation with subject matter experts within the state DOT and/or outside organizations, suppliers and contractors; published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Lifecycle costs:** This sheet assists users in gathering inputs and calculating all costs related to the change in lifecycle as a result of the research implementation. The inputs required for this sheet depend the type project and the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
    - Inputs:
        - Life cycle assumption: lifecycle of the existing and alternative products or materials (i.e. How long do the old and new material last?)
        - Upfront investments: the costs to purchase the existing and alternative products or materials.
    - Potential resources: relevant research reports, consultation with subject matter experts within the state DOT and/or outside organizations, suppliers and contractors; published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Road user costs:** This sheet was designed to assist users in gathering inputs and calculating all costs related to road users in terms of time and monetary values as a result of the research implementation (e.g., the research implementation lowers travel time, saves fuel).

- Inputs: travel time costs, fuel costs, wear and tear costs and other applicable road costs to road users.
- Potential resources: the research report, US DOT's Benefit-Cost Analysis Guidance for Discretionary Grant Programs *(7)* and Departmental Guidance on Valuation of Travel Time in Economic Analysis *(8)* published reports related to the topics, consultation with subject matter experts within the state DOT and/or outside organizations, published resources and databases (via web search).
- Please refer to Appendix A for more detailed description of each section in this spreadsheet.

- **Safety costs:** This sheet assists users in gathering inputs and calculating all societal costs related to reduction of crash frequency and severity in monetary terms as a result of the research implementation (e.g., the research implementation lowers severity of crashes and saves overall crash costs). The inputs required for this sheet depend the type project and the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet. The availability of crash data and crash modification factors (CMF) also dictate the way inputs are gathered and processed.
  - Inputs: Comprehensive crash cost for each crash by type/severity level, number of crashes targeted by the implementation of the research findings, CMFs for each crash type or number of crashes observed after the implementation of the research findings.
  - Potential resources: State-specific crash cost data, US DOT's Benefit-Cost Analysis Guidance for Discretionary Grant Programs *(7)*, FHWA's Crash Costs for Highway Safety Analysis (FHWA-SA-17-071) *(9)*, State-developed or calibrated CMFs (if available), CMF Clearinghouse *(10)*, State crash database, consultation with subject matter experts within the state DOT and/or outside organizations, published resources and databases (via web search).
  - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Environmental costs:** This sheet assists users in gathering inputs and calculating all costs related to environmental aspects (e.g., emissions, pollution, hazardous wastes and materials, recycling) of the implementation of research results. Three sections were designed to capture a wide variety of input data, depending on the makeup of the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
  - Inputs:
    - Direct labor: loaded labor rate for each labor category, number of labor hours required for one task or activity before and after the implementation of the research findings.
    - Material, equipment, and activity: unit costs and quantities for each applicable material, equipment and activity before and after the implementation of the research findings.
    - Emission costs: unit costs and quantities for all applicable sub-category or line item costs before and after the implementation of the research findings. The most commonly used unit cost is the US Environmental Protection Agency's (EPA) standard emission cost.

    - Potential resources: US DOT's Benefit-Cost Analysis Guidance for Discretionary Grant Programs *(7)*, EPA's The Social Cost of Carbon *(11)*, US Government's Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis *(12)*, consultation with subject matter experts within relevant state agencies and/or outside organizations; equipment manufacturers and suppliers, other published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Risk management costs:** This sheet assists users in gathering inputs and calculating all costs related to change in tort liability, insurance premiums, potential fines, or other risks as a result of the research implementation. The inputs required for this sheet depend the type project and the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
    - Inputs: unit cost and quantity for each applicable risk management sub-category or line item before and after the implementation of the research findings.
    - Potential resources: consultation with subject matter experts within the state DOT and/or outside organizations, published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.
- **Others:** This sheet was designed to assist users in gathering inputs and calculating all other costs that cannot be included in one of the above categories. The inputs required for this sheet depend the type project and the applicable sub-categories or line items identified in Step 2 of Chapter 3 and summarized in the Benefit Category Sheet.
    - Inputs: unit cost and quantity for each applicable sub-category or line item before and after the implementation of the research findings.
    - Potential resources: consultation with subject matter experts within the state DOT and/or outside organizations, published resources and databases (via web search).
    - Please refer to Appendix A for more detailed description of each section in this spreadsheet.

CHAPTER 5: SUMMARY AND RECOMMENDATIONS

- Under this effort, the research team adapted the MnDOT benefit estimation tool to develop an updated research benefit estimation tool to fit the needs of the NETC. The tool was built to provide the NETC with a consistent method for quantifying the benefit of research and support the evaluation and optimization of NETC's research program. This updated tool package includes:
    - A five-step procedure for quantifying the benefit of research.
    - A companion Excel-based benefit estimation tool that assists users with calculating the total benefits in dollar values and the B/C ratio.
- The five-step process for research benefit quantification developed in this effort was adapted from the seven-step process used for development of MnDOT's tool. Chapter 3 of this document guides users through the five steps, from identifying the applicable benefit categories to gathering and entering input data to calculating and evaluating the results.
- The Excel-based tool for NETC was developed based on the spreadsheet templates that are included with MnDOT's tool. Updated structure, layout, and user's interface were incorporated in the tool for NETC to add some automated calculation features and enhance its usability.
- The NETC research benefit estimation tool was applied to two sample projects selected by the TAC for demonstration and refinement of the tool.
- The NETC research benefit estimation tool can be used to test the benefits with various assumptions of inputs and different deployment/implementation of the research recommendations. This can help agencies in demonstrating value of their research program.
- NETC should consider including a requirement or at least preference for a list of applicable benefits to its future requests for proposals (RFPs). This will help NETC with quantifying the research benefits and evaluation of NETC's research program. This requirement (or preference) would not have any significant impact on the overall cost of the research project. Given the understanding and knowledge of the researchers on the subject, this addition should be very small. In the meantime, if the information is not included, and NETC wants to quantify the benefits, much greater effort might be needed to understand the research and determine the appropriate benefit categories.
- It is important to emphasize that not all research benefits can be quantified and monetized, at least within a reasonable level of effort and limited resources. Therefore, this tool and the process developed here should not be considered capable of quantifying all kinds of projects. I should be used as a tool assisting agencies in estimating, as much as possible, the monetary benefits of their research projects and providing useful information for assessing values of their research program and making informed research implementation decisions.

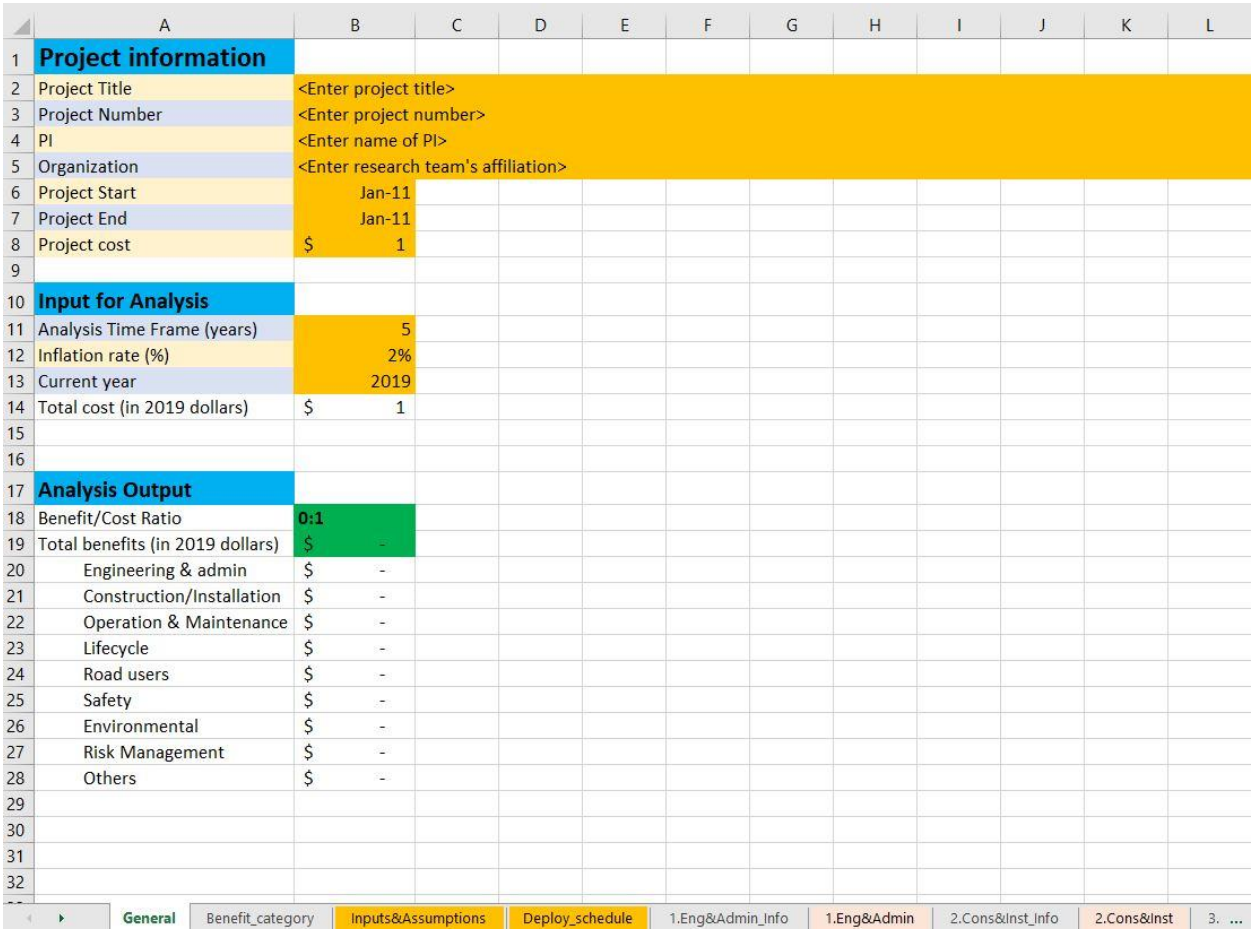
APPENDIX A. THE EXCEL BENEFIT ESTIMATION TOOL USER'S GUIDE

1) General Worksheet

This spreadsheet, shown below in Figure 3, provides the general information on the research project of which benefits are being quantified, and sections for general inputs and key outputs.

- ***Project information:*** This section shows the general information of the project. The user enters the information in the appropriate orange cells.
- ***Input for analysis:*** This section includes some key inputs necessary for the analysis.
    - Analysis timeframe: The period for which the project is being evaluated (in years). The user enters an integer number from 1 to 10 in the appropriate orange box. This number is used for generating number of years in the deployment/implementation schedule tab. The spreadsheet was set up for a maximum 10-year analysis timeframe. If a longer analysis timeframe is required, the user can modify the deployment/implementation schedule spreadsheet.
    - Inflation rate: Average annual U.S. inflation rate (percent). The user enters this value. It is used to calculate the present value costs and benefits so the user can compare results based on the same timeframe (current year).
    - Current year: The year of analysis. The user enters this value. It is used with the inflation rate to adjust the costs and benefits to present values.
    - Total cost: The total cost of the research project, adjusted for inflation (in current year U.S. dollars). This is a calculated field and users do not need to enter this value.
- ***Analysis Output:*** This section presents the key analysis outputs.
    - Benefit/cost ratio: The overall benefit/cost ratio of the research project. This is a calculated field based on all the analyses done for applicable benefit categories and the total cost.
    - Total benefits: The total monetized benefits of the research project (in current year U.S. dollars). This is the sum of all benefit categories:
        - *Engineering & Admin:* Total monetized benefit of the engineering and administration category. This value is calculated in the "1.Eng&Admin" spreadsheet.
        - *Construction & Installation:* Total monetized benefit of the construction and installation cost category. This value is calculated in the "2.Cons&Inst" spreadsheet.
        - *Operation & Maintenance:* Total monetized benefit of the operation and maintenance cost category. This value is calculated in the "3.Ops&Maint" spreadsheet.
        - *Lifecycle:* Total monetized benefit of the lifecycle cost category. This value is calculated in the "4.Lifecycle" spreadsheet.
        - *Road users:* Total monetized benefit of the road users cost category. This value is calculated in the "5.Road_users" spreadsheet.

- *Safety:* Total monetized benefit of the safety cost category. This value is calculated in the "6.Safety" spreadsheet.
- *Environmental:* Total monetized benefit of the environmental cost category. This value is calculated in the "7.Environment" spreadsheet.
- *Risk Management:* Total monetized benefit of the risk Management cost category. This value is calculated in the "8.Risk_Mgmt" spreadsheet.
- *Others:* Total monetized benefit of the other cost category. This value is calculated in the "9.Others" spreadsheet.



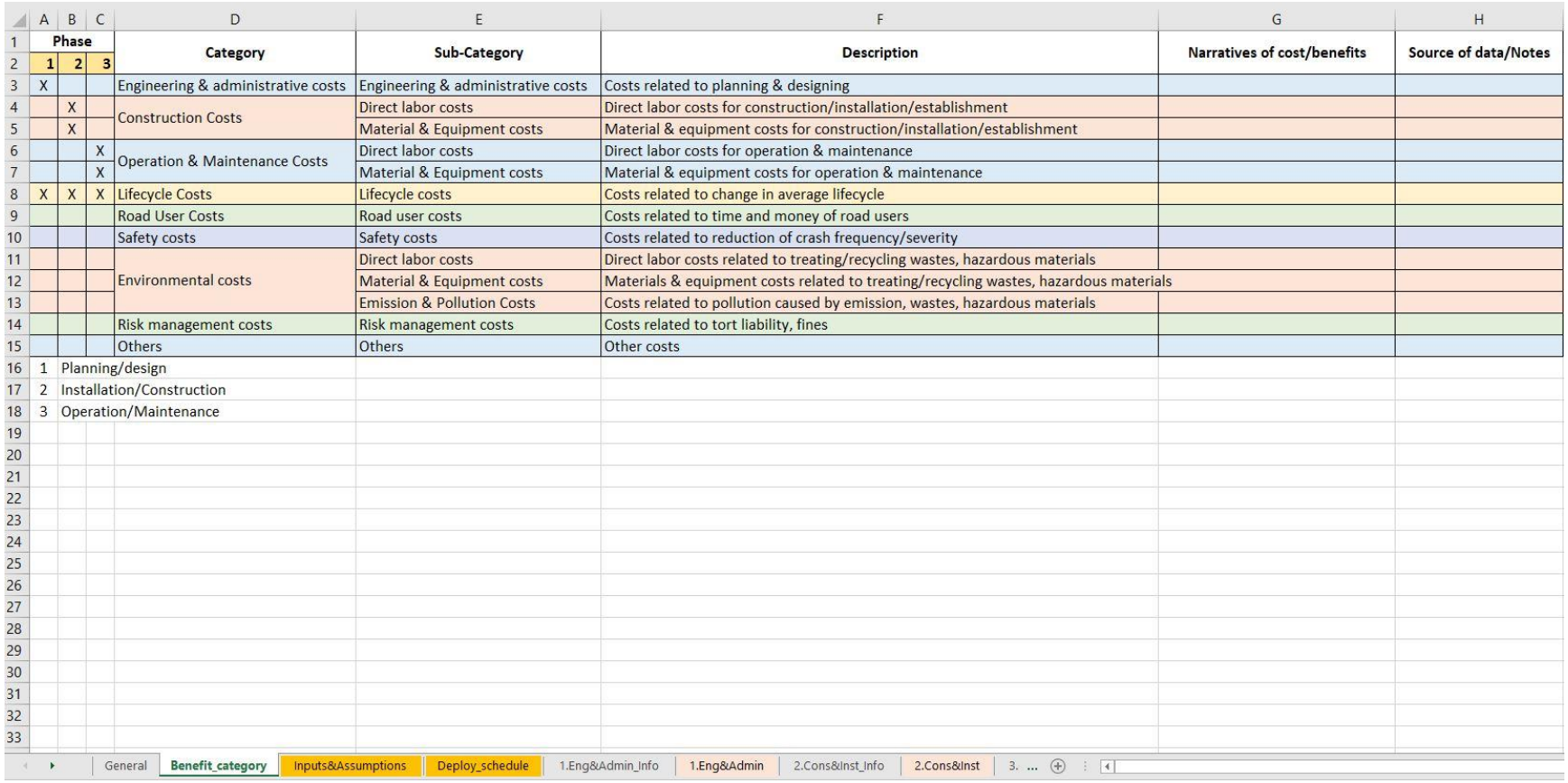
	A	B
1	**Project information**	
2	Project Title	<Enter project title>
3	Project Number	<Enter project number>
4	PI	<Enter name of PI>
5	Organization	<Enter research team's affiliation>
6	Project Start	Jan-11
7	Project End	Jan-11
8	Project cost	$ 1
9		
10	**Input for Analysis**	
11	Analysis Time Frame (years)	5
12	Inflation rate (%)	2%
13	Current year	2019
14	Total cost (in 2019 dollars)	$ 1
15		
16		
17	**Analysis Output**	
18	Benefit/Cost Ratio	0:1
19	Total benefits (in 2019 dollars)	$ -
20	Engineering & admin	$ -
21	Construction/Installation	$ -
22	Operation & Maintenance	$ -
23	Lifecycle	$ -
24	Road users	$ -
25	Safety	$ -
26	Environmental	$ -
27	Risk Management	$ -
28	Others	$ -
29		
30		
31		
32		

Figure 3. Screenshot of General worksheet

2) Benefit Category Spreadsheet

This sheet, shown in Figure 4, was developed to assist users in the identification of potential benefit categories.

- Phase: The user can reference these check boxes to identify all phases of the project applicable to the benefit category and sub-category if the research recommendations are implemented.
- Category: The user identifies the benefit categories that might be applicable to the research project. These benefit categories are pre-determined and should not be changed.
- Sub-category: These are the sub-categories or line items under each benefit category. Although the table is pre-filled with a list of generic sub-categories as suggestions, the user can consider a different way of categorization/itemization depending on the project and data availability.
- Description: This is a brief description of each sub-category or line item. The user provides an appropriate description for each sub-category or line item.
- Narratives of cost/benefit: The user provides a brief description of how the sub-category or line item is applicable to the research project. A line item or sub-category could lead to a cost increase, decrease or no change. This will be the basis for the determination of applicable benefit categories and sub-categories, as well as all subsequent analyses.
- Source of data/note: The user identifies and provides a brief description potential sources of data or other notes



	A	B	C	D	E	F	G	H
1	Phase			Category	Sub-Category	Description	Narratives of cost/benefits	Source of data/Notes
2	1	2	3					
3	X			Engineering & administrative costs	Engineering & administrative costs	Costs related to planning & designing		
4		X		Construction Costs	Direct labor costs	Direct labor costs for construction/installation/establishment		
5		X			Material & Equipment costs	Material & equipment costs for construction/installation/establishment		
6			X	Operation & Maintenance Costs	Direct labor costs	Direct labor costs for operation & maintenance		
7			X		Material & Equipment costs	Material & equipment costs for operation & maintenance		
8	X	X	X	Lifecycle Costs	Lifecycle costs	Costs related to change in average lifecycle		
9				Road User Costs	Road user costs	Costs related to time and money of road users		
10				Safety costs	Safety costs	Costs related to reduction of crash frequency/severity		
11				Environmental costs	Direct labor costs	Direct labor costs related to treating/recycling wastes, hazardous materials		
12					Material & Equipment costs	Materials & equipment costs related to treating/recycling wastes, hazardous materials		
13					Emission & Pollution Costs	Costs related to pollution caused by emission, wastes, hazardous materials		
14				Risk management costs	Risk management costs	Costs related to tort liability, fines		
15				Others	Others	Other costs		
16	1	Planning/design						
17	2	Installation/Construction						
18	3	Operation/Maintenance						

Figure 4. Screenshot of Benefit Category Worksheet

3) Inputs and Assumptions Spreadsheet

This spreadsheet, shown below in Figure 5, assists users in gathering data, making key assumptions and calculating key quantity inputs that are necessary for all cost/benefit estimations. The type of raw data and assumptions needed vary vastly from one project to another, depending on the type of research project. Thus, this spreadsheet is not meant to be a template but a suggestion for the user. The goal is to gather and process data so that key quantity inputs are ready for all other calculation spreadsheets. The user can refer to the appendix for examples on how this spreadsheet is used for two very different projects.

