Final Report

Financial Achievability of Florida Department of Transportation Research Projects

Florida Department of Transportation Research Project

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16. Abstract The Florida State University Center for Insurance Research conducted research and developed a financial analysis framework that will allow the Florida Department of Transportation (FDOT) Research Center to better assess research projects. The framework developed recognizes that the research process contains multiple stages of decision-making, and details the information that is needed at each stage. Cost and benefit data must be collected and analyzed in order to decide whether new projects should be pursued, whether current projects should be continued, and whether the results of research projects should be implemented. The framework is described as it applies to each step in the research process: identifying potential research projects, evaluating research proposals, monitoring ongoing research projects, and evaluating final research reports. It also considers the decision to implement the research and its potential effects on employees. We illustrate the application of the framework using a family of FDOT research projects involving the development of the Multi-Purpose Survey Vehicle (MPSV) for evaluation of Florida roadways. While the framework is flexible, and can be adapted for use in evaluating different types of projects, some judgment will be required when considering the specific inputs to the model. Successful implementation of the framework within FDOT will require focused data collection efforts with emphasis on identifying the potential net benefits of research projects.		

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EXECUTIVE SUMMARY

The Florida State University Center for Insurance Research conducted research and developed a financial analysis framework that will allow the Florida Department of Transportation (FDOT) Research Center to better assess research projects. The framework developed recognizes that the research process contains multiple stages of decision-making, and details the information that is needed at each stage. Cost and benefit data must be collected and analyzed in order to decide whether new projects should be pursued, whether current projects should be continued, and whether the results of research projects should be implemented. The framework is described as it applies to each step in the research process: identifying potential research projects, evaluating research proposals, monitoring ongoing research projects, and evaluating final research reports. It also considers the decision to implement the research and its potential effects on employees. We illustrate the application of the framework using a family of FDOT research projects involving the development of the Multi-Purpose Survey Vehicle (MPSV) for evaluation of Florida roadways. This illustration allows us to explain each step in the framework using actual data obtained from the research reports, from other sources within FDOT, or from external sources. We identify areas in which data on costs and benefits that would be useful to the decision process were not readily available. While the framework is flexible, and can be adapted for use in evaluating different types of projects, some judgment will be required when considering the specific inputs to the model. Successful implementation of the framework within FDOT will require focused data collection efforts with emphasis on identifying the potential net benefits of research projects.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The purpose of this project is to develop a financial analysis framework that will allow the Florida Department of Transportation (FDOT) to better assess research proposals and completed projects. As with any economics-based decision framework, the successful application of this framework requires the identification, capture and valuation of the relevant cost and benefit data. We develop a financial analysis framework using a completed FDOT series of projects as a guide. These projects, which involve the development of the Multi-Purpose Survey Vehicle (MPSV) to analyze road surfaces, subsequently are used to illustrate the application of the framework.

In discussions with project managers during the initial phases of the project, it is apparent that the process of identifying and quantifying (or monetizing) benefits is not currently embedded in the FDOT decision process in the same manner as are costs. Even though many costs currently are more thoroughly captured and specified, it also is clear that capturing additional cost data at the proposal/project level (e.g., project manager time) would help to better inform the evaluation process (proposal through completed project). Improvements in identifying and quantifying cost and benefit data should enhance both the quality of the decisions to implement projects and the effectiveness of completed projects. As such, one of the objectives of this task and the overall report is to illustrate the benefit identification and collection process based on the MPSV projects and the potential sources for this type of data, assisting in the development of an initial "guidebook" of data sources.

In this project, we consider five possible measures commonly used to evaluate outcomes or performance. Each of these could serve as the basis for determining individual proposal acceptability or relative performance in a competitive proposal selection process. Several of these measures use quantitative cost and benefit data while others use qualitative performance measures either in total (e.g., Quality/Performance) or in part (Cost-Effectiveness Analysis). Collectively, these measures provide the tools that can be applied across a wide range of situations. Our framework considers and incorporates fundamental aspects of all five measures into an integrated decision tool.

The measures we employ include:

1. Cost-Effectiveness Analysis (CEA) – This analysis considers the lifecycle costs of achieving particular outcomes in using the status quo approaches of not implementing a research program versus employing the research. CEA is a quasi-numerical method, where the numerator in the ratio is monetized costs and the denominator, quality, such as lives saved, is not monetized. Thus, CEA uses a ratio in which the lower the ratio the "better" the outcome. Formulaically, CEA is denoted as

$$\frac{C_a - C_b}{Q_a - Q_b} = \frac{\Delta C}{\Delta Q}$$

   where C_a and C_b are the costs of options A and B, respectively, and Q_a and Q_b are the qualities of options A and B, respectively.

2. Cost Benefit Analysis (CBA) – Cost benefit analysis considers all costs and benefits in monetary units as opposed to any units of quality as in CEA. In cost benefit analysis, anything with a positive net benefit is considered a "better" outcome.

3. Return on Investment (ROI) – ROI is a performance measure used to evaluate the economic efficiency of an investment or to compare the efficiency of a number of different investments. In ROI, the benefit (return) of an investment is divided by the cost of the investment; the result is expressed as a percentage or a ratio. The higher the ROI the "better" the investment. ROI is denoted as:

$$ROI = \frac{(Gain\ from\ Investment - Cost\ of\ investment)}{Cost\ of\ Investment}$$

4. Quality/Performance – One of the goals of this study is to examine the likelihood of maintaining or increasing quality standards using the implemented research. Measurement of quality or performance focuses on the variation in performance (e.g., worker satisfaction) between planned and actual activities, variation in costs, and the change in costs over the years.

5. Management Costs – This criterion examines the types of managerial changes (both positive and negative) that are likely to be experienced under the implementation of a research project.