	A	B	C	D	E	F
1	**RAW DATA INPUTS**					
2	**State**	**Quantity**				
3	Connecticut					
4	Maine					
5	Massachusetts					
6	New Hampshire					
7	Rhode Island					
8	Vermont					
9	Total					
10						
11	**ASSUMPTIONS**				Value	Notes
12	<Add description of assumption 1>				0	
13	<Add description of assumption 2>				0	
14	<Add description of assumption 3>				0	
15	<Add description of assumption 4>				0	
16	<Add description of assumption 5>				0	
17	<Add description of assumption 6>				0	
18	<Add description of assumption 7>				0	
19	<Add description of assumption 8>				0	
20						
21						
22	**QUANTITY ESTIMATION**					
23	**State**	**Quantity**	**Number of replacements**			
24	Connecticut	0	0			
25	Maine	0	0			
26	Massachusetts	0	0			
27	New Hampshire	0	0			
28	Rhode Island	0	0			
29	Vermont	0	0			
30	**Total**		**0**			
31						
32						

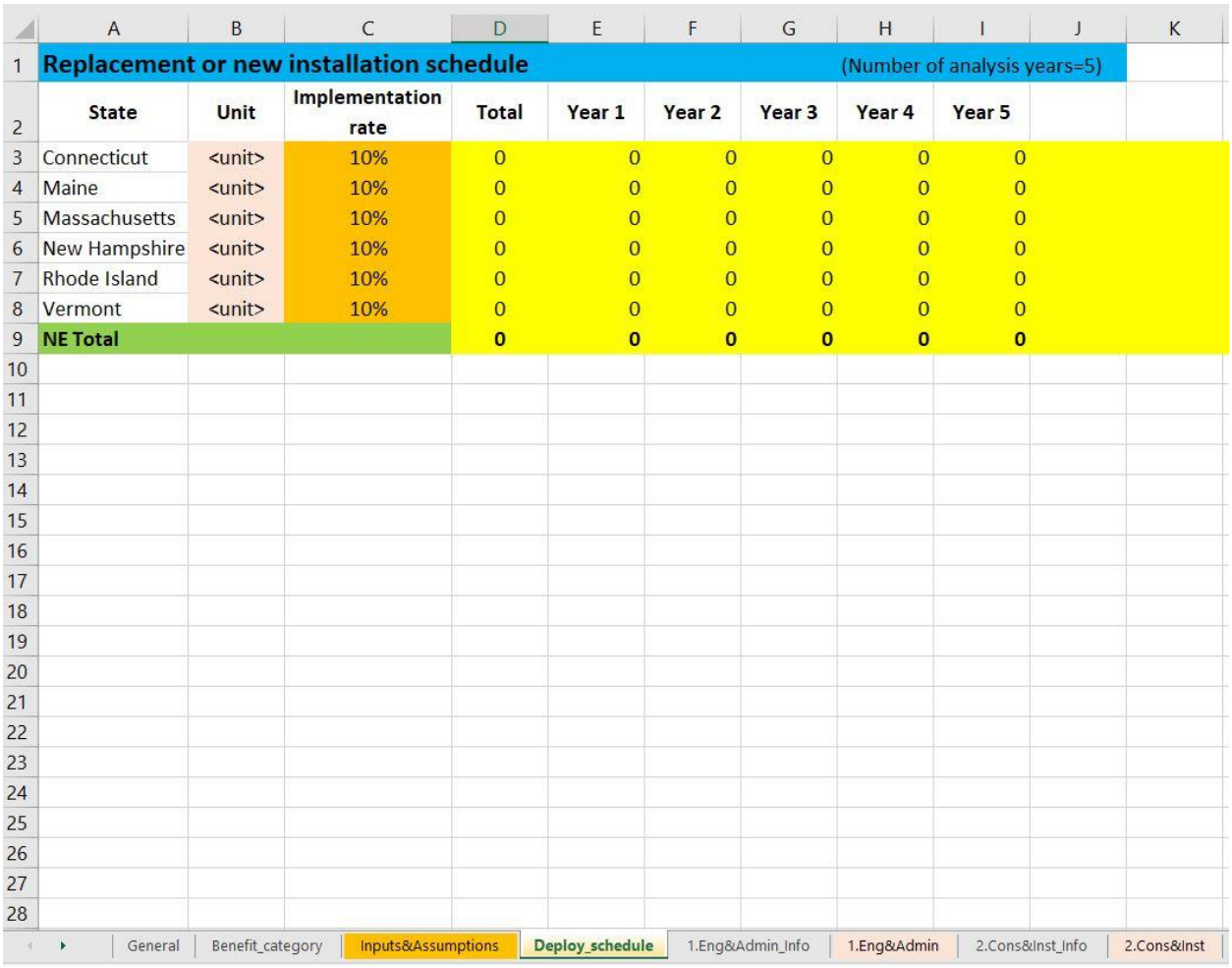
General | Benefit_category | Inputs&Assumptions | Deploy_schedule | 1.Eng&Admin_Info | 1.Eng&Admin | 2.Cons&Inst_Info | 2.Cons&Inst

Figure 5. Screenshot of Inputs and Assumptions Worksheet

4) Deployment/Implementation Schedule

This spreadsheet, shown below in Figure 6, assists users in gathering and entering the anticipated level of deployment or frequency of activities. The total benefits are dependent upon the level of implementation, and this might include information such as number of locations that received the improvement recommended by the research, and when they received such improvements.

- State: List of all NETC member states. This allows the user to enter the input by state. The user can also perform the analysis for the entire NETC or as few as one state.
- Unit: The user enters the appropriate unit. This should be consistent throughout the reason. If the inputs differ from one state to another, the data should be converted to a common unit.
- Implementation rate: This is the deployment/implementation rate by each state (percent). For example, if a state plans to replace an old material with a new, innovative one at a rate of 10% per year, enter 10.
- Total: This is the sum of all replacement/new installation throughout the analysis period (total=year1+year2+year3…etc.). The user has the option of calculating these numbers from the quantities from "Inputs&Assumptions" spreadsheet and the implementation rate (Column C) or entering these numbers directly (if the overall replacement/new installation numbers for the entire analysis period are known).
- Year 1, 2, 3: These is the implementation/deployment quantities for the first, second, third year and so on. The user has the option of calculating these numbers from the quantities from "Inputs&Assumptions" spreadsheet and the implementation rate (Column C) if the implementation/deployment rate is consistent every year throughout the analysis timeframe. The user can also enter these numbers directly if the implementation/numbers vary from year to year.
- (Number of analysis year=X): This is for information purposes only. The information reflects the analysis timeframe that the user inputs in the general spreadsheet.



	A	B	C	D	E	F	G	H	I	J	K
1	**Replacement or new installation schedule**								(Number of analysis years=5)		
2	**State**	**Unit**	**Implementation rate**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**		
3	Connecticut	<unit>	10%	0	0	0	0	0	0		
4	Maine	<unit>	10%	0	0	0	0	0	0		
5	Massachusetts	<unit>	10%	0	0	0	0	0	0		
6	New Hampshire	<unit>	10%	0	0	0	0	0	0		
7	Rhode Island	<unit>	10%	0	0	0	0	0	0		
8	Vermont	<unit>	10%	0	0	0	0	0	0		
9	**NE Total**			**0**	**0**	**0**	**0**	**0**	**0**		
10											
11											
12											
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Figure 6. Screenshot of Deployment/Implementation Schedule Worksheet

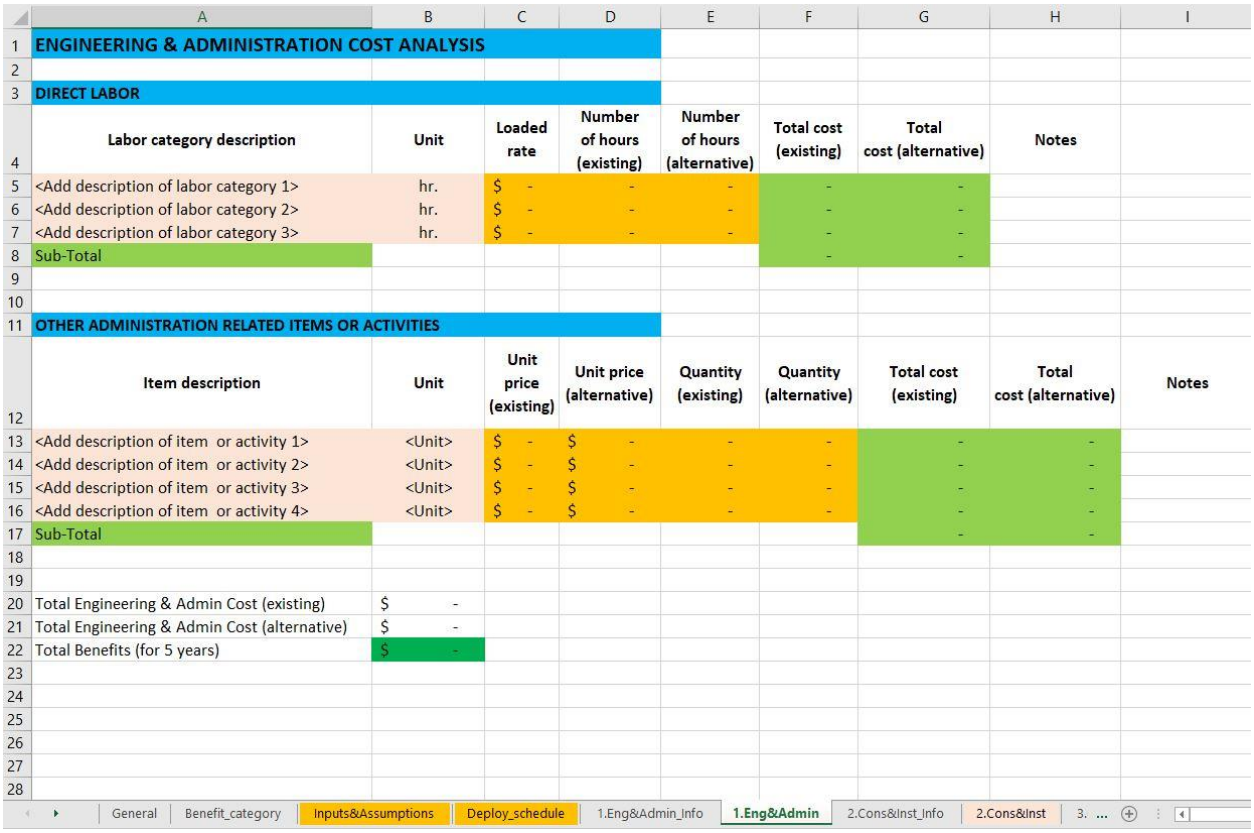
5) Engineering and Administration Cost Analysis Spreadsheet

This spreadsheet, shown below in Figure 7, assist users in gathering inputs and calculating all costs related to planning, design and managing the implementation of research findings.

- ***Direct labor***

This section assists users in calculating the change and potential savings in cost of direct labor after implementing the research findings. The change could be the results of a) a change in labor hours and/or b) a change in labor rates (e.g. using less labor hours of the more expensive labor categories). The user only enters information in this section if changes in direct labor costs have been identified.

  - Labor category description: A brief description for each labor category of which costs changed as a result of implementing the research findings, as identified in the benefit category spreadsheet.
  - Unit: The user enters the unit for the labor cost (e.g. hour).
  - Loaded rate: The user enters the fully-loaded labor rate for each labor category (i.e. including overhead and all other related costs).
  - Number of hours (existing): The user enters the value that reflects the number of labor hours required to complete the activity/task using the old method (before the implementation of the research findings).
  - Number of hours (alternative): The user enters the value that reflects the number of labor hours required to complete the activity/task using the new method (after the implementation of the research findings).
  - Total cost (existing): The total labor cost for each labor category, calculated from number of hours (existing) and loaded rate. This is a calculated field, using a built-in formula.
  - Total cost (alternative): The total labor cost for each labor category, calculated from number of hours (alternative) and loaded rate. This is a calculated field, using a built-in formula.
  - Note: The user can enter additional notes related to labor category and costs.



	A	B	C	D	E	F	G	H	I
1	**ENGINEERING & ADMINISTRATION COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	<Add description of labor category 1>	hr.	$ -	-	-	-	-		
6	<Add description of labor category 2>	hr.	$ -	-	-	-	-		
7	<Add description of labor category 3>	hr.	$ -	-	-	-	-		
8	Sub-Total					-	-		
9									
10									
11	**OTHER ADMINISTRATION RELATED ITEMS OR ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	<Add description of item or activity 1>	<Unit>	$ -	$ -	-	-	-	-	
14	<Add description of item or activity 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item or activity 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item or activity 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						-	-	
18									
19									
20	Total Engineering & Admin Cost (existing)	$ -							
21	Total Engineering & Admin Cost (alternative)	$ -							
22	Total Benefits (for 5 years)	$ -							
23									
24									
25									
26									
27									
28									

Figure 7. Screenshot of Engineering and Administration Cost Analysis Worksheet

- ***Other administration related items or activities***

This section assists users in calculating the change and potential savings in cost of material, equipment and activities after implementing the research findings. The change could be the results of a) a change in quantities and/or b) a change in unit prices of material, equipment and activities (e.g. using cheaper materials). The user only enters information in this section if changes in material, equipment and activity costs have been identified.

- Item description: A brief description for each sub-category of material, equipment and activities with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
- Unit: The user enters the unit for the material, equipment and activities (e.g. mile, sqft, set, equipment hour).
- Unit price (existing): The user enters the unit price for each sub-category of material, equipment and activities before the implementation of the research findings.
- Unit price (alternative): The user enters the unit price for each sub-category of material, equipment and activities after the implementation of the research findings.

- Quantity (existing): The user enters the quantity for each sub-category of material, equipment and activities before the implementation of the research findings.
- Quantity (alternative): The user enters the quantity for each sub-category of material, equipment and activities after the implementation of the research findings.
- Total cost (existing): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
- Total cost (alternative): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (alternative) and unit price (alternative). This is a calculated field, using a built-in formula.
- Note: The user can enter additional notes related to material, equipment and activity sub-category and costs.

- ***Total Engineering & Admin Cost (existing):*** The total engineering and administration costs before the implementation of the research findings. This is a calculated field using a built-in formula and the user does not need to enter a value or make changes to it unless it is necessary to make major modifications to the spreadsheet.
- ***Total Engineering & Admin Cost (existing):*** The total engineering and administration costs after the implementation of the research findings. This is a calculated field using a built-in formula and the user does not need to enter a value or make changes to it unless it is necessary to make major modifications to the spreadsheet.
- ***Total benefits (for X years):*** The total engineering and administration benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the user does not need to enter a value or make changes to it unless it is necessary to make major modifications to the spreadsheet.

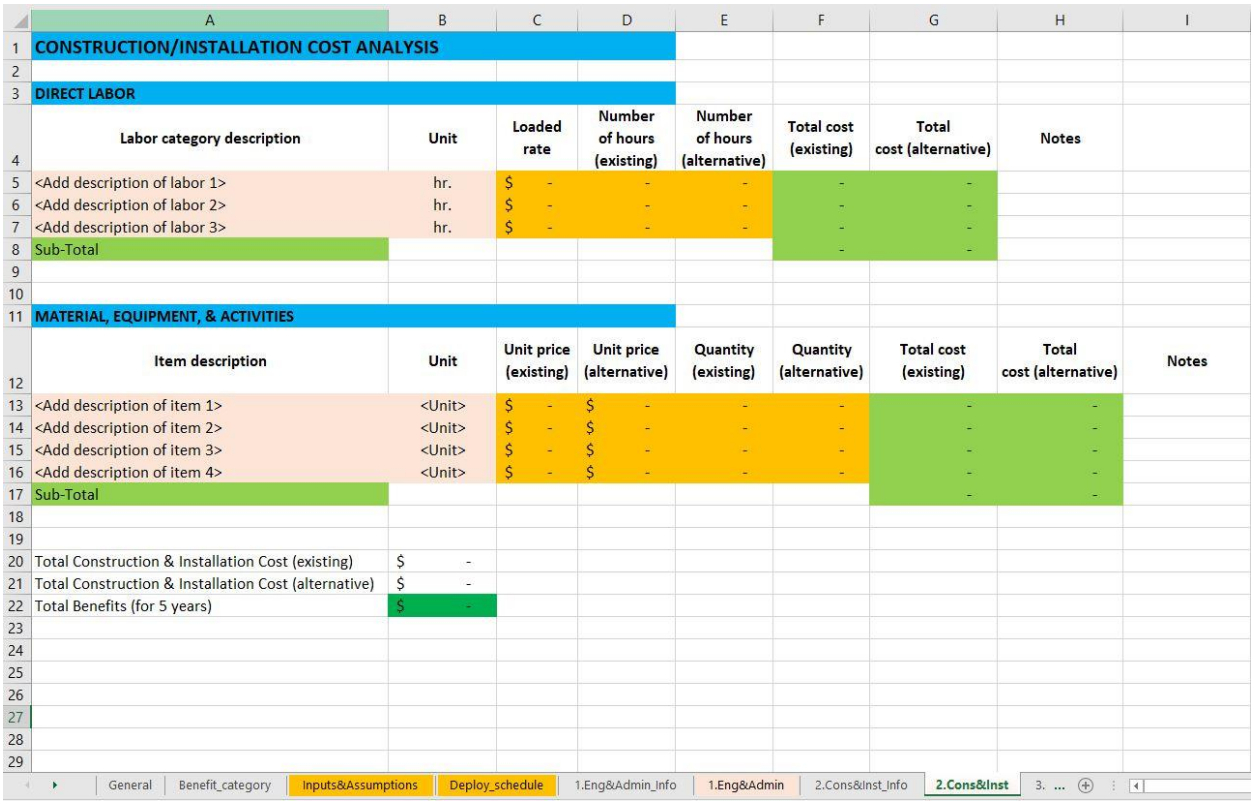
6) Construction/Installation Cost Analysis

This spreadsheet, shown below in Figure 8 assist users in gathering inputs and calculating all costs related to fabrication, manufacture, installation, construction, and establishment as a part of the implementation of research results.

- ***Direct labor***

This section assists users in calculating the change and potential savings in cost of direct labors after implementing the research findings. The change could be the results of a) a change in labor hours and/or b) a change in labor rates (e.g. using less labor hours of the more expensive labor categories). The user only enters information in this section if changes in direct labor costs have been identified.