We recognize that the process of identifying, collecting, and quantifying cost and benefit data has its own costs (e.g., search time, data management) and these costs will vary based on the type of research project. All proposed research projects have their own costs and benefits and while most of these can be captured and monetized; there are some that may not be easily identified. Also, some aspects of a research project may result in improvements in efficiencies and job satisfaction. Although correlated, efficiency measures are easily monetized while measures that capture a perception or feeling can be more difficult to translate into monetary terms. Further, each research proposal to FDOT could/should in part be evaluated at a higher level against the stated mission of FDOT which is to "provide a safe transportation system that ensures the mobility of people and goods, enhances economic prosperity and preserves the quality of our environment and communities." The challenge here is to determine the benefits that are relevant at this higher level and the weights that should be applied to these benefits to make them useful and relevant to the proposals under consideration. For example, a research proposal states that the research will make for a safer transportation system. At one extreme, fully weighting the benefit would suggest that all projects should be pursued that demonstrate any improvement in transportation safety. This is not feasible or practical in a world with limited resources; however, to ignore the benefit that improved transportation safety provides is also problematic.

It also is important to recognize that any project has some degree of uncertainty regarding the likelihood of successfully satisfying the project objectives. Given the very nature of the questions being asked in research projects, uncertainty is firmly embedded in the research process and it should therefore be considered through all phases of the evaluation process. Decisions to pursue, continue, or reject research projects should be informed to the greatest extent possible so as to minimize this uncertainty on a cost-effective basis. As such, the initial framework for this project was developed in the context of decision-making under uncertainty.

Additionally, it is important to recognize that while the derivation of the framework has a theoretical grounding, the application of the framework is technical only as it relates to data necessary for the framework to function properly and to the weights that would be applied to the costs and benefits. Both of these require some professional expertise and judgment, at a level that would be expected of a project manager.

This report is a synthesis of all work performed in developing our final proposed framework for use in analyzing FDOT research activities. Per our initial proposal, we completed a variety of intermediary activities which are explained, in detail, in the four task reports submitted previously. Each step yielded important information for development of the model and the subsequent trial of the model on a specific set of FDOT research projects. The completed tasks are listed below with a brief summary of each.

Task 1: Identify data needs. Evaluate available data as compared to data needed to accomplish proposed financial framework. Provide initial assessment of potential limitations of financial analyses based on identified data.

In the initial phase of the project, we had a series of meetings and conference calls with FDOT Research Center management, reviewed proposals and final reports for several different research project areas (e.g., concrete structures, pavement), and held four conference calls with FDOT project managers. We had two main objectives in arranging these calls. Our first objective was to learn about the operations of the Research Center so that we had a clear understanding of the environment in which our decision-making framework would be applied. The project managers and Research Center staff explained their current decision-making process and we were able to develop a better understanding of the focus and breadth of projects as well as the problems and challenges faced by project managers. The second objective was to understand the types of cost and benefit data that might be available. Here, we did not ask for specific variables that could be used in an analytic framework (e.g., salaries of FDOT staff). Rather, we asked for general information about whether certain types of data were collected and if so, where this data might be obtained. In these discussions, we were able to identify the areas where data were likely to be available, determine the feasibility of acquiring or accessing necessary information from within FDOT, ascertain project managers' use of performance metrics, and gain a better understanding of how managerial costs and overhead are allocated across projects. The project managers identified some sources of more detailed information (i.e., contacts in human resources), and we discussed with FDOT personnel our intent to identify proxy variables where actual data might not be available.

Task 2: Develop data collection process. Provide a data collection process for data needed to conduct financial achievability analysis using the derived framework. Provide assessment of the feasibility of data collection including assessment of the identified immediately available data. Include a time/benefit assessment of the data collection process.

The second task involved furthering our understanding of data used in the current process and data available for use in a new framework. We captured data from within FDOT and from external sources while concurrently developing the decision-making framework. Besides reporting on the development of the initial framework, we provided a taxonomy of costs and benefits, which is provided in the next section of this report.

Task 3: Develop management costs process. Researchers will gather all information to identify and assess management costs as defined in the Introduction

Our focus for Task 3 was to assess FDOT's internal management costs. In order to determine the extent of management cost data that is readily available (i.e., within FDOT's current data reporting systems), we held conversations with project managers. In these conversations, we asked about the time that is spent on all phases of a research project. Since managers are often involved in multiple projects simultaneously and have projects beginning and ending at different points during the year, it is not surprising that project managers' responses varied substantially. We decided to conduct a broader survey to collect information from a larger sample of project managers to obtain information about the time spent on various stages of research projects. The survey results are presented in more detail later in this report.

Task 4: *Evaluate. Researchers will trial the developed framework on one completed FDOT research project, contingent on available data. Researchers will then evaluate the strengths, weaknesses, and challenges associated with the proposed framework, data gathering, and collection processes as they relate to further financial achievability analysis using the framework in FDOT research projects.*

In our fourth task report, we present our completed theoretical framework and show how it can be applied to the family of research projects pertaining to the MPSV. The report contains four main components: our theoretical framework for decision-making, an application of the framework to the MPSV project, a discussion of data collection process, and a discussion of the issues and challenges of the model. Each of these components is discussed in more detail in the following sections.

The report proceeds as follows. Section 2 presents the theoretical development of our framework for decision-making. Section 3 contains information about our data collection process and includes a discussion of the results of the project manager survey. In section 4, we apply the framework to the MPSV research projects and in section 5 we discuss the issues and challenges associated with applying the model to FDOT research projects.

2. THEORETICAL DETERMINANTS OF THE FRAMEWORK FOR RESEARCH AND DEVELOPMENT

In this section, we provide a theoretical framework for assessing research and development projects integrating multiple analysis techniques and measures. There are costs and benefits of research projects present in both the research phase (i.e., proposal to completed research) and implementation phase (i.e., how the research is adopted by the current labor force and/or user). Additionally, both phases have a physical and psychic dimension.