  - Labor category description: A brief description for each labor category of which costs changed as a result of implementing the research findings, as identified in the benefit category spreadsheet.
  - Unit: The user enters the unit for the labor cost (e.g. hour).
  - Loaded rate: The user enters the fully loaded labor rate for each labor category (i.e. including overhead and all other related costs).
  - Number of hours (existing): The user enters the value that reflects the number of labor hours required to complete the activity/task using the old method (before the implementation of the research findings).
  - Number of hours (alternative): The user enters the value that reflects the number of labor hours required to complete the activity/task using the new method (after the implementation of the research findings).
  - Total cost (existing): The total labor cost for each labor category, calculated from number of hours (existing) and loaded rate. This is a calculated field, using a built-in formula.
  - Total cost (alternative): The total labor cost for each labor category, calculated from number of hours (alternative) and loaded rate. This is a calculated field, using a built-in formula.
  - Note: The user can enter additional notes related to labor category and costs.



	A	B	C	D	E	F	G	H	I
1	CONSTRUCTION/INSTALLATION COST ANALYSIS								
2									
3	DIRECT LABOR								
4	Labor category description	Unit	Loaded rate	Number of hours (existing)	Number of hours (alternative)	Total cost (existing)	Total cost (alternative)	Notes	
5	<Add description of labor 1>	hr.	$ -	-	-	-	-		
6	<Add description of labor 2>	hr.	$ -	-	-	-	-		
7	<Add description of labor 3>	hr.	$ -	-	-	-	-		
8	Sub-Total					-	-		
9									
10									
11	MATERIAL, EQUIPMENT, & ACTIVITIES								
12	Item description	Unit	Unit price (existing)	Unit price (alternative)	Quantity (existing)	Quantity (alternative)	Total cost (existing)	Total cost (alternative)	Notes
13	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
14	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						-	-	
18									
19									
20	Total Construction & Installation Cost (existing)	$ -							
21	Total Construction & Installation Cost (alternative)	$ -							
22	Total Benefits (for 5 years)	$ -							
23									
24									
25									
26									
27									
28									
29									

Figure 8. Screenshot of Construction/Installation Cost Analysis Worksheet

- ***Material, Equipment & Activities***

This section assists users in calculating the change and potential savings in cost of material, equipment and activities after implementing the research findings. The change could be the results of a) a change in quantities and/or b) a change in unit prices of material, equipment and activities (e.g. using cheaper materials). The user only enters information in this section if changes in material, equipment and activity costs have been identified.

- Item description: A brief description for each sub-category of material, equipment and activities with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
- Unit: The user enters the unit for the material, equipment and activities (e.g. mile, sqft, set, equipment hour).
- Unit price (existing): The user enters the unit price for each sub-category of material, equipment and activities before the implementation of the research findings.
- Unit price (alternative): The user enters the unit price for each sub-category of material, equipment and activities after the implementation of the research findings.

    - Quantity (existing): The user enters the quantity for each sub-category of material, equipment and activities before the implementation of the research findings.
    - Quantity (alternative): The user enters the quantity for each sub-category of material, equipment and activities after the implementation of the research findings.
    - Total cost (existing): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (existing) and unit price (existing). This is a calculated field, using a built-in formula.
    - Total cost (alternative): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (alternative) and unit price (alternative). This is a calculated field, using a built-in formula.
    - Note: The user can enter additional notes related to material, equipment and activity sub-category and costs.
- ***Total Construction & Installation Cost (existing):*** The total construction and installation costs before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total Construction & Installation Cost (existing):*** The total construction and installation costs after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (for X years):*** The total construction and installation benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.

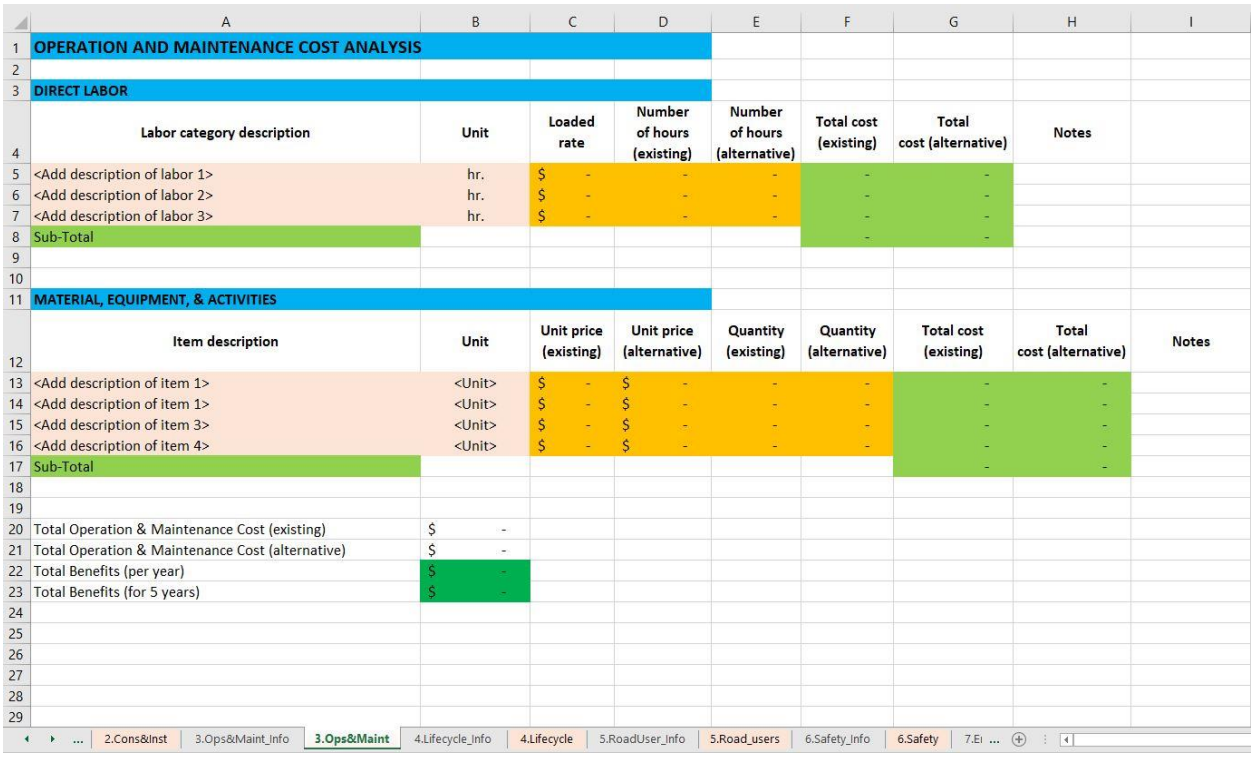
7) Operation and Maintenance Cost Analysis Worksheet

This spreadsheet, shown below in Figure 9 assists users in gathering inputs and calculating all costs related to operation and maintenance as a part of the implementation of research results.

- ***Direct labor***

  This section assists users in calculating the change and potential savings in cost of direct labors after implementing the research findings. The change could be the results of a) change in labor hours and/or b) change in labor rates (e.g. using less labor hours of the more expensive labor categories). The users only enter information in this section if changes in direct labor costs have been identified.

  - Labor category description: A brief description for each labor category of which costs changed as a result of implementing the research findings, as identified in the benefit category spreadsheet.
  - Unit: The user enters the unit for the labor cost (e.g. hour)
  - Loaded rate: The user enters the fully loaded labor rate for each labor category (i.e. including overhead and all other related costs)
  - Number of hours (existing): The user enters the value that reflects the number of labor hours required to complete the activity/task using the old method (before the implementation of the research findings)
  - Number of hours (alternative): The user enters the value that reflects the number of labor hours required to complete the activity/task using the new method (after the implementation of the research findings)
  - Total cost (existing): The total labor cost for each labor category, calculated from number of hours (existing) and loaded rate. This is a calculated field, using a built-in formula.
  - Total cost (alternative): The total labor cost for each labor category, calculated from number of hours (alternative) and loaded rate. This is a calculated field, using a built-in formula.
  - Note: The user can enter additional notes related to labor category and costs.



	A	B	C	D	E	F	G	H	I
1	**OPERATION AND MAINTENANCE COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	<Add description of labor 1>	hr.	$ -	-	-	-	-		
6	<Add description of labor 2>	hr.	$ -	-	-	-	-		
7	<Add description of labor 3>	hr.	$ -	-	-	-	-		
8	Sub-Total					-	-		
9									
10									
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
14	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						-	-	
18									
19									
20	Total Operation & Maintenance Cost (existing)	$ -							
21	Total Operation & Maintenance Cost (alternative)	$ -							
22	Total Benefits (per year)	$ -							
23	Total Benefits (for 5 years)	$ -							
24									
25									
26									
27									
28									
29									

... | 2.Cons&Inst | 3.Ops&Maint_Info | 3.Ops&Maint | 4.Lifecycle_Info | 4.Lifecycle | 5.RoadUser_Info | 5.Road_users | 6.Safety_Info | 6.Safety | 7.E ...

Figure 9. Screenshot of Operation and Maintenance Cost Analysis Worksheet

- ***Material, Equipment & activities***

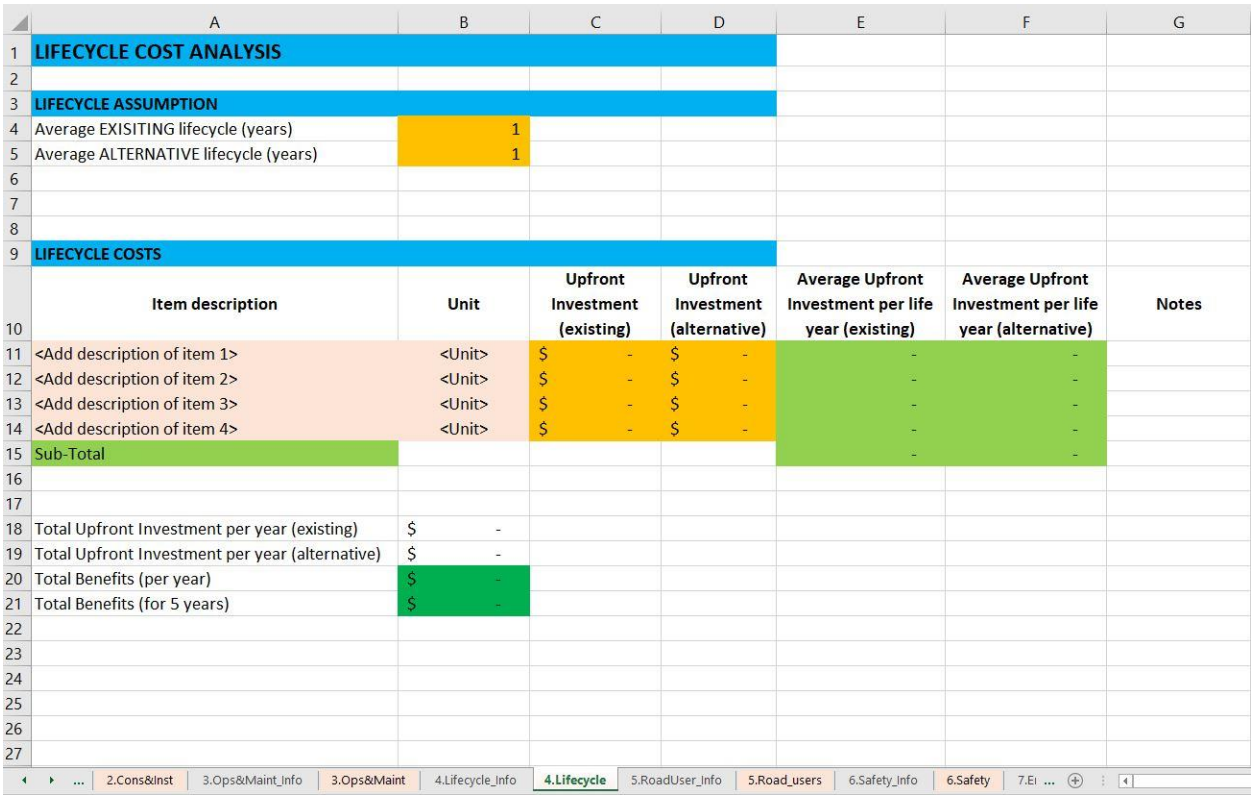
This section assists users in calculating the change and potential savings in cost of material, equipment and activities after implementing the research findings. The change could be the results of a) change in quantities and/or b) change in unit prices of material, equipment and activities (e.g. using cheaper materials). The users only enter information in this section if changes in material, equipment and activity costs have been identified.

  - Item description: A brief description for each sub-category of material, equipment and activities with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
  - Unit: The user enters the unit for the material, equipment and activities (e.g. mile, sqft, set, equipment hour)
  - Unit price (existing): The user enters the unit price for each sub-category of material, equipment and activities before the implementation of the research findings.
  - Unit price (alternative): The user enters the unit price for each sub-category of material, equipment and activities after the implementation of the research findings.
  - Quantity (existing): The user enters the quantity for each sub-category of material, equipment and activities before the implementation of the research findings.

    - Quantity (alternative): The user enters the quantity for each sub-category of material, equipment and activities after the implementation of the research findings.
    - Total cost (existing): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
    - Total cost (alternative): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (alternative) and unit price (alternative). This is a calculated field using a built-in formula.
    - Note: The user can enter additional notes related to material, equipment and activity sub-category and costs.
- *Total Operation & Maintenance Cost (existing):* The total operations and maintenance costs before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- *Total Operation & Maintenance Cost (existing):* The total operations and maintenance costs after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- *Total benefits (per year):* The annual operations and maintenance benefit, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- *Total benefits (for X years):* The total operations and maintenance benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.

8) Lifecycle Cost Analysis Worksheet

This spreadsheet, shown below in Figure 10, assists users in calculating the change and potential savings in lifecycle costs as a result of implementing the research findings. The potential lifecycle benefits could be realized by using a new product or material with longer lifecycle and therefore lowers the overall costs over time. It is important to note that the change in cost does not always mean cost savings. The new product or material might cost more to purchase and/or install but with longer lifecycle could mean lower average cost per year. Even if the longer lifecycle is not enough to make up for the higher initial cost of purchase or installation, it could still lead to savings in other aspects (e.g. lower operation & maintenance cost) and the end goal is to take all changes into consideration and estimate the overall benefits. The users only enter information in this section if changes in lifecycle costs have been identified.



	A	B	C	D	E	F	G
1	**LIFECYCLE COST ANALYSIS**						
2							
3	**LIFECYCLE ASSUMPTION**						
4	Average EXISITING lifecycle (years)	1					
5	Average ALTERNATIVE lifecycle (years)	1					
6							
7							
8							
9	**LIFECYCLE COSTS**						
10	**Item description**	**Unit**	**Upfront Investment (existing)**	**Upfront Investment (alternative)**	**Average Upfront Investment per life year (existing)**	**Average Upfront Investment per life year (alternative)**	**Notes**
11	<Add description of item 1>	<Unit>	$ -	$ -	-	-	
12	<Add description of item 2>	<Unit>	$ -	$ -	-	-	
13	<Add description of item 3>	<Unit>	$ -	$ -	-	-	
14	<Add description of item 4>	<Unit>	$ -	$ -	-	-	
15	Sub-Total				-	-	
16							
17							
18	Total Upfront Investment per year (existing)	$ -					
19	Total Upfront Investment per year (alternative)	$ -					
20	Total Benefits (per year)	$ -					
21	Total Benefits (for 5 years)	$ -					
22							
23							
24							
25							
26							
27							

Figure 10. Screenshot of Lifecycle Cost Analysis Worksheet

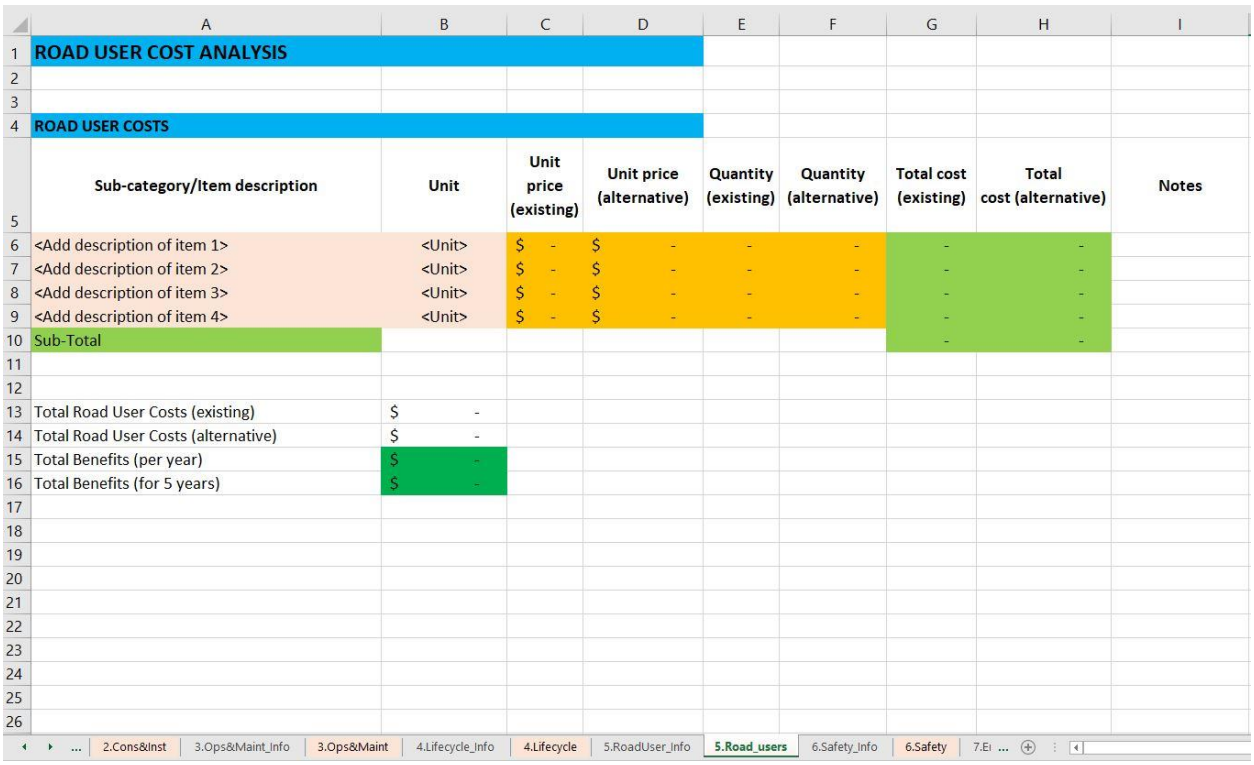
- ***Lifecycle Assumption***
  - Average lifecycle BEFORE (years): The average lifecycle of the product or material before the implementation of research findings (e.g. the old steel material lasts 10 years on average, users enter 10).

    - Average lifecycle AFTER (years): The average lifecycle of the product or material after the implementation of research findings (e.g. the old steel material lasts 10 years on average, users enter 10).
- ***Lifecycle costs***
    - Item description: A brief description for each item/sub-category of lifecycle with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
    - Unit: The user enters the unit lifecycle sub-category
    - Upfront investment (existing): The user enters the upfront cost for each item or sub-category of lifecycle before the implementation of research findings.
    - Upfront investment (alternative): The user enters the upfront cost for each item or sub-category of lifecycle after the implementation of research findings.
    - Average upfront investment per life year (existing): The average upfront cost for each item or sub-category of lifecycle before the implementation of research findings, calculated from the upfront investment (existing) and the assumed lifecycle (existing). This is a calculated field using a built-in formula.
    - Average upfront investment per life year (alternative): The average upfront cost for each item or sub-category of lifecycle after the implementation of research findings, calculated from the upfront investment (alternative) and the assumed lifecycle (alternative). This is a calculated field using a built-in formula.
    - Note: The user can enter additional notes related to lifecycle and costs.
- ***Total upfront investment per year (existing):*** The total annual upfront investment before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total upfront investment per year (alternative):*** The total annual upfront investment after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (per year):*** The annual lifecycle benefits, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (for X years):*** The total lifecycle benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.

9) Road User Cost Analysis Worksheet

This spreadsheet, shown below in Figure 11, assists users in calculating the change and potential savings in costs to road users as a result of implementing the research findings. The potential road user benefits could in the forms of savings in travel time, fuel, wear & tear etc. The users only enter information in this section if changes in user costs have been identified.

- ***Road user costs***
    - Sub-category/item description: A brief description for each sub-category related to the road users with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
    - Unit: The user enters the unit for road user costs (e.g. hours or minutes saved).
    - Unit price (existing): The user enters the unit price for each sub-category of road user costs before the implementation of the research findings.
    - Unit price (alternative): The user enters the unit price for each sub-category of road user costs after the implementation of the research findings.
    - Quantity (existing): The user enters the quantity for each sub-category of road user costs before the implementation of the research findings.
    - Quantity (alternative): The user enters the quantity for each sub-category of road user costs after the implementation of the research findings.
    - Total cost (existing): The total cost for each sub-category of road user costs, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
    - Total cost (alternative): The total cost for each sub-category of user costs, calculated from quantity (alternative) and unit price (alternative). This is a calculated field using a built-in formula.
    - Notes: The user can enter additional notes related to road user costs.
- ***Total road user costs (existing):*** The total road user costs before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total road user costs (alternative):*** The total road user costs after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (per year):*** The annual road user benefit, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (for X years):*** The total road user benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.



	A	B	C	D	E	F	G	H	I
1	**ROAD USER COST ANALYSIS**								
2									
3									
4	**ROAD USER COSTS**								
5	**Sub-category/Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
6	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
7	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
8	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
9	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
10	Sub-Total						-	-	
11									
12									
13	Total Road User Costs (existing)	$ -							
14	Total Road User Costs (alternative)	$ -							
15	Total Benefits (per year)	$ -							
16	Total Benefits (for 5 years)	$ -							
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									

... | 2.Cons&Inst | 3.Ops&Maint_Info | 3.Ops&Maint | 4.Lifecycle_Info | 4.Lifecycle | 5.RoadUser_Info | 5.Road_users | 6.Safety_Info | 6.Safety | 7.E ...

Figure 11. Screenshot of Road User Cost Analysis Worksheet

10) Safety Cost Analysis Worksheet

This spreadsheet, shown below in Figure 12, assists users in calculating the change in crash costs and potential safety benefits as a result of implementing the research findings. The potential safety benefits could in the forms of savings reduction of crash frequency or severity. The users only enter information in this section if changes in crash costs have been identified.

- ***Comprehensive Crash Costs***

This section provides the basic inputs for crash cost calculation. These are comprehensive crash costs by type and severity. They are pre-filled with crash costs by severity in 2017 dollars, using U.S DOT's values of statistical life and injuries. The user can apply the state's numbers if they are available.

    - Crash type: Type or severity of crash.
    - Comprehensive crash costs: Comprehensive cost per crash for each type of severity level.
- ***Estimation of Crash Reduction***
    - Crash type: Type or severity of crash.
    - Crash modification factors: Crash modification factor for the crash type, as a result of implementing the research findings.
    - Total crashes per year (existing): Total number of crashes for the crash type before the implementation of research findings.
    - Total/expected crashes per year (alternative): Total number of crashes for the crash type after the implementation of research findings.
    - Crash reduction per year: The estimated reduction in number of crashes per year as a result of implementing the research findings. This is a calculated field using a built-in formula.
    - Crash cost saved per year: The estimated crash costs saved per year as a result of implementing the research findings. This is a calculated field using a built-in formula.
- ***Total safety benefits (per year):*** The annual safety benefit, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total safety benefits (for X years):*** The total safety benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.

	A	B	C	D	E	F	G
1	**CRASH COST ANALYSIS**						
2							
3	**COMPREHENSIVE CRASH COSTS**						
4	**Crash type**	**Comprehensive crash costs**					
5	Fatal crashes	$ 11,295,400					
6	Type A crashes (Incapacitating)	$ 655,000					
7	Type B crashes (Non-Incapacitating)	$ 198,500					
8	Type C crashes (Possible injury)	$ 125,600					
9	PDO crashes, including severity unknown (No injury, property damage only)	$ 11,900					
10							
11							
12	**ESTIMATION OF CRASH REDUCTION**						
13	**Crash type**	**Crash modification factors**	**Total crashes per year (existing)**	**Total/Expected crashes per year (alternative)**	**Crash reduction per year**	**Crash cost saved per year**	**Notes**
14	Fatal crashes	1.00	-	-	-	-	
15	Type A crashes (Incapacitating)	1.00	-	-	-	-	
16	Type B crashes (Non-Incapacitating)	1.00	-	-	-	-	
17	Type C crashes (Possible injury)	1.00	-	-	-	-	
18	PDO crashes, including severity unknown (No injury, property damage only)	1.00	-	-	-	-	
19	Sub-Total					-	
20							
21							
22							
23							
24	Total safety benefits (per year)	$ -					
25	Total safety benefits (for 5 years)	$ -					
26							
27							
28							

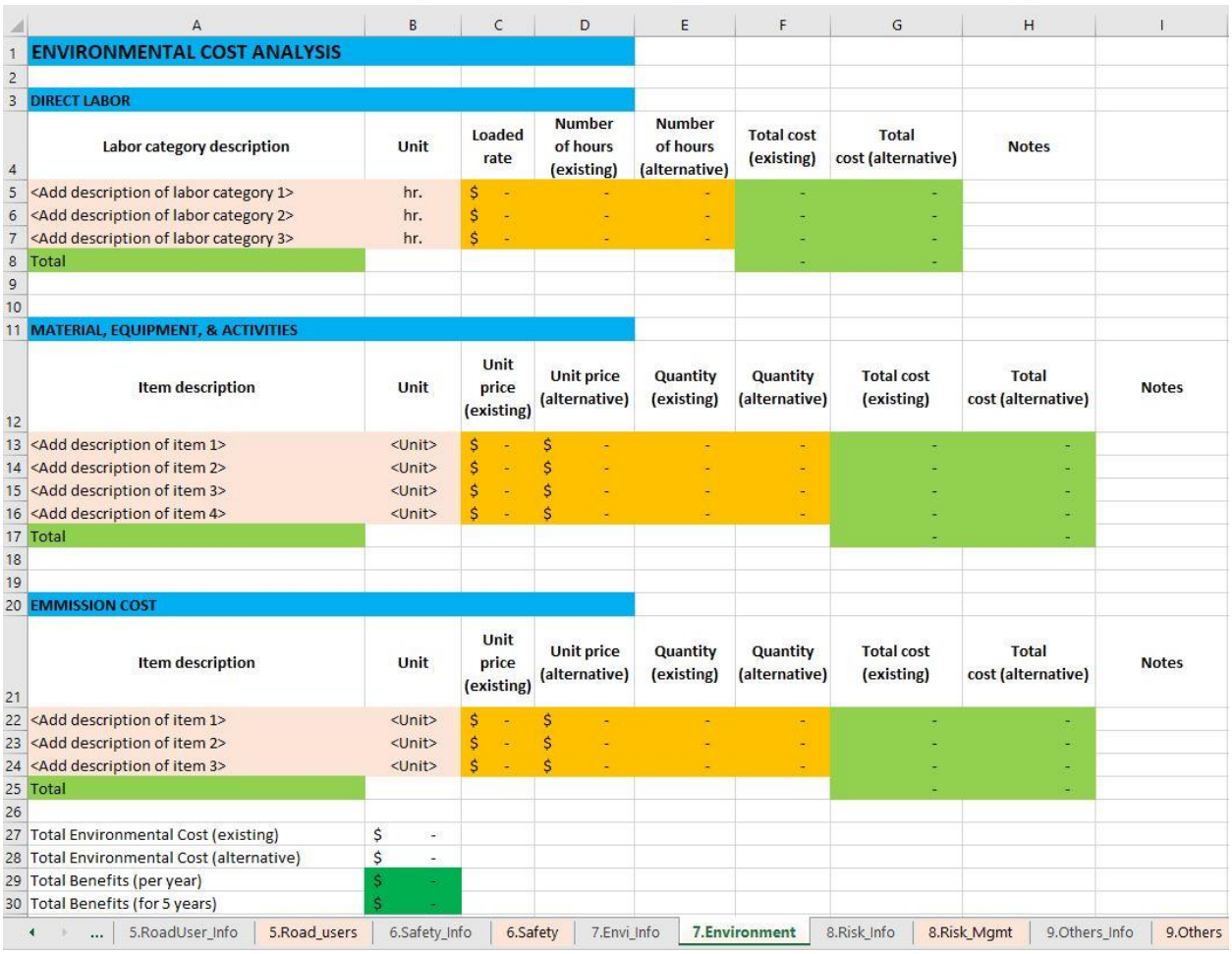
... | 4.Lifecycle | 5.RoadUser_Info | 5.Road_users | 6.Safety_Info | **6.Safety** | 7.Envi_Info | 7.Environment | 8.Risk_Info | 8.Risk_Mgmt | 9.Others_Info ...

Figure 12. Screenshot of Safety Cost Analysis Worksheet

11) Environmental Cost Analysis Spreadsheet

This spreadsheet, shown below in Figure 13, assists users in gathering inputs and calculating all costs related to environmental aspects (e.g., emissions, pollution, hazardous wastes and materials, recycling) of the implementation of research results.

- ***Direct labor***
  This section assists users in calculating the change and potential savings in cost of direct labors after implementing the research findings. The change could be the results of a) change in labor hours and/or b) change in labor rates (e.g. using less labor hours of the more expensive labor categories). The users only enter information in this section if changes in direct labor costs have been identified.
  - Labor category description: A brief description for each labor category of which costs changed as a result of implementing the research findings, as identified in the benefit category spreadsheet.
  - Unit: The user enters the unit for the labor cost (e.g. hour).
  - Loaded rate: The user enters the fully loaded labor rate for each labor category (i.e. including overhead and all other related costs).
  - Number of hours (existing): The user enters the value that reflects the number of labor hours required to complete the activity/task using the old method (before the implementation of the research findings).
  - Number of hours (alternative): The user enters the value that reflects the number of labor hours required to complete the activity/task using the new method (after the implementation of the research findings).
  - Total cost (existing): The total labor cost for each labor category, calculated from number of hours (existing) and loaded rate. This is a calculated field, using a built-in formula.
  - Total cost (alternative): The total labor cost for each labor category, calculated from number of hours (alternative) and loaded rate. This is a calculated field, using a built-in formula.
  - Note: The user can enter additional notes related to labor category and costs.



	A	B	C	D	E	F	G	H	I
1	**ENVIRONMENTAL COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	<Add description of labor category 1>	hr.	$ -	-	-	-	-		
6	<Add description of labor category 2>	hr.	$ -	-	-	-	-		
7	<Add description of labor category 3>	hr.	$ -	-	-	-	-		
8	Total					-	-		
9									
10									
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
14	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Total						-	-	
18									
19									
20	**EMMISSION COST**								
21	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
22	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
23	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
24	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
25	Total						-	-	
26									
27	Total Environmental Cost (existing)	$ -							
28	Total Environmental Cost (alternative)	$ -							
29	Total Benefits (per year)	$ -							
30	Total Benefits (for 5 years)	$ -							

... | 5.RoadUser_Info | 5.Road_users | 6.Safety_Info | 6.Safety | 7.Envi_Info | **7.Environment** | 8.Risk_Info | 8.Risk_Mgmt | 9.Others_Info | 9.Others

Figure 13. Screenshot of Environmental Cost Analysis Worksheet

- ***Material, Equipment & activities***

This section assists users in calculating the change and potential savings in cost of material, equipment and activities after implementing the research findings. The change could be the results of a) change in quantities and/or b) change in unit prices of material, equipment and activities (e.g. using cheaper materials). The users only enter information in this section if changes in material, equipment and activity costs have been identified.

  - Item description: A brief description for each sub-category of material, equipment and activities with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
  - Unit: The user enters the unit for the material, equipment and activities (e.g. mile, sqft, set, equipment hour).
  - Unit price (existing): The user enters the unit price for each sub-category of material, equipment and activities before the implementation of the research findings.

- Unit price (alternative): The user enters the unit price for each sub-category of material, equipment and activities after the implementation of the research findings.
- Quantity (existing): The user enters the quantity for each sub-category of material, equipment and activities before the implementation of the research findings.
- Quantity (alternative): The user enters the quantity for each sub-category of material, equipment and activities after the implementation of the research findings.
- Total cost (existing): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
- Total cost (alternative): The total labor cost for each sub-category of material, equipment and activities, calculated from quantity (alternative) and unit price (alternative). This is a calculated field using a built-in formula.
- Note: The user can enter additional notes related to material, equipment and activity category and costs.

- ***Emission cost***

This section assists users in calculating the change and potential savings in cost of emission and other hazardous wastes after implementing the research findings (e.g. the new method leads to less emission). The EPA's standard emission cost can be used to for this calculation. The users only enter information in this section if changes in emission and/or hazardous waste costs have been identified.

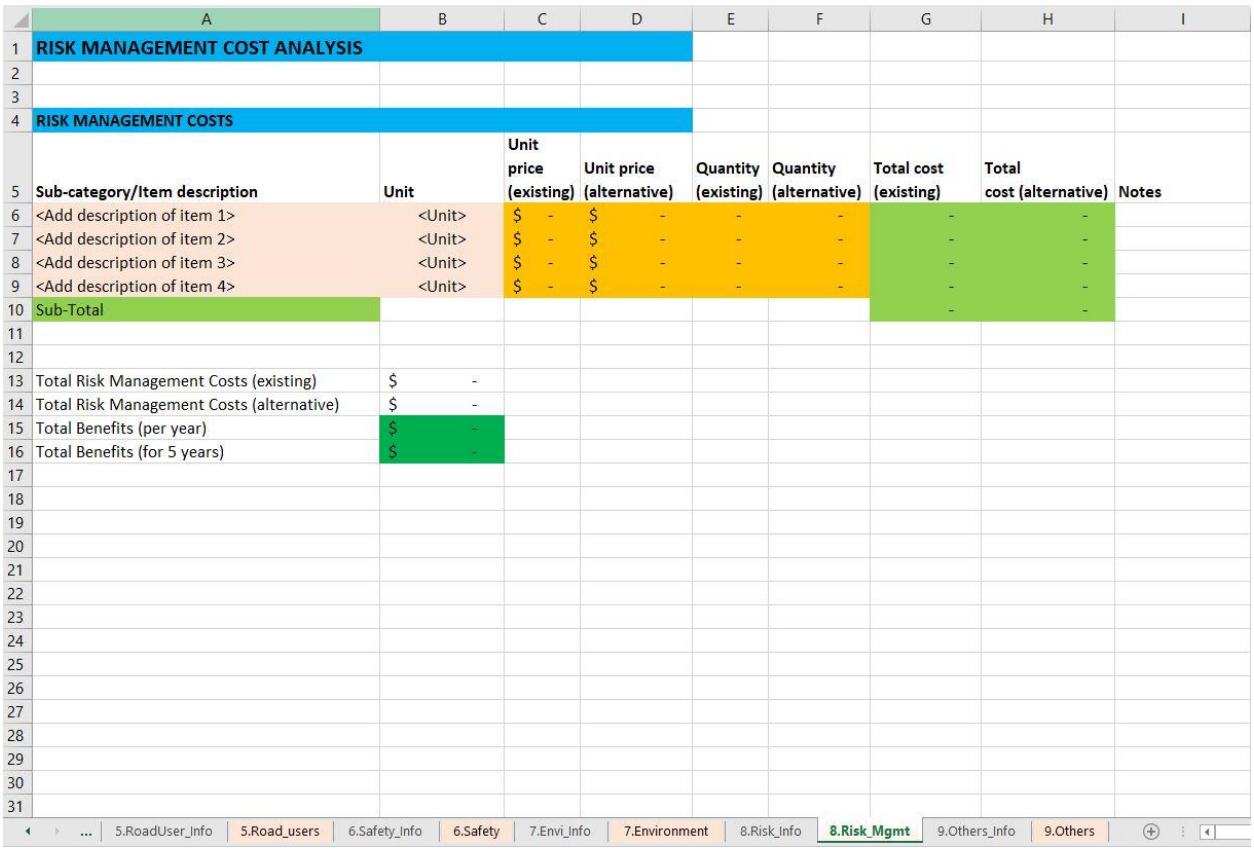
- Item description: A brief description for each sub-category of emission and/or hazardous wastes with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
- Unit: The user enters the unit for emission or hazardous waste (e.g. ton).
- Unit price (existing): The user enters the unit price for each sub-category of emission or hazardous waste before the implementation of the research findings. The most commonly used input is the EPA's standard emission cost.
- Unit price (alternative): The user enters the unit price for each sub-category of emission or hazardous waste after the implementation of the research findings. The most commonly used input for this is the EPA's standard emission cost.
- Quantity (existing): The user enters the quantity for each sub-category of emission or hazardous waste before the implementation of the research findings.
- Quantity (alternative): The user enters the quantity for each sub-category of emission or hazardous waste after the implementation of the research findings.
- Total cost (existing): The total cost for each sub-category of emission and/or hazardous waste, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
- Total cost (alternative): The total cost for each sub-category of emission and/or hazardous waste, calculated from quantity (alternative) and unit price (alternative). This is a calculated field using a built-in formula.

    - Note: The user can enter additional notes related to emission sub-category and costs.
- ***Total Environmental Cost (existing):*** The total environmental costs before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total Environmental Cost (alternative):*** The total environmental costs after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (per year):*** The annual environmental benefit, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (for X years):*** The total environmental benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.

12) Risk Management Cost Analysis Worksheet

This spreadsheet, shown below in Figure 14, assists users in calculating the change and potential savings in risk management costs as a result of implementing the research findings. The potential risk management benefits could in the forms of lower risk and insurance premium, lower risk of tort liability, fines etc. The users only enter information in this section if changes in user costs have been identified.