2.1 Taxonomy of Costs and Benefits

In Figure 1, we introduce a taxonomy of the four primary types of costs categorized either as physical/psychic or research/ implementation. We define research costs as those costs that occur before the project is implemented. Once the research has been completed, implementation costs and benefits are then a function of the level of implementation. Physical costs are usually well known in advance and are normally accurately predicted. For example, costs of materials, labor, and transportation will usually stay within a known range and one would expect these costs to be accurately estimated. For research proposals, these costs would typically include payments made to the researchers (including graduate students), travel costs, materials/capital equipment, and publication costs.

Psychic costs are typically more difficult to predict or to quantify. As research proposals are often related to some type of application in the field, the implementation phase of the research project is where psychic costs are likely to occur. Estimating the psychic costs of research is further complicated by the fact that it is not always clear whether the implementation of the research will lead to further costs, produce benefits, or perhaps result in both. As an example, the

implementation of innovation that automates a dangerous task produces benefits in terms of fewer workers exposed to a dangerous situation and a reduction in worker injuries. If the innovation also leads to a reduction in the workforce, its implementation results in a benefit in terms of lower labor costs. However, besides reducing labor costs, the innovation can also impose additional costs (physical and psychic) related to termination costs and reductions in employee morale. Additionally, innovation may result in an increase in the workload. This increase in workload is most likely to take place over the short-run as workers are forced to adapt to the new technology while also fulfilling their normal duties. Even temporary increases in the workload may breed contempt for the new procedures and implementation. In the aggregate, the physical workforce reduction can lead to an overall cost, when consideration is given to the psychic costs, although the resizing of the labor force through the implementation of the innovation was intended to produce an overall benefit.

Figure 1: Taxonomy of Costs		
	Examples of Research Costs	Examples of Implementation Costs
Physical	Labor/Capital Expenditures Publication Expenditures	Labor/Capital Expenditures Additional management/staff time Temporary workload increases
Psychic	Stress Project Failure	Project failure Morale drops from temporary workload increases

Figure 2 shows the Taxonomy of Benefits. As with Figure 1, the benefits from the research or implementation phase are categorized by whether they are physical or psychic in nature. Identifying and quantifying the physical benefits in the research phase may be more challenging than for the implementation phase where examples of benefits include, for example, money saved or higher quality.

Figure 2: Taxonomy of Benefits		
	Examples of Research Benefits	Examples of Implementation Benefits
Physical	New methods & capital	Money saved Higher quality good/service
Psychic	Knowledge spread Higher skilled labor force Identification of other research topics	Project Success Increased team mentality Increased feeling of "Safeness"

Psychic research benefits include but are not limited to a more highly skilled labor force, knowledge contagion and the identification of new research topics. The psychic implementation benefits will largely be determined by the utility of having a safer environment or, for the consumer, more confidence in the environment.

2.2 Uncertainty and Innovation
A common problem with innovation is that often there are two general unknowns. First, the probability that the innovation will lead to a desired outcome is unknown to the decision maker (DM) as discussed in the taxonomy with both the physical and psychic costs. Second, the DM does not know the number of possible payoffs or what those payoffs may be. As such, this represents a very different problem than those normally involving risk where the DM knows the number outcomes, the probabilities of these outcomes, and the corresponding payoffs of each of these outcomes.

A common method of dealing with uncertainty is to assume the DM selects subjective probabilities for each of the possible outcomes and chooses the option providing the highest subjective utility. As such, a subjective expected utility function, SE[U], can be written as shown in equation 1 and where U(w_i) is the utility derived from wealth gained in outcome (i).

$$SE[U] = \sum_{i=1}^{N} \propto_i U(w_i) \tag{1}$$

Since there are N possible outcomes, the probabilities of each possible outcome must sum to 1 as shown in equation 2.

$$1 = \sum_{i=1}^{N} \propto_i \tag{2}$$

In this report we use subjective expected utility but extend it to apply to the profit generated by the implementation of a research project. At the onset of a project, the DM knows there are multiple possible outcomes when the research is implemented. In some cases the maximized expected profit may be extremely low while in others it will be much greater. What we posit is

that the DM assigns a subjective probability to each of these possible outcomes. Consequently the subjective expected profit of research $(SE[\pi])$ can be written as shown in equation 3.

$$SE[\pi] = \sum_{i=1}^{N} \propto_i \pi_i \tag{3}$$

$$\text{Where} \quad \pi_i = B_i(\propto) - C_{Ii}(\propto) \tag{4}$$

Note in equation 4, $B_i(\alpha)$ is the benefits of outcome i as a function of implementation level α and $C_{Ii}(\alpha)$ is the cost of implementation level α. If outcome i is realized, then the DM selects the optimal level of implementation (α_i*) such that the marginal cost of implementation is equal to the marginal benefit. This (α_i*) satisfies the equation below with equality:

$$\frac{\partial \pi}{\partial \propto} = \frac{\partial B(\propto)}{\partial \propto} - \frac{\partial C_I(\propto)}{\partial \propto} = 0 \tag{5}$$

Note, there are multiple optimal implementation levels (α_i*) that may or may not be identical. We note that α will always be strictly positive as any level of implementation that leads to less than a zero profit should not be implemented. This is important as it truncates the worst case scenario.

2.3 Intermediate versus Final Profit

It is necessary that we differentiate between the different types of "profit". We denote the final profit of implementation of research as π_F. This final profit is simply the benefits of the research minus the costs of implementation and the costs associated with pursuing the research. The final profit function is what the DM maximizes as a function of α in order to gain the most from the research. However, because of the nature of fixed costs, the costs associated with pursuing the research (sunk costs) do not impact the level of implementation as they have already been paid.