- ***Risk management costs***
    - Sub-category/item description: A brief description for each sub-category related to risk management with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
    - Unit: The user enters the unit for risk management costs.
    - Unit price (existing): The user enters the unit price for each sub-category of risk management costs before the implementation of the research findings.
    - Unit price (alternative): The user enters the unit price for each sub-category of risk management costs after the implementation of the research findings.
    - Quantity (existing): The user enters the quantity for each sub-category of risk management costs before the implementation of the research findings.
    - Quantity (alternative): The user enters the quantity for each sub-category of risk management costs after the implementation of the research findings.
    - Total cost (existing): The total cost for each sub-category of risk management costs, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
    - Total cost (alternative): The total cost for each sub-category of risk management costs, calculated from quantity (alternative) and unit price (alternative). This is a calculated field using a built-in formula.
    - Notes: The user can enter additional notes related to risk management costs.
- *Total risk management cost (existing):* The total risk management costs before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- *Total risk management cost (existing):* The total risk management costs after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- *Total benefits (per year):* The annual risk management benefit, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- *Total benefits (for X years):* The total risk management benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.



	A	B	C	D	E	F	G	H	I
1	**RISK MANAGEMENT COST ANALYSIS**								
2									
3									
4	**RISK MANAGEMENT COSTS**								
5	**Sub-category/Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
6	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
7	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
8	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
9	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
10	Sub-Total						-	-	
11									
12									
13	Total Risk Management Costs (existing)	$ -							
14	Total Risk Management Costs (alternative)	$ -							
15	Total Benefits (per year)	$ -							
16	Total Benefits (for 5 years)	$ -							
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									

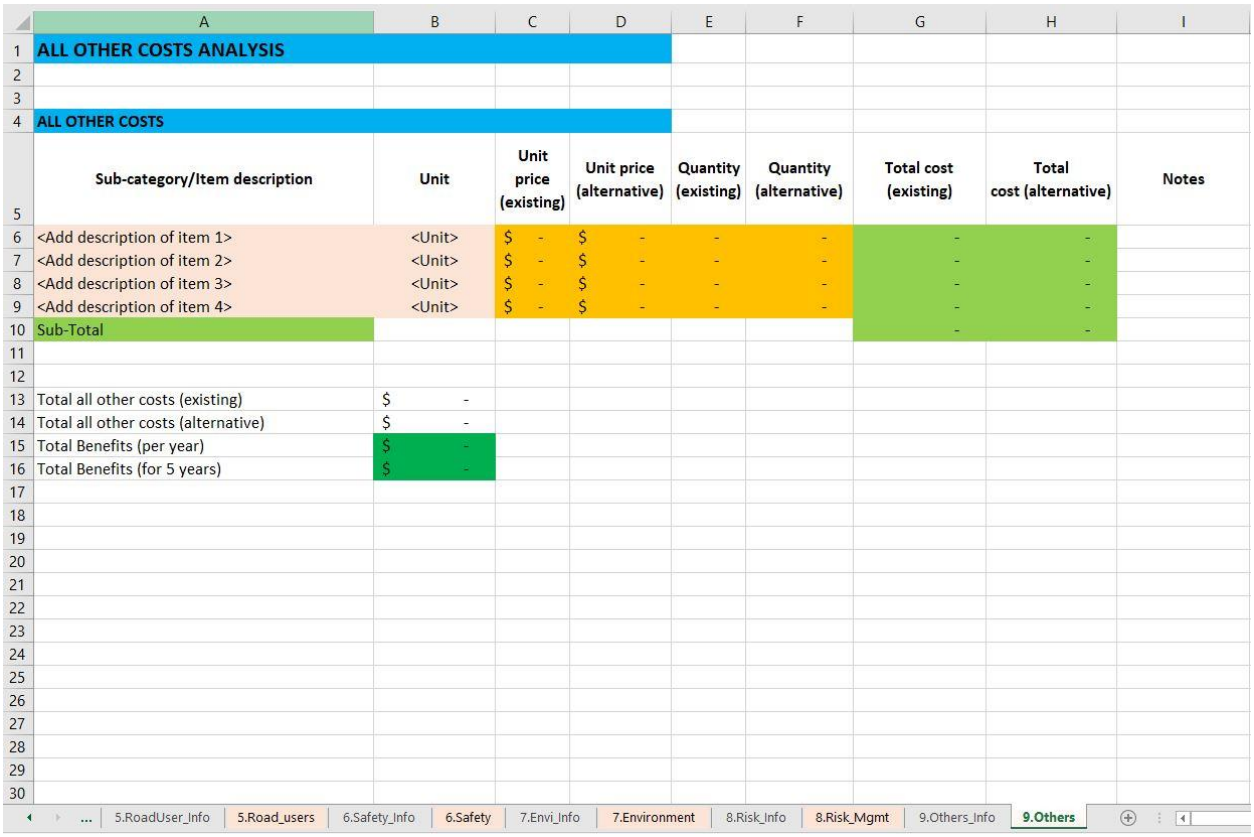
... | 5.RoadUser_Info | 5.Road_users | 6.Safety_Info | 6.Safety | 7.Envi_Info | 7.Environment | 8.Risk_Info | 8.Risk_Mgmt | 9.Others_Info | 9.Others

Figure 14. Screenshot of Risk Management Cost Analysis Worksheet

13) Other Cost Analysis Worksheet

This spreadsheet, shown below in Figure 15, assists users in calculating the change in all other costs and potential savings, as a result of implementing the research findings, that could not be included in any of the above categories. The users only enter information in this section if changes in user costs have been identified.

- ***All other costs***
    - Sub-category/item description: A brief description for each sub-category with change in costs as a result of implementing the research findings, as identified in the benefit category spreadsheet.
    - Unit: The user enters the unit for the cost item or sub-category.
    - Unit price (existing): The user enters the unit price for each sub-category of all other costs before the implementation of the research findings.
    - Unit price (alternative): The user enters the unit price for each sub-category of all other costs after the implementation of the research findings.
    - Quantity (existing): The user enters the quantity for each sub-category before the implementation of the research findings.
    - Quantity (alternative): The user enters the quantity for each sub-category after the implementation of the research findings.
    - Total cost (existing): The total cost for each sub-category related to all other costs, calculated from quantity (existing) and unit price (existing). This is a calculated field using a built-in formula.
    - Total cost (alternative): The total cost for each sub-category related to all other costs, calculated from quantity (alternative) and unit price (alternative). This is a calculated field using a built-in formula.
    - Notes: The users can enter additional notes related to all other costs.
- ***Total all other cost (existing):*** The total other costs before the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total all other cost (alternative):*** The total other costs after the implementation of the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (per year):*** The annual other benefits, expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.
- ***Total benefits (for X years):*** The total other benefits for analysis period (X years), expressed in US dollars, as a result of implementing the research findings. This is a calculated field using a built-in formula and the users do not need to enter a value or make changes to it unless it is necessary to making major modification to the spreadsheet.



	A	B	C	D	E	F	G	H	I
1	**ALL OTHER COSTS ANALYSIS**								
2									
3									
4	**ALL OTHER COSTS**								
5	**Sub-category/Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
6	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
7	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
8	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
9	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
10	Sub-Total						-	-	
11									
12									
13	Total all other costs (existing)	$ -							
14	Total all other costs (alternative)	$ -							
15	Total Benefits (per year)	$ -							
16	Total Benefits (for 5 years)	$ -							
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									

... | 5.RoadUser_Info | 5.Road_users | 6.Safety_Info | 6.Safety | 7.Envi_Info | 7.Environment | 8.Risk_Info | 8.Risk_Mgmt | 9.Others_Info | 9.Others

Figure 15. Screenshot of Other Cost Analysis Worksheet

APPENDIX B. QUANTIFYING THE BENEFITS OF EXAMPLE PROJECT 1

Project number: NETC 09-03

Project title: Advanced Composite Materials in New England's Transportation Infrastructure: Design, Fabrication, and Installation of ACM Bridge Drain System

Principal Investigator: Dr. Roberto A. Lopez-Anido

Organization: Advanced Structures and Composites Center, University of Maine

Project Start: September 08, 2013

Project End: August 08, 2016

Project Cost: $165,000

Estimated total benefits (5 years): $21.4mil

B/C Ratio: 125:1

The benefits of research project NETC 09-03 was estimated based on inputs from the following sources:

- NETC 09-03 project report *(4)*
- NETC 01-01 project report *(13)*
- Consultation with VHB's Structure/Bridge team
- FHWA Office of Bridges and Structures' National Bridge Inventory *(14)*
- MassDOT's Bride Inspection Management System *(15)*
- CTDOT's Master Bid Item List for 2018 *(16)*

Specifically, the input data was gathered, and assumptions were made as the following:

1) ***General project information:*** all general project information came from the NETC 09-03 project report. *(4)*

2) Benefit category determination:

The benefit categories and subcategories applicable to NETC 09-03 project were determined, and potential data sources for each item were identified based on a thorough review of the NETC 09-03 project report *(4)*, information from the NETC 01-01 project report *(13)*, and consultation with VHB's structure/bridge team. Table 2 provides a summary of the applicable benefit categories and subcategories with potential data sources for each sub-category.

Table 2. Applicable Benefit Categories for Project NETC 09-03

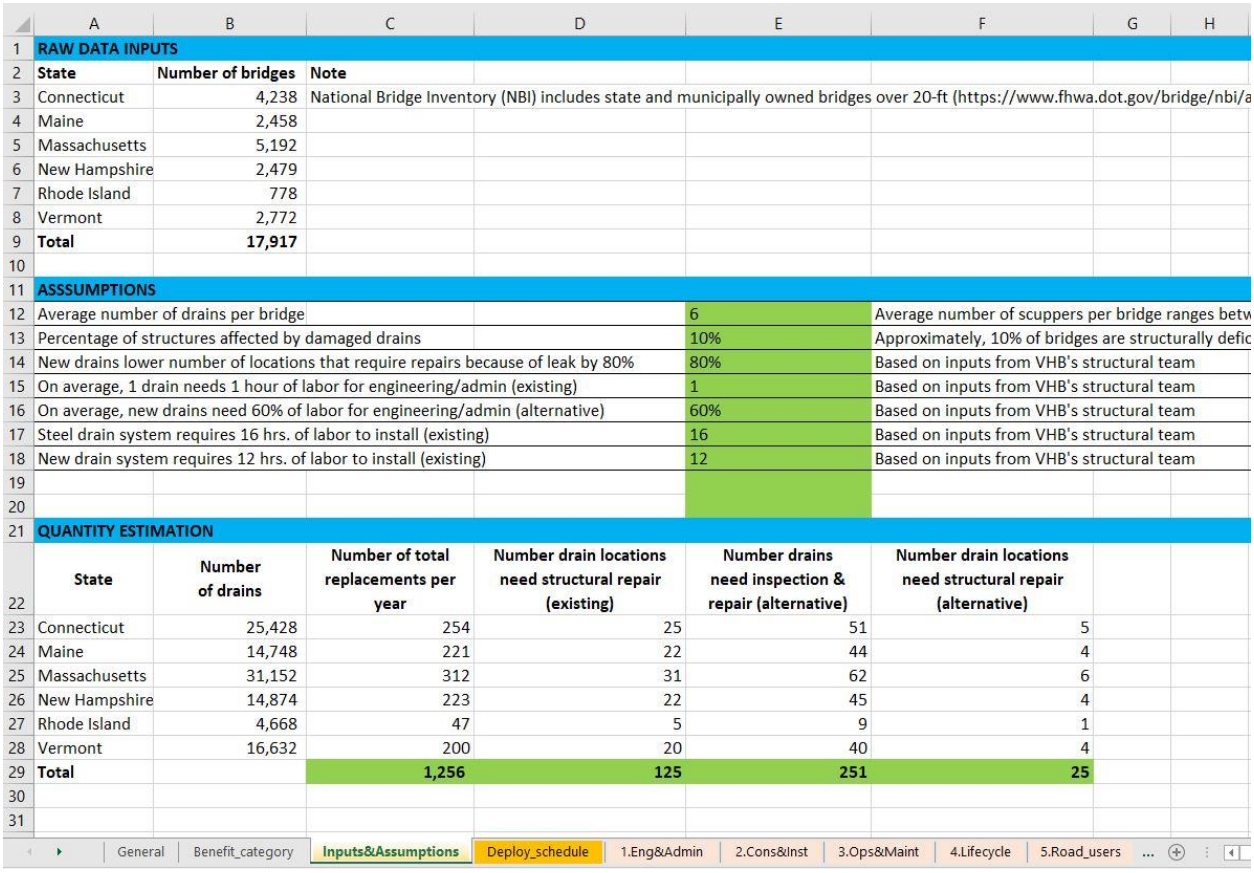
Phase			Category	Sub-Category/Item	Narratives of change/benefits	Data sources/Note
1	2	3				
X			Engineering & administrative costs	Engineering & administrative costs	Standardized specifications, lower engineering, planning and paperwork costs	1) NETC 09-03 project report (Lopez-Anido & Goslin) 2) Inputs from VHB's structure/bridge team
	X		Construction Costs	Direct labor costs	light weight, easier installation, lower labor costs	1) NETC 09-03 project report (Lopez-Anido & Goslin) 2) NETC 01-01 project report (Brena et al.) 3) Inputs from VHB's structure/bridge team
	X			Material & Equipment costs	Higher initial purchase price; light weight, easier installation, lower material & equipment costs	1) NETC 09-03 project report (Lopez-Anido & Goslin) 2) CTDOT Master Bid Item List for 2018 3) Inputs from VHB's structure/bridge team
		X	Operation & Maintenance Costs	Direct labor costs	Resistant to de-icing salt, lower operation and maintenance costs, including to maintain/repair bridge structures (beam, bearing)	1) NETC 09-03 project report (Lopez-Anido & Goslin) 2) NETC 01-01 project report (Brena et al.) 3) Inputs from VHB's structure/bridge team
		X		Material & Equipment costs	Resistant to de-icing salt, lower operation and maintenance costs, including to maintain/repair bridge structures (beam, bearing)	1) NETC 09-03 project report (Lopez-Anido & Goslin) 2) NETC 01-01 project report (Brena et al.) 3) Inputs from VHB's structure/bridge team
X	X	X	Lifecycle Costs	Lifecycle costs	ACM drains have longer lifecycle	1) NETC 09-03 project report (Lopez-Anido & Goslin) 2) Inputs from VHB's structure/bridge team

Phase			Category	Sub-Category/Item	Narratives of change/benefits	Data sources/Note
1	2	3				
			Road User Costs	Road user costs	No change	N/A
			Safety costs	Safety costs	No change	N/A
			Environmental costs	Direct labor costs	No change	N/A
				Material & Equipment costs	No change	N/A
				Emission & Pollution Costs	No change	N/A
			Risk management costs	Risk management costs	No change	N/A
			Others	Others	N/A	N/A

3) Inputs and Assumptions

- Number of bridges: Number of bridges throughout New England states was obtained from FHWA's National Bridge Inventory *(13).* The number of bridges was used to estimate the total number of drains.
- Average number of drains per bridge: This is an assumption made based on inputs from VHB's structure/bridge team. On average, each bridge has 4 to 8 drains. We assumed 6 drains per bridge for the calculation.
- Percentage of structures affected by damaged drains: This is an assumption based on inputs from VHB's structure/bridge team with information from MassDOT's Bridge Inspection Management System *(15).* On average, about 10 percent of structural elements are assumed to be affected by leak caused by damaged drains. It is also assumed that new ACM drains will reduce these affected locations by 80 percent.
- Average Engineering and Administrative labor requirement: This is an assumption based on inputs from VHB's structure/bridge team. On average, existing bridge drains would need about one hour of labor for engineering and administration while the new ACM drain would cut the labor hours by about 40 percent.
- Labor required to install bridge drains: This is an assumption based on inputs from VHB's structure/bridge team. On average, existing bridge drains would need about 16 labor hours for installing a complete set of drain while the new, lightweight ACM drain would lower this to 12 labor hours.
- Engineering and Management labor rate: This is an assumption based on inputs from VHB's structure/bridge team. It is a assumed the loaded hourly rate for this labor category is 150 dollars for both existing and new ACM drains.
- Drain installation cost: This is an assumption made based on inputs from VHB's structure/bridge team. It is a assumed the loaded hourly rate for this labor category is 100 dollars for both existing and new ACM drains.
- Drain purchase cost: The average purchase prices were obtained from CTDOT Master Bid Item List for 2018 *(16)* with additional inputs from VHB's structure/bridge team.
- Cost of inspection and replacement of damaged drain parts: This is an assumption based on inputs from VHB's structure/bridge team. It is assumed that, on average, the cost of inspecting and replacing damaged parts is 1,000 dollars per drain location.
- Inspection and repair of structures caused by leak: This is an assumption based on inputs from VHB's structure/bridge team. It is assumed that, on average, the cost of inspecting and repairing structural damages (e.g. beam, bearing) caused by leaked drain is 25,000 dollars per drain location.
- Lifecycle assumptions: This is an assumption based on inputs from VHB's structure/bridge team. It is assumed that, on average, the existing drains last 20 years while the new ACM drains last 50 years.

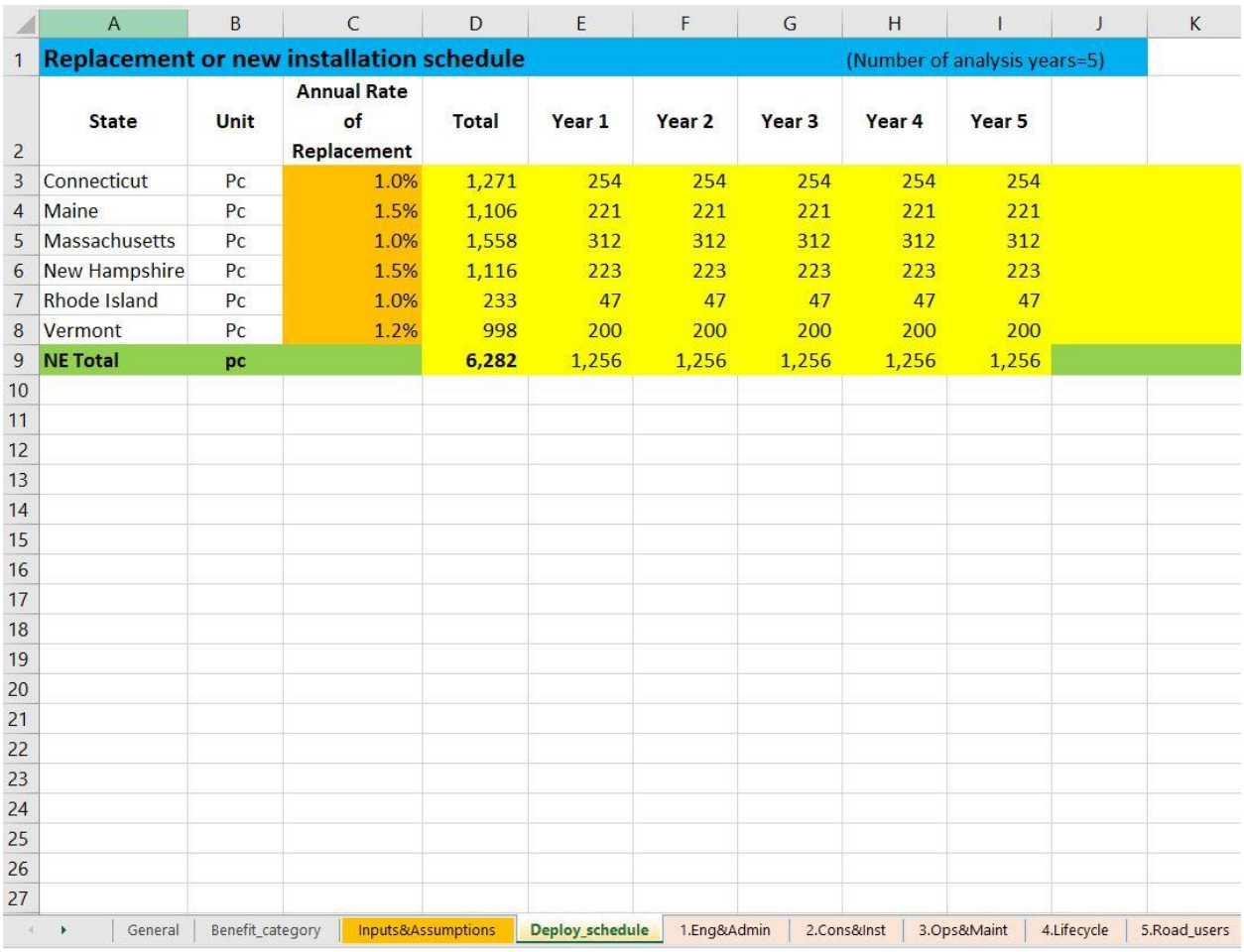
Figure 16 to Figure 21 are the screenshots of the applicable worksheets for example project NETC 09-03.



	A	B	C	D	E	F	G	H
1	**RAW DATA INPUTS**							
2	**State**	**Number of bridges**	**Note**					
3	Connecticut	4,238	National Bridge Inventory (NBI) includes state and municipally owned bridges over 20-ft (https://www.fhwa.dot.gov/bridge/nbi/a					
4	Maine	2,458						
5	Massachusetts	5,192						
6	New Hampshire	2,479						
7	Rhode Island	778						
8	Vermont	2,772						
9	**Total**	**17,917**						
10								
11	**ASSSUMPTIONS**							
12	Average number of drains per bridge				6	Average number of scuppers per bridge ranges betw		
13	Percentage of structures affected by damaged drains				10%	Approximately, 10% of bridges are structurally defic		
14	New drains lower number of locations that require repairs because of leak by 80%				80%	Based on inputs from VHB's structural team		
15	On average, 1 drain needs 1 hour of labor for engineering/admin (existing)				1	Based on inputs from VHB's structural team		
16	On average, new drains need 60% of labor for engineering/admin (alternative)				60%	Based on inputs from VHB's structural team		
17	Steel drain system requires 16 hrs. of labor to install (existing)				16	Based on inputs from VHB's structural team		
18	New drain system requires 12 hrs. of labor to install (existing)				12	Based on inputs from VHB's structural team		
19								
20								
21	**QUANTITY ESTIMATION**							
22	**State**	**Number of drains**	**Number of total replacements per year**	**Number drain locations need structural repair (existing)**	**Number drains need inspection & repair (alternative)**	**Number drain locations need structural repair (alternative)**		
23	Connecticut	25,428	254	25	51	5		
24	Maine	14,748	221	22	44	4		
25	Massachusetts	31,152	312	31	62	6		
26	New Hampshire	14,874	223	22	45	4		
27	Rhode Island	4,668	47	5	9	1		
28	Vermont	16,632	200	20	40	4		
29	**Total**		**1,256**	**125**	**251**	**25**		
30								
31								

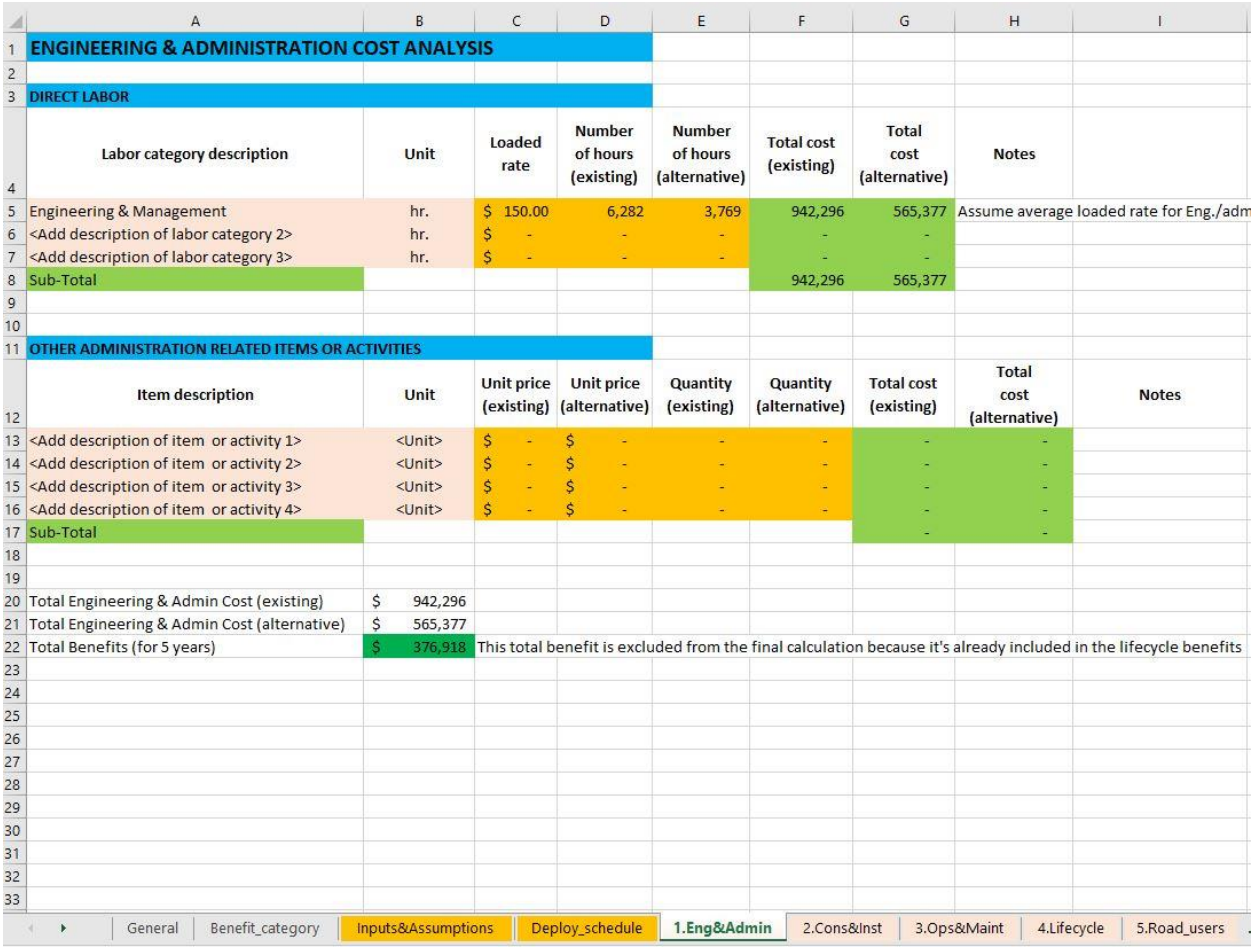
General | Benefit_category | Inputs&Assumptions | Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users ...

Figure 16. Screenshot of Inputs and Assumptions Worksheet for Project NETC 09-03



	A	B	C	D	E	F	G	H	I	J	K
1	**Replacement or new installation schedule**							(Number of analysis years=5)			
2	**State**	**Unit**	**Annual Rate of Replacement**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**		
3	Connecticut	Pc	1.0%	1,271	254	254	254	254	254		
4	Maine	Pc	1.5%	1,106	221	221	221	221	221		
5	Massachusetts	Pc	1.0%	1,558	312	312	312	312	312		
6	New Hampshire	Pc	1.5%	1,116	223	223	223	223	223		
7	Rhode Island	Pc	1.0%	233	47	47	47	47	47		
8	Vermont	Pc	1.2%	998	200	200	200	200	200		
9	**NE Total**	**pc**		**6,282**	1,256	1,256	1,256	1,256	1,256		
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											

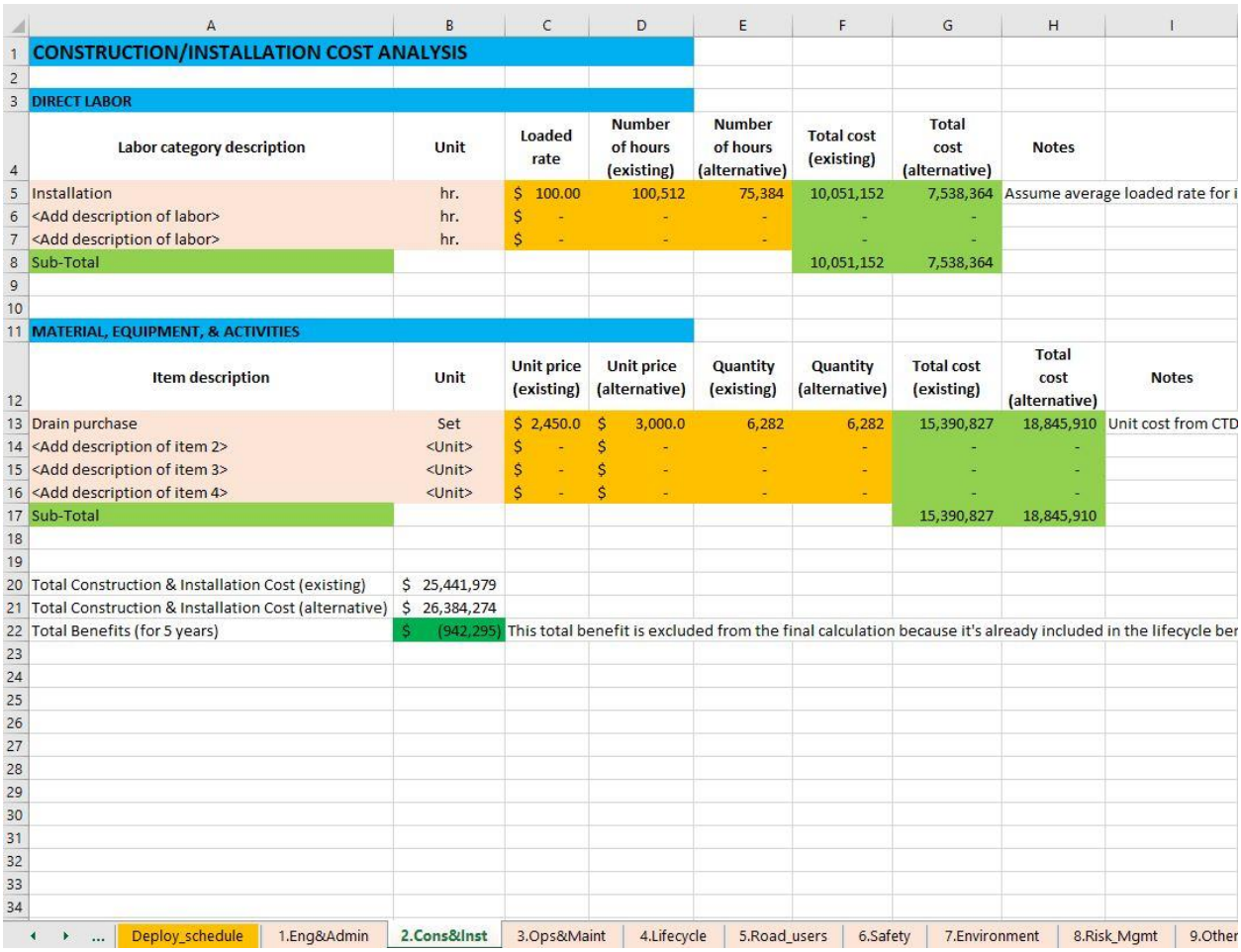
Figure 17. Screenshot of Replacement Schedule Worksheet for Project NETC 09-03



	A	B	C	D	E	F	G	H	I
1	**ENGINEERING & ADMINISTRATION COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	Engineering & Management	hr.	$ 150.00	6,282	3,769	942,296	565,377	Assume average loaded rate for Eng./adm	
6	<Add description of labor category 2>	hr.	$ -	-	-	-	-		
7	<Add description of labor category 3>	hr.	$ -	-	-	-	-		
8	Sub-Total					942,296	565,377		
9									
10									
11	**OTHER ADMINISTRATION RELATED ITEMS OR ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	<Add description of item or activity 1>	<Unit>	$ -	$ -	-	-	-	-	
14	<Add description of item or activity 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item or activity 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item or activity 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						-	-	
18									
19									
20	Total Engineering & Admin Cost (existing)	$ 942,296							
21	Total Engineering & Admin Cost (alternative)	$ 565,377							
22	Total Benefits (for 5 years)	$ 376,918	This total benefit is excluded from the final calculation because it's already included in the lifecycle benefits						
23									
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									

General | Benefit_category | Inputs&Assumptions | Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users

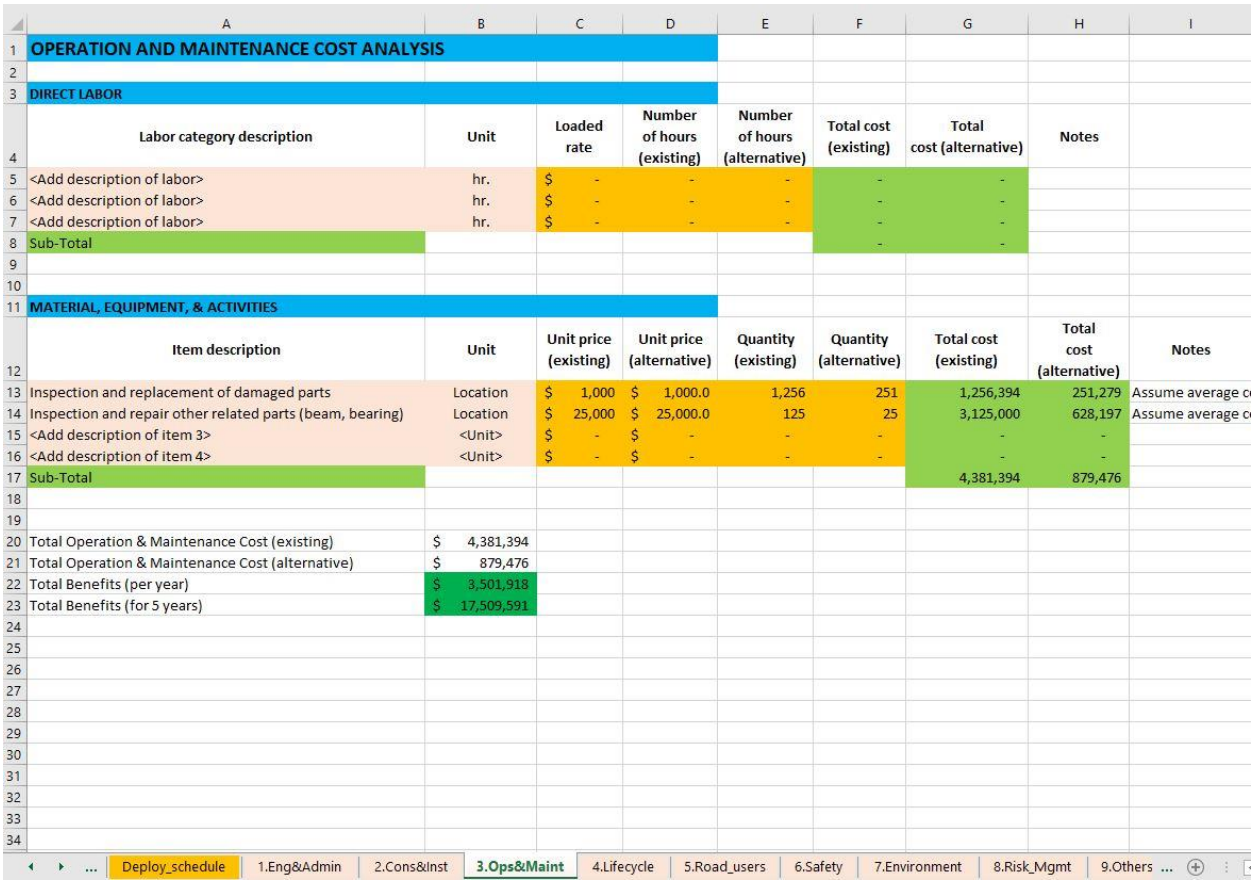
Figure 18. Screenshot of Engineering and Administrative Cost Analysis Worksheet for Project NETC 09-03



	A	B	C	D	E	F	G	H	I
1	**CONSTRUCTION/INSTALLATION COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	Installation	hr.	$ 100.00	100,512	75,384	10,051,152	7,538,364	Assume average loaded rate for i	
6	<Add description of labor>	hr.	$ -	-	-	-	-		
7	<Add description of labor>	hr.	$ -	-	-	-	-		
8	Sub-Total					10,051,152	7,538,364		
9									
10									
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	Drain purchase	Set	$ 2,450.0	$ 3,000.0	6,282	6,282	15,390,827	18,845,910	Unit cost from CTD
14	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						15,390,827	18,845,910	
18									
19									
20	Total Construction & Installation Cost (existing)	$ 25,441,979							
21	Total Construction & Installation Cost (alternative)	$ 26,384,274							
22	Total Benefits (for 5 years)	$ (942,295)	This total benefit is excluded from the final calculation because it's already included in the lifecycle ber						
23									
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									

... | Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | 6.Safety | 7.Environment | 8.Risk_Mgmt | 9.Other

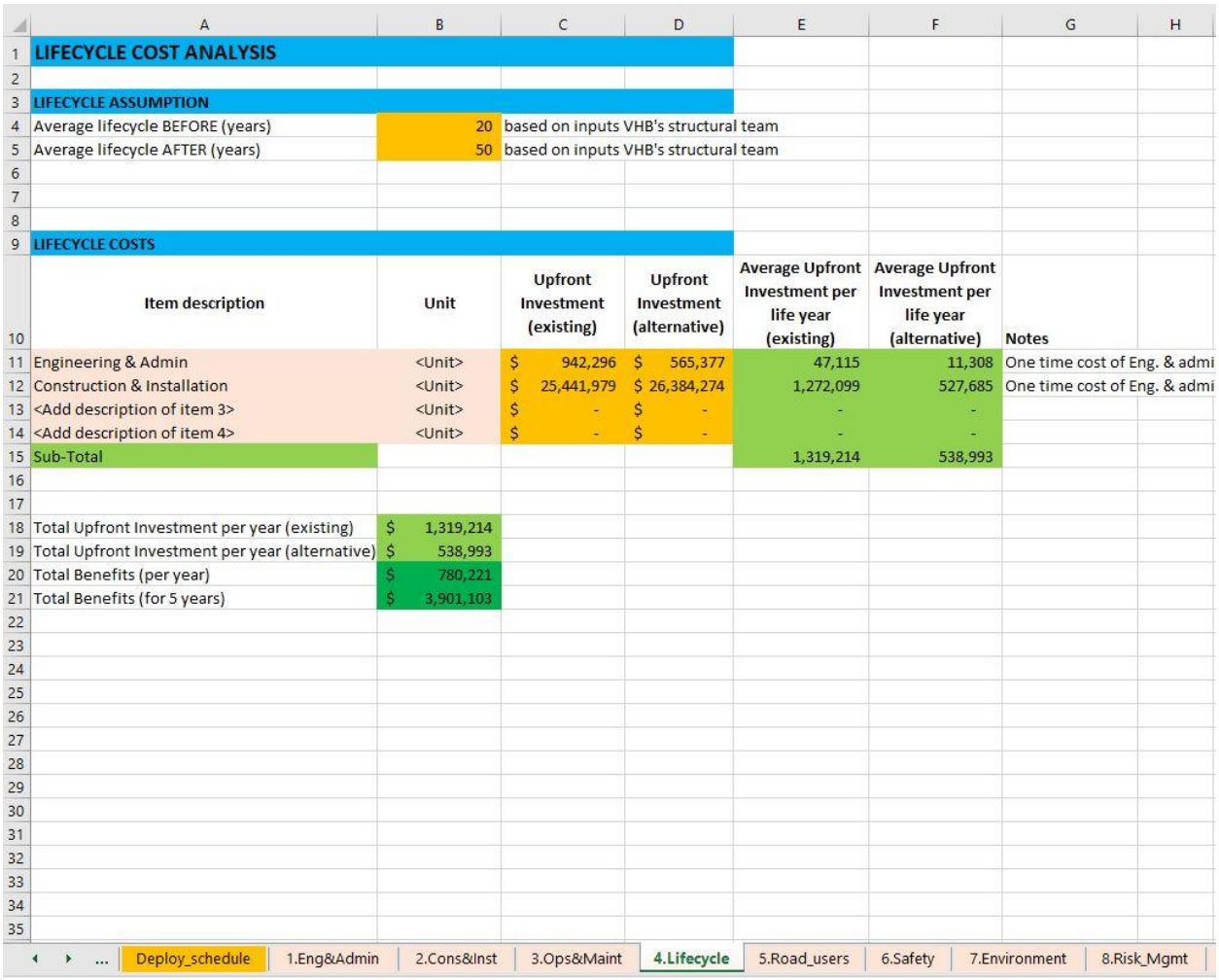
Figure 19. Screenshot of Construction/Installation Cost Analysis Worksheet for Project NETC 09-03