On the other hand, the subjective expected profit $(SE[\pi])$ is the subjectively weighted expected net benefit minus the cost of moving to the next stage. Unlike final profit, the subjective expected profit must be greater than zero for the DM to continue toward implementation. If the

intermediate profit is less than zero – that is, the cost of moving to the next stage is greater than the expected benefits – the DM simply ceases work on the research project and incurs no new costs as the fixed costs have already been incurred.

2.4 A Decision Framework

The subjective expected profit function introduced in the previous section is a fundamental input to the decision tree presented in Figure 3. We assume that at each stage shown on the decision tree, the DM gains additional information and that this new information reduces uncertainty. In the absence of any uncertainty the DM's profit function could be written as:

$$\pi = B(\propto) - C_I(\propto) - (N\gamma + \mu + \delta + C_r) \tag{6}$$

Where $N\gamma$ is the cost of reviewing N proposals, δ is the cost of identifying the problem (e.g., background research and preparing a problem statement), μ is the cost of sending out a request for proposals and C_r is the funding cost for the selected proposals.

In a real world setting, the DM does not know the ex-ante outcomes of the research and therefore a decision tree is useful as it helps to illustrate a basic framework for the decision-making process. Each step along the decision tree is assumed to be determined by the DM. While we assume for the purposes of the narrative that the DM is a single person, the DM also can be a committee or even a number of committees.

As with any large scale public works entity, we assume that FDOT has multiple projects in various stages and that it should seek to maximize an objective function that depends on the profits generated by existing projects as well as those recently approved and implemented (see equation 7). Additionally, we assume that new projects may fill a variety of roles and/or complement existing technologies.
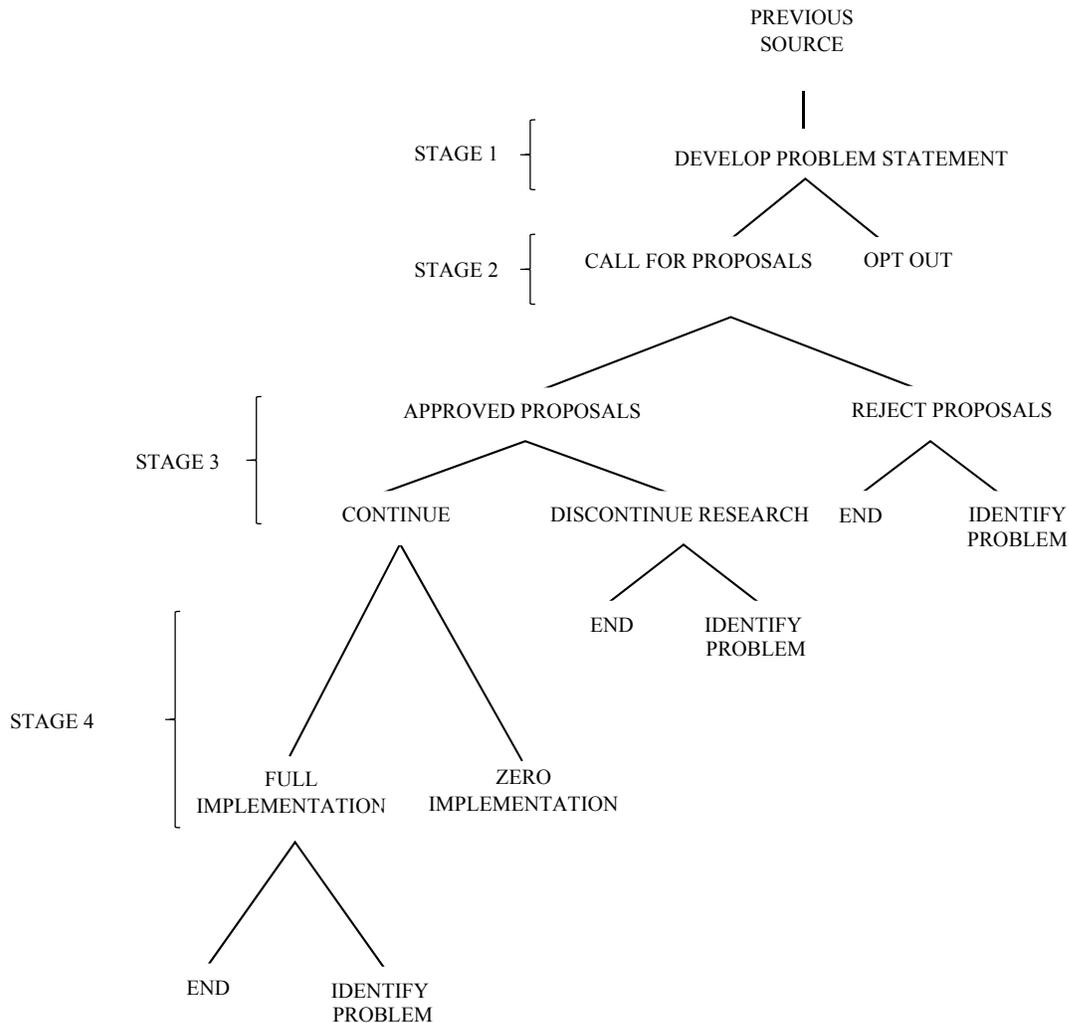
$$\prod(\propto) = \sum_{i=1}^{n} \pi_i + \sum_{j=1}^{z} \pi_j \tag{7}$$

In the framework we describe here, we are primarily concerned with the decision regarding the implementation of a single new project.

Figure 3: Decision Tree

The first stage of the process is the identification of an existing problem that could be addressed via a successful research project. In this first stage, a problem can be identified by researchers, the DM, politicians or identified through the failure of a previous project. While costs may be incurred in clarifying and developing the problem statement, the DM is not required to make a decision in stage one.