	A	B	C	D	E	F	G	H	I
1	**OPERATION AND MAINTENANCE COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	<Add description of labor>	hr.	$ -	-	-	-	-		
6	<Add description of labor>	hr.	$ -	-	-	-	-		
7	<Add description of labor>	hr.	$ -	-	-	-	-		
8	Sub-Total					-	-		
9									
10									
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	Inspection and replacement of damaged parts	Location	$ 1,000	$ 1,000.0	1,256	251	1,256,394	251,279	Assume average c
14	Inspection and repair other related parts (beam, bearing)	Location	$ 25,000	$ 25,000.0	125	25	3,125,000	628,197	Assume average c
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						4,381,394	879,476	
18									
19									
20	Total Operation & Maintenance Cost (existing)	$ 4,381,394							
21	Total Operation & Maintenance Cost (alternative)	$ 879,476							
22	Total Benefits (per year)	$ 3,501,918							
23	Total Benefits (for 5 years)	$ 17,509,591							
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									

... Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | 6.Safety | 7.Environment | 8.Risk_Mgmt | 9.Others ...

Figure 20. Screenshot of Operation and Maintenance Cost Analysis Worksheet for Project NETC 09-03



	A	B	C	D	E	F	G	H
1	**LIFECYCLE COST ANALYSIS**							
2								
3	**LIFECYCLE ASSUMPTION**							
4	Average lifecycle BEFORE (years)	20	based on inputs VHB's structural team					
5	Average lifecycle AFTER (years)	50	based on inputs VHB's structural team					
6								
7								
8								
9	**LIFECYCLE COSTS**							
10	**Item description**	**Unit**	**Upfront Investment (existing)**	**Upfront Investment (alternative)**	**Average Upfront Investment per life year (existing)**	**Average Upfront Investment per life year (alternative)**	**Notes**	
11	Engineering & Admin	<Unit>	$ 942,296	$ 565,377	47,115	11,308	One time cost of Eng. & admi	
12	Construction & Installation	<Unit>	$ 25,441,979	$ 26,384,274	1,272,099	527,685	One time cost of Eng. & admi	
13	<Add description of item 3>	<Unit>	$ -	$ -	-	-		
14	<Add description of item 4>	<Unit>	$ -	$ -	-	-		
15	Sub-Total				1,319,214	538,993		
16								
17								
18	Total Upfront Investment per year (existing)	$ 1,319,214						
19	Total Upfront Investment per year (alternative)	$ 538,993						
20	Total Benefits (per year)	$ 780,221						
21	Total Benefits (for 5 years)	$ 3,901,103						
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								

... | Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | 6.Safety | 7.Environment | 8.Risk_Mgmt

Figure 21. Screenshot of Lifecycle Cost Analysis Worksheet for Project NETC 09-03

APPENDIX C. QUANTIFYING THE BENEFITS OF EXAMPLE PROJECT 2

Project number: NETC 09-02

Project title: Effective Establishment of Native Grasses on Roadsides in New England

Principal Investigators: Yulia Kuzovkina, Cristian Schulthess, Robert Ricard, Glenn Dreyer

Organization: University of Connecticut & Connecticut College of Arboretum

Project Start: September 08, 2013

Project End: February 02, 2016

Project Cost: $200,000

Estimated total benefits (7 years): US$9mil

B/C Ratio: 43:1

The benefits of research project NETC 09-03 was estimated based on inputs from the following sources and subject matter experts (SMEs):

- The NETC 09-02 project report *(5)*
- Consultation with VHB's environmental and botanical sciences team
- Ernst conservation seeds *(17)*
- George Batchelor, Supervisor of Landscape Design, MassDOT
- Susan Fiedler, State Design Landscape Architect, CTDOT
- Craig Digiammarino, Environmental Program Manager, VTrans
- VTrans State Highway System Mowing Best Management Practices *(18)*
- TxDOT's roadside mowing manual *(19)*
- WIDOT's Highway Maintenance Manual *(20)*
- VTrans' 2018 Fact book and Annual Report (21)
- FHWA Office of Highway Policy Information *(22)*
- US Environmental Protection Agency's The Social Cost of Carbon (11)
- US Government's Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis (12)
- US Energy Information Administration *(23)*

Specifically, the input data was gathered, and assumptions were made as the following:

1) ***General project information:*** all general project information came from the NETC 09-02 project report. *(5)*

2) ***Benefit category determination:***

The benefit categories and subcategories applicable to NETC 09-02 project were determined, and potential data sources for each item were identified based on a thorough review of the NETC 09-02 project report *(5)*, information from the NETC 01-01 project report *(13)*, and

consultation with VHB's environmental and botanical sciences team. Table 3 provides a summary of the applicable benefit categories.

3) ***Inputs and Assumptions***

- Roadway mileage by functional class: roadway mileage information was obtained from FHWA Office of Highway Policy Information. *(21)*
- Mowing width: 30ft mowing width is a common practice and is used in this effort. The information was obtained from VTrans State Highway System Mowing Best Management Practices *(18)*, TxDOT's Roadside mowing guide *(19)*, WIDOT's Highway Maintenance Manual *(20)*.
- Average mowing width by functional class: Assumptions on the average mowing width were made based on inputs from VHB's environmental and botanical sciences team and discussions with SMEs. Under these assumptions, only rural interstates, principal and minor arterials, major and minor collectors are mowed on a regular basis. On average, interstates require 4 full mowing widths for both roadsides and median. Lower classes of roadways need less mowing.
- Average mower's capacity: this is an assumption based on the average mower's cutting width. It is assumed that, on average, a mower can cut one acre of grass for each linear mile it travels. The assumption was made based on information from VTrans State Highway System Mowing Best Management Practices *(18)*, TxDOT's Roadside mowing guide *(19)*, WIDOT's Highway Maintenance Manual *(20)*.
- Average mower's fuel consumption: Based on information from manufacturers of tractors commonly used for roadside mowing (e.g. New Holland, John Deere), average fuel consumption ranges from 4 to 7 miles per gallon (MPG). An average of 6 MPG is assumed for this effort.
- Average CO2 emission: On average a gallon of diesel fuel produces 22.4 lbs of CO2. The information was obtained from the US Energy Information Administration. *(23)*
- Mowing requirement for native grass: This is an assumption based on inputs from VHB's environmental and botanical sciences team and discussions with SMEs. On average, native grass requires about 20 percent less mowing.
- Grass seed prices: prices for both non-native and native grass seeds came from Ernst conservation seeds *(17)* with additional inputs from VHB's environmental and botanical sciences team.
- Average annual mowing/regular maintenance cost per acre: This is an assumption based on inputs from VHB's environmental and botanical sciences team and information provided by VTrans' 2018 Fact book and Annual Report. *(21)*
- Re-seeding/repairing cost: This is an assumption based on inputs from VHB's environmental and botanical sciences team and discussions with SMEs.
- Invasive species treatment cost: This is an assumption based on inputs from VHB's environmental and botanical sciences team and discussions with SMEs.

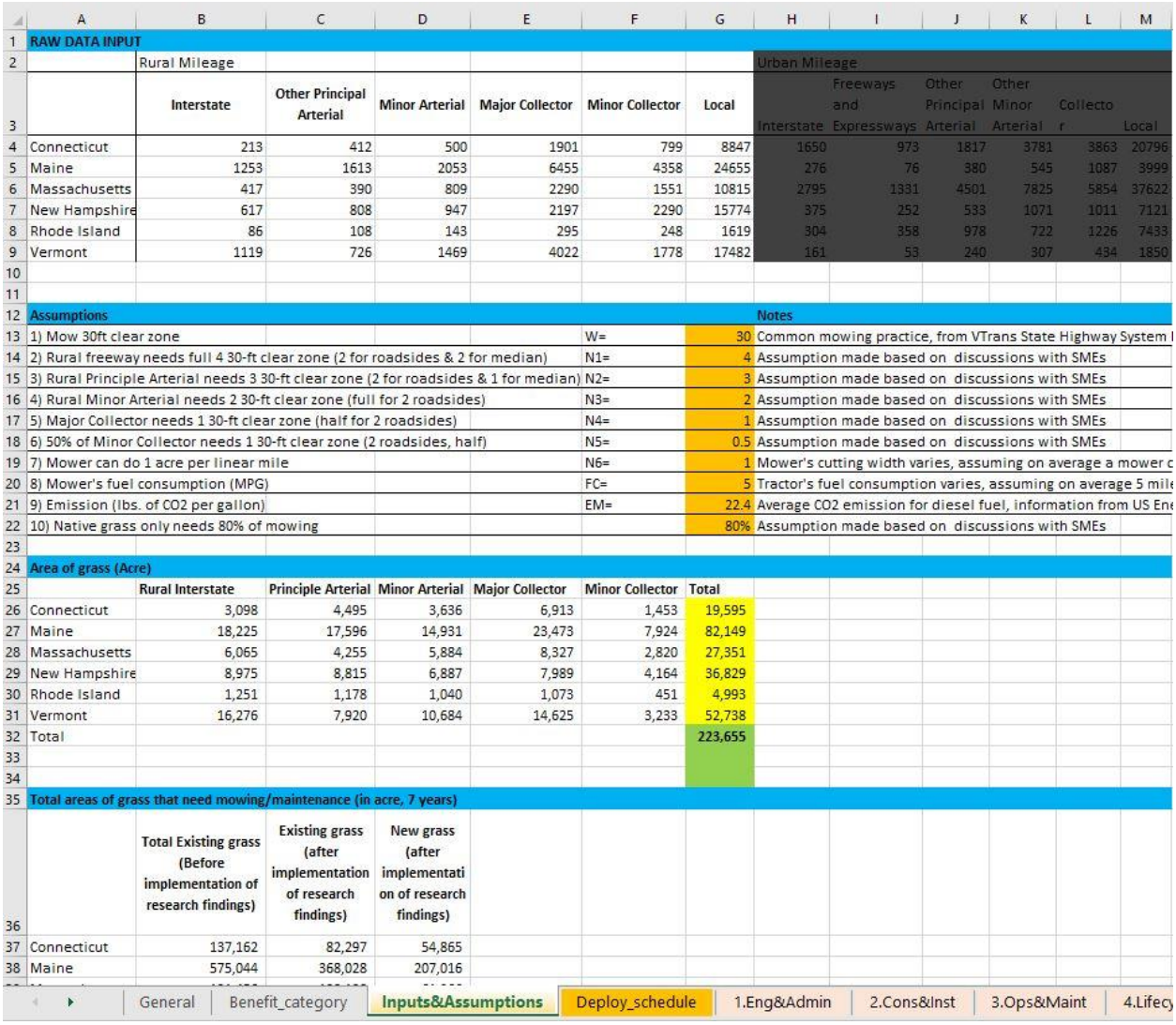
- Standard CO2 emission cost: the comprehensive cost of CO2 emission and information related to emission cost calculation were obtained from US EPA's The Social Cost of Carbon *(11)* and US Government's Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis. *(12)*

Table 3. Applicable Benefit Categories for Project NETC 09-02

Phase			Category	Sub-Category/Item	Narratives of change/benefits	Data sources/Note
1	2	3				
			Engineering & administrative costs	Engineering & administrative costs	No change, about the same for both	Inputs from VHB's environmental and botanical sciences team
	X		Construction/Installation Costs	Seed purchase	Native grass seeds are more expensive	1) Ernst Conservation Seeds 2) George Batchelor, Supervisor of Landscape Design, MassDOT
				Surface/soil treatment	No special treatment of soil required, cost about the same	Inputs from VHB's environmental and botanical sciences team
				Application	hydroseeding, same for both, no change in cost	1) NETC 09-02 project report (Kuzovkina et al.) 2) George Batchelor, Supervisor of Landscape Design, MassDOT
		X	Operation & Maintenance Costs	Mowing/regular maintenance	Native grass requires less frequent mowing, so it costs less	1) NETC 09-02 project report (Kuzovkina et al.) 2) Susan Fiedler, State Design Landscape Architect, CTDOT 3) Craig Digiammarino, Environmental Program Manager, Vtrans 4) VTrans State Highway System Mowing Best Management Practices 5) TxDOT Roadside mowing guide 6) WIDOT's Highway Maintenance Manual
		X		Re-seeding/repairing	Native grass is more resilient and requires less repair and it costs less	1) NETC 09-02 project report (Kuzovkina et al.) 2) Inputs from VHB's environmental and botanical sciences team
		X		Treating invasive species	Native grass requires less or no treatment, so it costs less	Inputs from VHB's environmental and botanical sciences team
			Lifecycle Costs	Lifecycle costs	Native grass lasts longer but this cost is included in the re-seeding/patching costs	Inputs from VHB's environmental and botanical sciences team

Phase			Category	Sub-Category/Item	Narratives of change/benefits	Data sources/Note
1	2	3				
			Road User Costs	Road user costs	No change	N/A
			Safety costs	Safety costs	No change	N/A
			Environmental costs	Direct labor costs	N/A	N/A
				Material & Equipment costs	N/A	N/A
		X		Emission & Pollution Costs	Native grass requires less frequent mowing so less emission	1) US Environmental Protection Agency's the Social Cost of Carbon 2) US Government's Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis 3) US Energy Information Administration
			Risk management costs	Risk management costs	No change	N/A
			Others	Pollination	Both self and cross pollination, pollinator population	Not quantifiable
				Roadside aesthetics and quality of life	Roadside aesthetics and quality of life	Not quantifiable

Figure 22 to Figure 26 are the screenshots of the applicable worksheets for example project NETC 09-02.



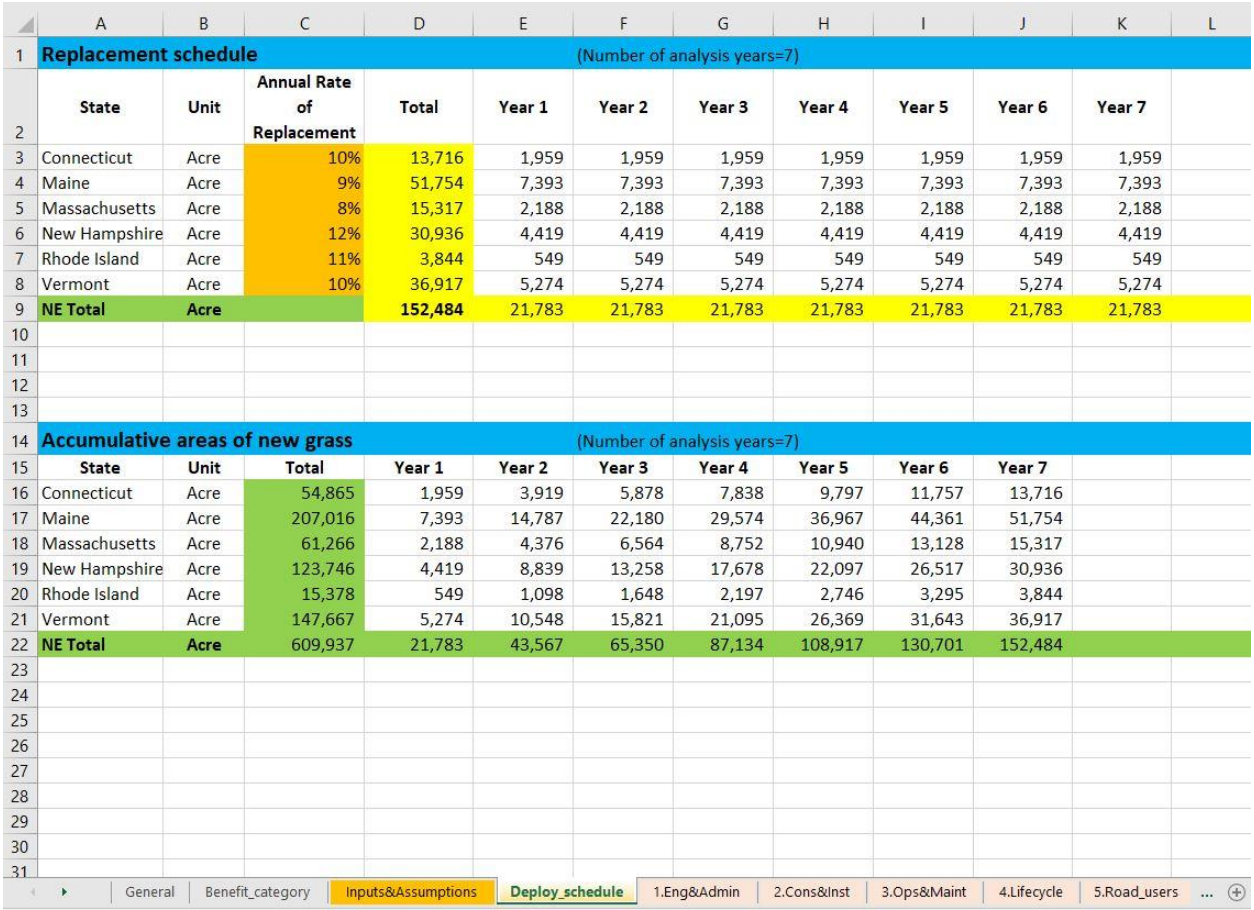
RAW DATA INPUT												
	Rural Mileage						Urban Mileage					
	Interstate	Other Principal Arterial	Minor Arterial	Major Collector	Minor Collector	Local	Interstate	Freeways and Expressways	Other Principal Arterial	Other Minor Arterial	Collector	Local
Connecticut	213	412	500	1901	799	8847	1650	973	1817	3781	3863	20796
Maine	1253	1613	2053	6455	4358	24655	276	76	380	545	1087	3999
Massachusetts	417	390	809	2290	1551	10815	2795	1331	4501	7825	5854	37622
New Hampshire	617	808	947	2197	2290	15774	375	252	533	1071	1011	7121
Rhode Island	86	108	143	295	248	1619	304	358	978	722	1226	7433
Vermont	1119	726	1469	4022	1778	17482	161	53	240	307	434	1850