Equation 8 describes the subjective expected profit ($SE[\pi]$) at the second stage of the decision tree. At this stage, not only is the net benefit unknown but it is also not known how many competing proposals will be received and what the expected cost of the selected proposal will be. What is known is the cost of identifying the problem (δ), which has already been paid and the cost of requesting proposals (μ).

$$SE[\pi] = \sum_{i=1}^{N} \propto_i \left(B_i(\propto) - C_{li}(\propto) \right) - (E[N\gamma] + \delta + \mu + E[C_r]) \tag{8}$$

Once the problem is identified the DM can select to pursue an RFP (i.e., further research) or end the process if it is determined that the original problem would not yield sufficient results or that it would not to be feasible. If no RFP is pursued, the DM only incurs cost δ. Equation 9 shows this binary decision:

$$if \begin{cases} \sum_{i=1}^{N} \propto_i \pi_i - (E[N\gamma] + \delta + \mu + E[C_r]) \geq -\delta & Pursue \\ \\ \sum_{i=1}^{N} \propto_i \pi_i - (E[N\gamma] + \delta + \mu + E[C_r]) < -\delta & End \end{cases} \to \tag{9}$$

If the DM selects to pursue the research the DM accrues cost $N\gamma$ (i.e., the cost of reviewing all the proposals) and the cost of requesting proposals (μ). If all RFPs are rejected, the DM faces a total loss equal to the costs associated with stage two, ($N\gamma + \mu$), plus the identification costs (δ) in stage one.

Once all the RFPs have been reviewed the cost of the selected project is known. In stage three, a proposal has been accepted and the decision rules can be rewritten as shown in equation 10. Note that the left hand side of the equations is the expected final profit of the research while the right hand side is the loss suffered if the research is ended.

$$if \begin{cases} \sum_{i=1}^{N} \propto_i \pi_i - (N\gamma + \delta + \mu + C_r) \geq -N\gamma - \delta - \mu & Pursue \\ \sum_{i=1}^{N} \propto_i \pi_i - (N\gamma + \delta + \mu + C_r) < -N\gamma - \delta - \mu & End \end{cases} \rightarrow \tag{10}$$

In stage three, the DM is fully aware of the research costs and breaks them into z parts. Each one of these parts represents a point at which the DM reviews the approved project's progress (e.g., via task reports). If sufficient progress has not been made and/or if new information regarding the project's costs and benefits is unfavorable, the project is discontinued at part *i*. If the project ends, the new additional costs are simply the research costs that have been accrued.

$$C_r = \sum_{i=1}^{z} C_i \tag{11}$$

As such, the decision rules for *i* RFP renewals may be re-written as:

$$if \begin{cases} \sum_{i=1}^{N} \propto_i \pi_i - \left(N\gamma + \delta + \mu + \sum_{i=1}^{z} C_i\right) \geq -\sum_{i=1}^{i} C_i - N\gamma - \delta - \mu & Pursue \\ \sum_{i=1}^{N} \propto_i \pi_i - \left(N\gamma + \delta + \mu + \sum_{i=1}^{z} C_i\right) < -\sum_{i=1}^{i} C_i - N\gamma - \delta - \mu & End \end{cases} \rightarrow \tag{12}$$

Thus, the total costs for ending the project at point *i* are the accrued costs in stage three plus the costs of stages one and two.

In the final stage, the approved research has been completed and therefore the final research costs have been paid. The DM's final decision is to select the optimal level of implementation and therefore maximize profit conditional on the accepted project making it through the third decision stage.

$$\pi(|Pursued) = \sum_{i=1}^{N} \propto_i \pi_i \tag{13}$$

Or

13

$$\pi(|Pursued) = \sum_{i=1}^{N} \propto_i \left(B_i(\propto) - C_{Ii}(\propto) \right) \tag{14}$$

Because costs have been realized, the DM now knows the form of the costs of implementation and the benefits that will be derived from implementation of the research. In the example below, outcome i is realized.

$$\pi(|Pursued) = B_i(\propto) - C_{Ii}(\propto) \tag{15}$$

With some simplifying assumptions regarding the functional form of the costs, the project's "profits" are maximized where the marginal benefits are equal to the marginal costs.

$$\frac{\partial \pi}{\partial \propto} = \frac{\partial B(\propto)}{\partial \propto} - \frac{\partial C_I(\propto)}{\partial \propto} = 0 \tag{16}$$

We denote the optimal level of implementation as $\propto^*$. This level of implementation satisfies the condition above.

The optimal amount of implementation is likely to not end in the complete replacement of a previous innovation. This is for two reasons. First perfect substitutes are exceedingly rare. Even an innovation that is superior in multiple dimensions is likely to have factors inherent in it that make it less suitable in specific conditions. Secondly, timing matters. In some cases, when a new technology is being used in one location, it is implied it cannot be immediately used in another location.

While one may expect that at this point all projects that are implemented will be financially profitable, this is not necessarily always the case. The "final" profit function may still result in substantial losses even if the level of implementation is optimally selected and equation 15 is greater than zero. Here total profit may be less than zero because the net benefits conditional upon implementation may be modest and the other costs associated with the research outweigh the net benefits. This can be re-written as:

$$\pi = B(\propto^*) - C_I(\propto^*) - (N\gamma + \delta + \mu + C_r) \tag{17}$$

14

which will be less than zero if the equation below holds:

$$B(\alpha^*) - C_I(\alpha^*) < (N\gamma + \delta + \mu + C_r) \tag{18}$$

We would note that while this type of case is possible, the potential for underestimating benefits make it unlikely to occur.