Assumptions			Notes
1) Mow 30ft clear zone	W=	30	Common mowing practice, from VTrans State Highway System
2) Rural freeway needs full 4 30-ft clear zone (2 for roadsides & 2 for median)	N1=	4	Assumption made based on discussions with SMEs
3) Rural Principle Arterial needs 3 30-ft clear zone (2 for roadsides & 1 for median)	N2=	3	Assumption made based on discussions with SMEs
4) Rural Minor Arterial needs 2 30-ft clear zone (full for 2 roadsides)	N3=	2	Assumption made based on discussions with SMEs
5) Major Collector needs 1 30-ft clear zone (half for 2 roadsides)	N4=	1	Assumption made based on discussions with SMEs
6) 50% of Minor Collector needs 1 30-ft clear zone (2 roadsides, half)	N5=	0.5	Assumption made based on discussions with SMEs
7) Mower can do 1 acre per linear mile	N6=	1	Mower's cutting width varies, assuming on average a mower c
8) Mower's fuel consumption (MPG)	FC=	5	Tractor's fuel consumption varies, assuming on average 5 mil
9) Emission (lbs. of CO2 per gallon)	EM=	22.4	Average CO2 emission for diesel fuel, information from US En
10) Native grass only needs 80% of mowing		80%	Assumption made based on discussions with SMEs

Area of grass (Acre)						
	Rural Interstate	Principle Arterial	Minor Arterial	Major Collector	Minor Collector	Total
Connecticut	3,098	4,495	3,636	6,913	1,453	19,595
Maine	18,225	17,596	14,931	23,473	7,924	82,149
Massachusetts	6,065	4,255	5,884	8,327	2,820	27,351
New Hampshire	8,975	8,815	6,887	7,989	4,164	36,829
Rhode Island	1,251	1,178	1,040	1,073	451	4,993
Vermont	16,276	7,920	10,684	14,625	3,233	52,738
Total						223,655

Total areas of grass that need mowing/maintenance (in acre, 7 years)			
	Total Existing grass (Before implementation of research findings)	Existing grass (after implementation of research findings)	New grass (after implementation of research findings)
Connecticut	137,162	82,297	54,865
Maine	575,044	368,028	207,016

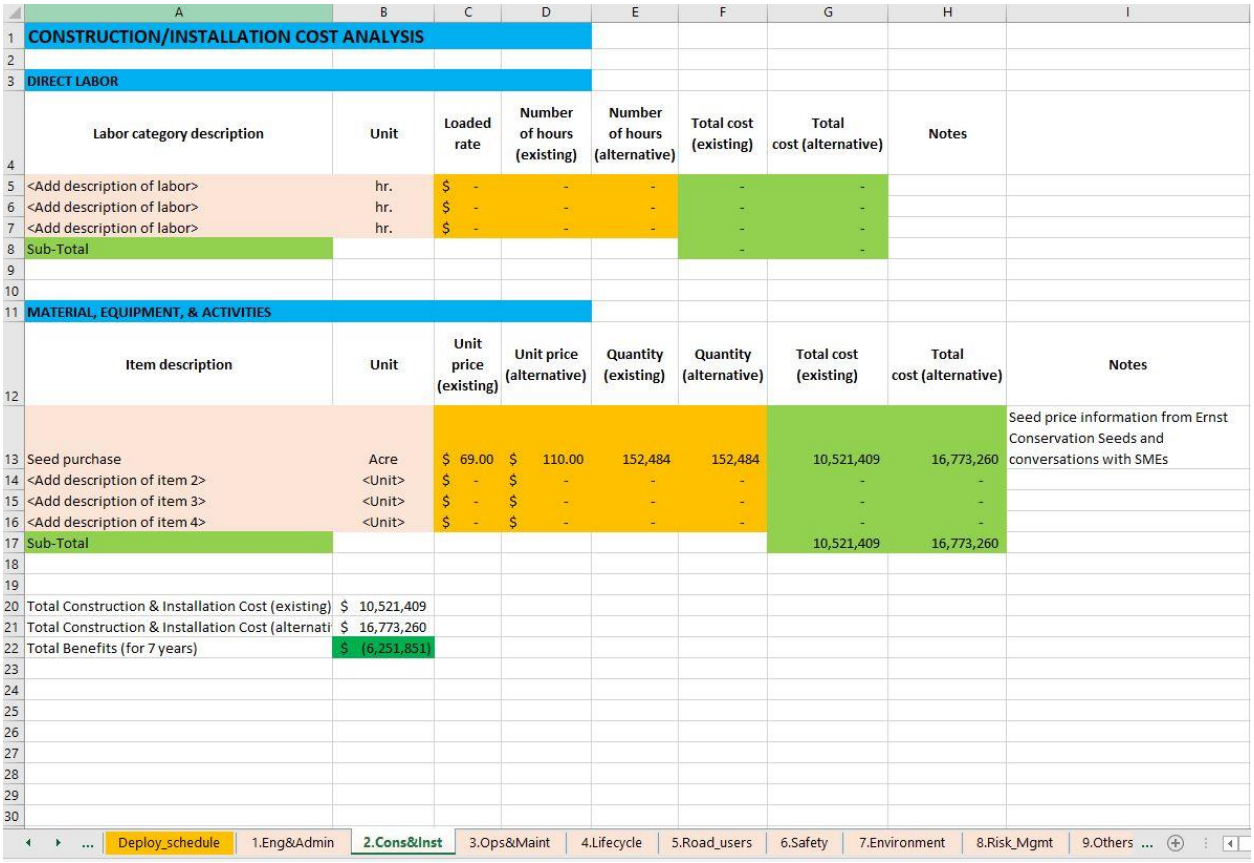
Figure 22. Screenshot of Inputs and Assumptions Worksheet for Project NETC 09-02



	A	B	C	D	E	F	G	H	I	J	K	L
1	**Replacement schedule**					(Number of analysis years=7)						
2	**State**	**Unit**	**Annual Rate of Replacement**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	
3	Connecticut	Acre	10%	13,716	1,959	1,959	1,959	1,959	1,959	1,959	1,959	
4	Maine	Acre	9%	51,754	7,393	7,393	7,393	7,393	7,393	7,393	7,393	
5	Massachusetts	Acre	8%	15,317	2,188	2,188	2,188	2,188	2,188	2,188	2,188	
6	New Hampshire	Acre	12%	30,936	4,419	4,419	4,419	4,419	4,419	4,419	4,419	
7	Rhode Island	Acre	11%	3,844	549	549	549	549	549	549	549	
8	Vermont	Acre	10%	36,917	5,274	5,274	5,274	5,274	5,274	5,274	5,274	
9	**NE Total**	**Acre**		**152,484**	21,783	21,783	21,783	21,783	21,783	21,783	21,783	
10												
11												
12												
13												
14	**Accumulative areas of new grass**					(Number of analysis years=7)						
15	**State**	**Unit**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**		
16	Connecticut	Acre	54,865	1,959	3,919	5,878	7,838	9,797	11,757	13,716		
17	Maine	Acre	207,016	7,393	14,787	22,180	29,574	36,967	44,361	51,754		
18	Massachusetts	Acre	61,266	2,188	4,376	6,564	8,752	10,940	13,128	15,317		
19	New Hampshire	Acre	123,746	4,419	8,839	13,258	17,678	22,097	26,517	30,936		
20	Rhode Island	Acre	15,378	549	1,098	1,648	2,197	2,746	3,295	3,844		
21	Vermont	Acre	147,667	5,274	10,548	15,821	21,095	26,369	31,643	36,917		
22	**NE Total**	**Acre**	609,937	21,783	43,567	65,350	87,134	108,917	130,701	152,484		
23												
24												
25												
26												
27												
28												
29												
30												
31												

General | Benefit_category | Inputs&Assumptions | Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | ...

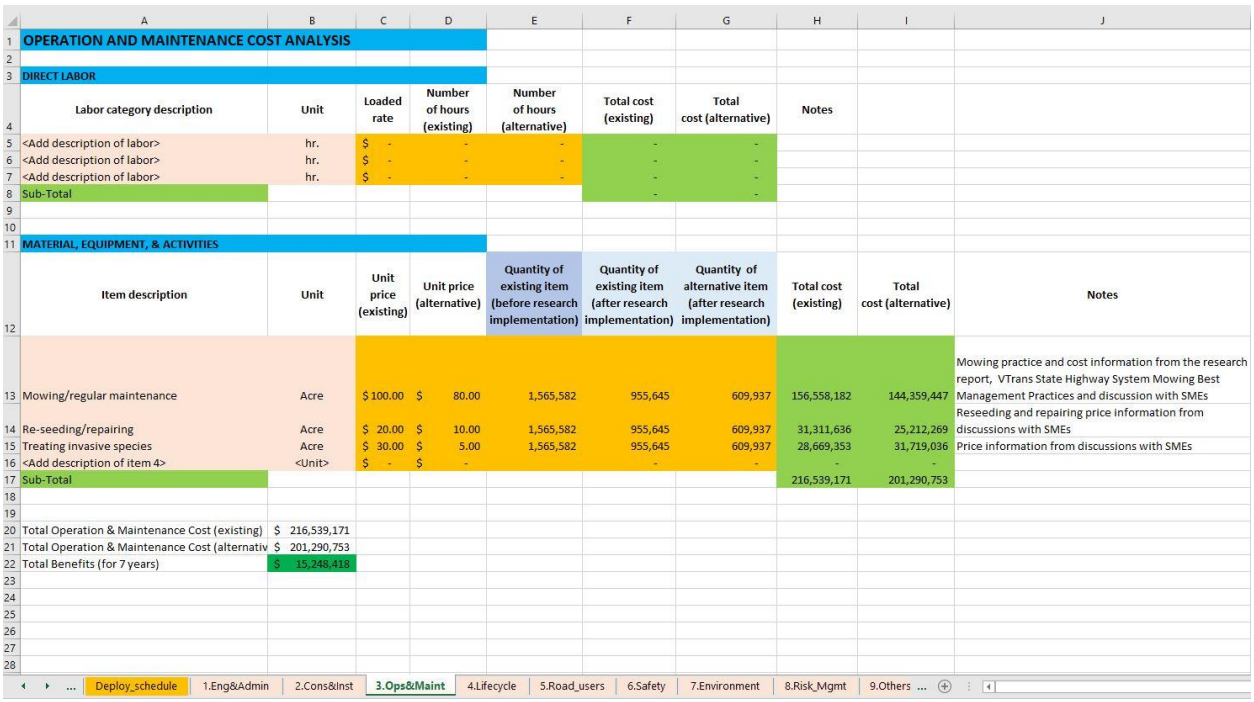
Figure 23. Screenshot of Implementation Schedule Worksheet for Project NETC 09-02



	A	B	C	D	E	F	G	H	I
1	**CONSTRUCTION/INSTALLATION COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	<Add description of labor>	hr.	$ -	-	-	-	-		
6	<Add description of labor>	hr.	$ -	-	-	-	-		
7	<Add description of labor>	hr.	$ -	-	-	-	-		
8	Sub-Total					-	-		
9									
10									
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	Seed purchase	Acre	$ 69.00	$ 110.00	152,484	152,484	10,521,409	16,773,260	Seed price information from Ernst Conservation Seeds and conversations with SMEs
14	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Sub-Total						10,521,409	16,773,260	
18									
19									
20	Total Construction & Installation Cost (existing)	$ 10,521,409							
21	Total Construction & Installation Cost (alternati	$ 16,773,260							
22	Total Benefits (for 7 years)	$ (6,251,851)							
23									
24									
25									
26									
27									
28									
29									
30									

... Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | 6.Safety | 7.Environment | 8.Risk_Mgmt | 9.Others ...

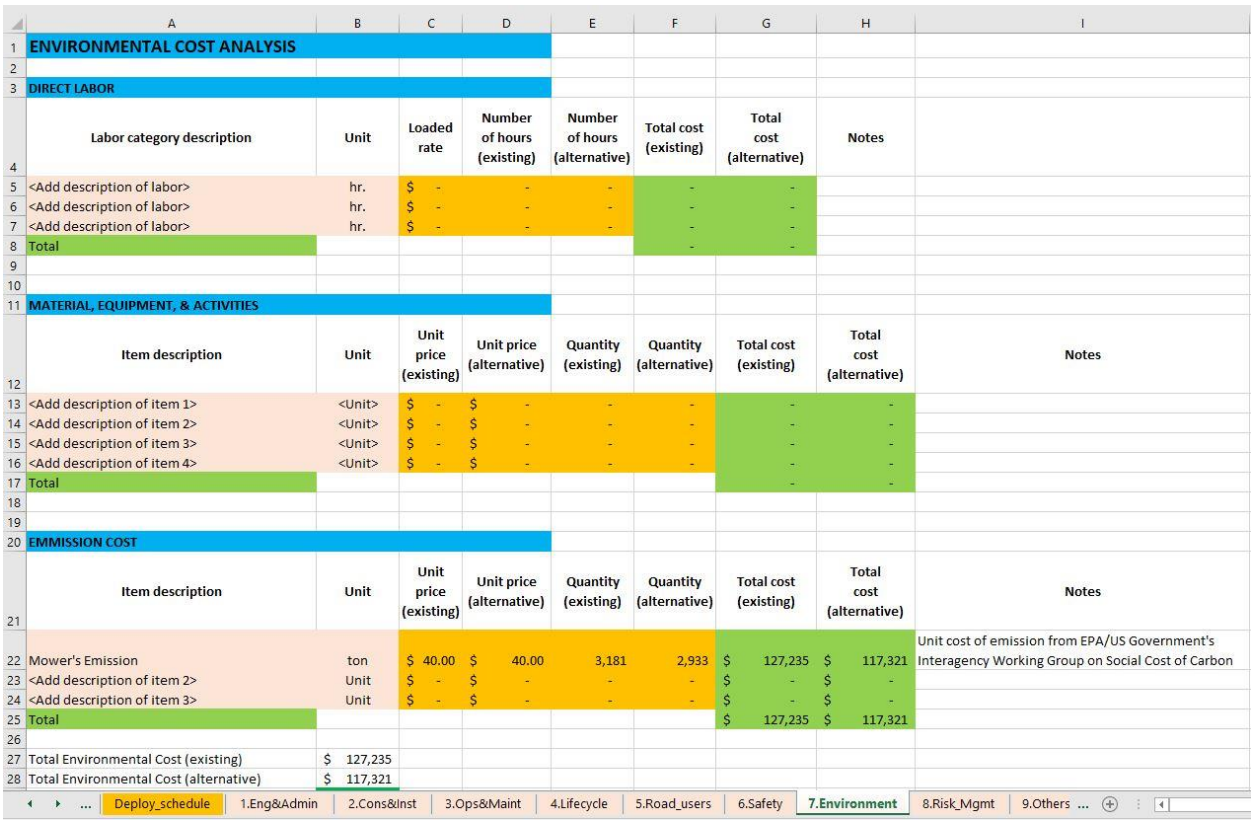
Figure 24. Screenshot of Construction/Installation Cost Analysis Worksheet for Project NETC 09-02



	A	B	C	D	E	F	G	H	I	J
1	**OPERATION AND MAINTENANCE COST ANALYSIS**									
2										
3	**DIRECT LABOR**									
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**		
5	<Add description of labor>	hr.	$ -	-	-	-	-			
6	<Add description of labor>	hr.	$ -	-	-	-	-			
7	<Add description of labor>	hr.	$ -	-	-	-	-			
8	Sub-Total					-	-			
9										
10										
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**									
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity of existing item (before research implementation)**	**Quantity of existing item (after research implementation)**	**Quantity of alternative item (after research implementation)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	Mowing/regular maintenance	Acre	$ 100.00	$ 80.00	1,565,582	955,645	609,937	156,558,182	144,359,447	Mowing practice and cost information from the research report, VTrans State Highway System Mowing Best Management Practices and discussion with SMEs
14	Re-seeding/repairing	Acre	$ 20.00	$ 10.00	1,565,582	955,645	609,937	31,311,636	25,212,269	Reseeding and repairing price information from discussions with SMEs
15	Treating invasive species	Acre	$ 30.00	$ 5.00	1,565,582	955,645	609,937	28,669,353	31,719,036	Price information from discussions with SMEs
16	<Add description of item 4>	<Unit>	$ -	$ -		-	-	-	-	
17	Sub-Total							216,539,171	201,290,753	
18										
19										
20	Total Operation & Maintenance Cost (existing)	$ 216,539,171								
21	Total Operation & Maintenance Cost (alternativ	$ 201,290,753								
22	Total Benefits (for 7 years)	$ 15,248,418								
23										
24										
25										
26										
27										
28										

Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | 6.Safety | 7.Environment | 8.Risk_Mgmt | 9.Others

Figure 25. Screenshot of Operation and Maintenance Cost Analysis Worksheet for Project NETC 09-02



	A	B	C	D	E	F	G	H	I
1	**ENVIRONMENTAL COST ANALYSIS**								
2									
3	**DIRECT LABOR**								
4	**Labor category description**	**Unit**	**Loaded rate**	**Number of hours (existing)**	**Number of hours (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**	
5	<Add description of labor>	hr.	$ -	-	-	-	-		
6	<Add description of labor>	hr.	$ -	-	-	-	-		
7	<Add description of labor>	hr.	$ -	-	-	-	-		
8	Total					-	-		
9									
10									
11	**MATERIAL, EQUIPMENT, & ACTIVITIES**								
12	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
13	<Add description of item 1>	<Unit>	$ -	$ -	-	-	-	-	
14	<Add description of item 2>	<Unit>	$ -	$ -	-	-	-	-	
15	<Add description of item 3>	<Unit>	$ -	$ -	-	-	-	-	
16	<Add description of item 4>	<Unit>	$ -	$ -	-	-	-	-	
17	Total						-	-	
18									
19									
20	**EMMISSION COST**								
21	**Item description**	**Unit**	**Unit price (existing)**	**Unit price (alternative)**	**Quantity (existing)**	**Quantity (alternative)**	**Total cost (existing)**	**Total cost (alternative)**	**Notes**
22	Mower's Emission	ton	$ 40.00	$ 40.00	3,181	2,933	$ 127,235	$ 117,321	Unit cost of emission from EPA/US Government's Interagency Working Group on Social Cost of Carbon
23	<Add description of item 2>	Unit	$ -	$ -	-	-	$ -	$ -	
24	<Add description of item 3>	Unit	$ -	$ -	-	-	$ -	$ -	
25	Total						$ 127,235	$ 117,321	
26									
27	Total Environmental Cost (existing)	$ 127,235							
28	Total Environmental Cost (alternative)	$ 117,321							

Deploy_schedule | 1.Eng&Admin | 2.Cons&Inst | 3.Ops&Maint | 4.Lifecycle | 5.Road_users | 6.Safety | 7.Environment | 8.Risk_Mgmt | 9.Others

Figure 26. Screenshot of Environmental Cost Analysis Worksheet for Project NETC 09-02

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