We decompose the benefit/cost equation, equation 19, into four parts that are a function of the new innovation's revenue and costs and (if applicable) the technology it is replacing.

$$B(\alpha) - C_I(\alpha) \tag{19}$$

The decomposition of equation 19 (essentially the increase in profits due to the innovation) leaves us with equation 20. In the case of a new technology replacing an old one, the benefits $(B(\alpha))$ would be the revenue generated from the new technology (R_2) plus the costs of the old technology that are no longer being accrued (C_1). Likewise, costs would be the foregone revenue (R_1) of the old technology plus the costs (C_2) attributed to the implementation of the new technology.

$$B(\alpha) - C_I(\alpha) = R_2 + C_1 - R_1 - C_2 \tag{20}$$

The implementation of a new technology does not necessarily imply the old technology is completely phased out. Rather, only some portion of the new technology is being implemented. In some cases, the new technology may completely replace the old technology or a substantial portion, while in others; the new technology may only be partially implemented. It is important to realize some technologies are either used in tandem or to supplement existing technologies, and the proposed framework accommodates those situations.

Note that we have only chosen to highlight a select few stages. Assuming the structure stays the same, the addition of new stages does not alter the primary conclusions of the decision model. That is, the DM does not let prior spending influence the propensity to pursue the next stage (sunk costs fallacy); conditional on reaching the final stage, the DM selects the optimal level of

implementation such that the level of implementation is greater than or equal to zero; and lastly, the project may still generate a significant loss even if the level of implementation is non-zero.

2.5 Benefits (a return)

Identifying the benefits of a project is often more complex than identifying the costs. One of the more difficult aspects of benefit calculation stems from the "lifetime earnings" of a particular project. While the benefits of completed projects typically accrue across time, the value of these benefits generally decreases as a function of time. This may occur because the asset generating the benefit depreciates or simply because future dollars are worth less than current dollars.

We will focus on three types of benefit streams: (1) those that continue indefinitely, (2) those that stop at time T and (3) those that continue as foundations for future projects. In figure 4 we graphically present the various benefit streams.

Figure 4: Types of Benefit Streams
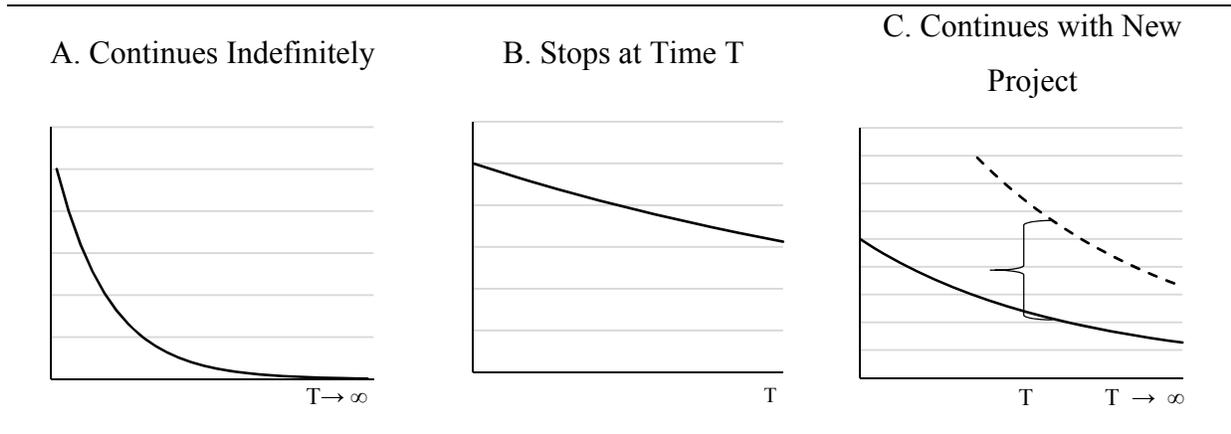
The "Continues Indefinitely" type of benefit stream can be written as the following:

$$\pi_L(\alpha, t|Pursued) = \pi + \beta^1\pi + \beta^2\pi + \beta^3\pi + \beta^4\pi \dots + \beta^n\pi \qquad (21)$$

$$\text{Where } \beta \in (0, 1)$$

If continued out to infinity, the total project's value can be simplified to the following equation:

$$\pi_L(\alpha, t|Pursued) = \frac{\pi}{(1 - \beta)} \qquad (22)$$

16

However, in many cases, the benefits are relatively short lived, as shown in panel B; consequently the benefits cease after a fixed number years. In this case, the project ends for a variety of reasons (e.g., it is replaced by a new innovation). This can be written as the following:

$$\pi_L(\alpha, t | Pursued) = \pi + \beta^1 \pi + \beta^2 \pi + \beta^3 \pi + \beta^4 \pi \dots + \beta^t \pi \tag{23}$$

$$\text{Where } t < \infty$$

In this situation, the benefit stream of the previous project ceases when the new project is implemented. If this occurs unexpectedly, it clearly implies the benefits of the original project will be overestimated.

Alternatively, as indicated in panel C, some projects would not be possible without an innovation or findings provided by prior research. In this case, the benefit stream continues as long as the new project continues. For example, imagine a prior project that has benefit stream:

$$\pi_l^o = \pi + \beta^1 \pi^o + \beta^2 \pi^o + \beta^3 \pi^o + \beta^4 \pi^o \dots + \beta^n \pi^o \tag{24}$$

Now assume at time t a new project is introduced that builds on the previous project and has benefit of stream of the following:

$$\pi_l^n = \pi_t^n + \beta^{t+1} \pi_t^n + \beta^{t+2} \pi_t^n + \beta^{t+3} \pi_t^n + \dots + \beta^{t+n} \pi_t^n \tag{25}$$

This benefit would overestimate the value of the new project as it would fail to account for the lifetime stream provided by the previous project. Consequently the benefits of the new project would be overestimated.

$$\pi_l^n = \pi_t^n + \beta^{t+1} \pi_t^n \dots + \beta^{t+n} \pi_t^n - (\beta^t \pi^o + \beta^{t+1} \pi^o \dots + \beta^{t+n} \pi^o) \tag{26}$$

Before a DM can make a decision on the project that will be pursued, the various factors that can increase or decrease the long run benefit stream must be taken into account. Using the equations above, we argue the long run benefit stream is a function of the time horizon of the project and

the discount rate. That is, the longer the project is implemented and the lower the discount rate, the greater the present value of the benefit stream will be.

The choice of discount rate presents a series of important issues based on the projects under evaluation. Certain projects will have a deprecation rate that is related to how the physical capital needed for the project gradually loses value. In addition to the depreciation rate for physical capital, a discount rate that is associated with the life span of the innovation is required for financial analysis. Many of these innovations, similar to the capital assets that may or may not be associated with the innovation, have short or mid-term life-cycles that do not exceed 20 years. The common discount rates associated with these short and mid-term capital assets are US Treasury, US Agency, or municipal bond yields. The investment grade on these debt instruments coincide nicely with many state restrictions on investments, where the investment grade requirement is a bond graded A or better. For example, if the innovation has a life cycle of 10 years, tying the discount rate to the US Treasury 10 year bond yield is both defensible and prudent given the grade of US Treasuries.

An alternative to the bond rates has been to use the interest rate of debt issued by the state itself. For example, if the state issues a 10 year revenue bond at 4.00%, then the state may use a 4.00% discount rate for an innovation with a 10 year life-cycle given that the known rate is associated with the state's current cost of capital. Note that the discount rate can be a function of numerous variables, such as a subjective discount rate, the interest rate, and rate of depreciation (see equation 27). All of these potential rates are explicitly decided by the DM in conjunction with information from the financing professionals within the organization. Some states use a fixed annual rate for analysis, while some states use the current market rate that coincides with the innovations life-cycle.

$$\beta = f(\rho_1, \rho_2, \rho_3 \ldots \rho_n) \tag{27}$$

3. DATA GATHERING COLLECTION PROCESS AND EFFORTS FOR MPSV PROJECT

Throughout the project, we have collected valuable information about the current processes from FDOT staff and project managers. As noted above, meetings with the project managers provided information on the data that are regularly collected and helped us better understand the feasibility of collecting additional data from within FDOT. In testing our framework on the MPSV project, one of our primary objectives was to illustrate the data collection process that was needed to produce the necessary input data for the application of our framework. This section highlights the data collection efforts and includes the results of the project manager survey. We hope that highlighting our data collection efforts for this project with prove useful in helping project managers identify and pursue relevant cost and benefit data for future research proposals and projects.

3.1 Data collection process for illustrating framework

In collecting data for the application of the framework, we utilized a variety of data gathering efforts. To learn about the MPSV project, a meeting was held on August 21, 2013 with FDOT project management. At this meeting, the project managers explained that the MPSV has capabilities that would replace survey crews on state highways for the tasks of determining cross-slope and rutting conditions. Two main benefits were identified- 1) the reduction in time it takes to analyze a section of road and 2) the reduction in worker injuries or fatalities.

Using past research projects available on the FDOT research website[1], we reviewed projects related to the MPSV to determine the extent to which costs and benefits were provided in a relevant sample of FDOT research project reports. Following this review, we identified four projects. To allow for comparability we discount the project costs using the US Treasury 10 year yield average for the period 2001 through 2013. The yield average is calculated by taking the US Treasury 10 year rate on January 1 of a given year over the 13 year time period, giving us an average nominal discount rate of 3.50%. We use the 10 year US Treasury rate under the assumption that the innovation has a similar life-cycle to that of the capital associated with the

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[1] http://www.dot.state.fl.us/research-center/. FDOT keeps records in the form of proposals, budgets, progress reports, and final reports) for all research grants. Collectively, these records contain a significant amount of data related to research costs

MPSV, as reflected in our discussions with FDOT. The first MPSV was retired after 10.3 years of service, providing support for the 10 year life-cycle assumption. Project costs in real terms are listed below based on completion date of the project:

- BDK05 (2009) – Using High-Speed Ground Penetrating Radar for Evaluation of Asphalt Density Measurements- Cost: $178,148.
- BD-544-36 (2008) – Investigation of Automated and Interactive Crack Measurement Systems - Cost: $179,742.
- BD-544-11 (2005) – Evaluation and Validation of a High-Speed Multi-Function System for Automated Pavement Condition Survey - Cost: $205,359.
- BC-965 (2002) – Feasibility of Video Logging- Cost: $721,372.

To address the capital costs in the projects, we depreciate capital costs associated with the MPSV using a straight-line depreciation method based on a 10 year service life. This follows the Governmental Accounting Standards Board (GASB) Statement 34 where governments are given two choices to depreciate their capital assets, straight-line or modified depreciation. Using straight-line reflects the use of physical capital, such as vehicles, which are prone to direct wear and tear and have a known life cycle.

Our next step was to identify all other relevant available costs related to the development and subsequent use of the MPSV. First, we obtained basic information on the number of survey vehicles currently in service and acquisition and maintenance costs for each of the vehicles. The project manager provided information from a case study involving seven road survey projects: two urban, three rural, and two interstate. The results of these projects indicated that use of the MPSV led to reduction in the number of survey points of 566% for urban use, 485% for rural use, and 782% for interstate use.[2] FDOT personnel reported that this translated to an average savings of $375 per lane mile. While MPSV specific, the process described above illustrates the type of data that should be captured on an ongoing basis for layered types of research projects such as the one involving the MPSV.

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[2] A survey point is one of several points collected over one mile of pavement that measures the cross-slope of the asphalt. A surveyor is also capable of noting landmarks and rutting at each survey point.

After attempting to identify available relevant costs, we worked to collect worksite statistics. A list of FDOT predesign coordinators for each project was obtained and an email questionnaire was distributed to these coordinators in order to gain a better understanding of process of determining actual benefits and data availability. The email questionnaire was sent to the seven FDOT districts on October 2, 2013. Three of the seven district coordinators responded promptly and provided estimates on survey crew cost, size, distance covered, differences in collecting the information, and safety concerns. The average responses were used to determine the costs of running a survey crew.

The State Transportation Statistics Office was contacted to obtain information on public road mileage, vehicle registration information and specific crash statistics. The FDOT Public Information Office was contacted to obtain road construction budgets and spending per county and they provided several other information sources (e.g., contact information for a construction systems engineer).

We requested information and received data from the FDOT project manager regarding the actual use of the MPSV, maintenance records, operational cost, vehicle equipment and driver information.[3] As much of the data was in PDF format, the data was then transformed over several days in order to recreate the data in a usable formatted excel file. We would note here that data consistency and usability across various FDOT platforms are important if the goal is to capture relevant existing cost and benefit data in an efficient and timely manner.

On October 21, 2013, a request was made through the Florida Division of Workers Compensation - Bureau of Data Quality and Collection to obtain workers' compensation claims for the Florida Department of Transportation. After several referrals, we contacted a staff member in the FDOT State Safety Office for data on worker related injuries on October 24th. During this time period, we also contacted a Principal Investigator and grants specialist from the USF College of Engineering to obtain specific information on two of the research projects; however, they stated that they were not able to share specific grant details (i.e., budget breakdown) without authorization from the professor. Several attempts were made to contact the

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[3] This information was compiled from http://www.flhsmv.gov/html/safety.html.

professor, but those were not successful. We would note here that transparency across FDOT projects is important if the goal is to capture relevant existing cost and benefit data in an efficient and timely manner.

On October 29, 2013, staff at the Bureau of Data Quality and Collection provided data on workers compensation claims for the following categories:

- Date of Injury
- Total Indemnity
- Total Indemnity Settlement
- Total Medical
- Total Medical Settlement
- Total Weeks
- Total Days

As the data did not include a description of the injury, we could not filter injuries related to surveying operations and ultimately did not use this data in the framework analysis.

On October 30, 2013, a staff member in Work Program Development provided total construction cost per year per county for the past ten years. On November 13th, information on the salaries of the driver and analyst were requested. These were provided by an FDOT project manager the next day.

On November 19, 2013, we obtained statewide injury reports over the past 10 years from the Office of the General Counsel of FDOT. This information was more detailed than the information previously provided. This data was analyzed over the next week and filtered in order to include only those injuries involving survey crew members.

The remainder of the data was obtained during December, 2013, and January, 2014. The Bureau of State Employee Workers' Compensation Claims was contacted to obtain the medical costs associated with each claim identified. We requested FDOT salary information and received an immediate response from the FDOT Research Development office that these data were available on www.floridahasarighttoknow.com. One FDOT project manager provided us with a case study from November that included the survey crew cost of a full Digital Terrain Model (DTM). We

requested the acquisition costs of the three MPSVs. This information was obtained from an FDOT project manager that same day. Finally, in January, we obtained information on the appropriate discount rates used within FDOT.

The following data were obtained to use in the decision framework as applied to the MPSV (in the next section):

- Research cost of the project
- Acquisition cost of the new equipment
- Cost to run a 3 to 4 man survey crew
    - Wages of employees
    - Injuries related to the task at hand
    - Timeframe of completion of a survey
- Cost of operating new equipment
    - External operational cost
    - Maintenance cost
    - Service life
    - Salaries of operators of new equipment
    - Timeframe of completion of a survey

A code book with all data sources is provided in the Appendix to this Report.

3.2. Survey of Project Managers

We held conversations with project managers to solicit information about the time that is spent on all phases of a research project. Since managers are often involved in multiple projects and have projects beginning and ending at different points during the year, it is not surprising that project managers' responses varied substantially. We decided to survey project managers in order to obtain information about the time spent on various stages of research projects. In response to an email request from FDOT, 38 project managers completed the survey. A second email request yielded an additional 20 responses. A total of 47 project managers completed the survey in its entirety. Responses were obtained from project managers in 11 divisions of FDOT, as shown in Table 1. Table 2 presents the raw sample statistics for these 47 responses.

Table 1. Responses by FDOT Division

Division	Number of Responses	Division	Number of Responses
Construction	1	Public Transportation	2
Environmental Management	2	Roadway Design	3
Geotechnical and Structures	1	Research	2
Hydraulics/Stormwater	1	Structures	6
Maintenance	4	Survey and Mapping	3
Materials	10	Traffic Engineering and Operations	6
Planning	5	Other (not specified)	1

Table 2. Sample Statistics

	Question	Mean	Median	Min	Max
Q1	How many projects did you manage, in total, over the past fiscal year?	2.53	2	0	12
Q2	During the past fiscal year, what was the greatest number of projects you managed concurrently?	2.40	2	0	13
Q3	On average, how many other staff members (not including other PMs) do you work with on a daily basis?	2.31	2	0	20
Q4	On average, how many hours per year do you spend on preparing potential research projects?	32.87	25	0	130
Q5	With respect to this developmental phase, how many additional hours per year are delegated to your staff?	47.48	7	0	1000
Q6	On average, how many hours per year do you spend on evaluating proposals for potential research projects?	23.34	20	0	150
Q7	With respect to the time you spend on evaluating proposals for potential research projects, how many additional hours per year are delegated to your staff?	44.70	2	0	1500
Q8	On average, how many hours per month, do you spend monitoring the status of ongoing projects and/or reviewing deliverables?	17.05	8	0	120
Q9	With respect to the time you spend monitoring the status of ongoing projects and evaluating deliverables, how many additional hours per month are delegated to your staff?	9.41	1.5	0	100
Q10	On average, how many hours per year do you spend on evaluating final reports?	28.79	20	0	120
Q11	With respect to the time you spend evaluating final reports, how many additional hours per year are delegated to your staff?	33.78	3	0	1000

We analyzed the responses further to identify the sources of variation across project managers' responses to the survey questions. First, with respect to divisions, we note that one project manager from the Office of Environmental Management division reported that he/she did not manage any projects in the last fiscal year. While not actively involved in managing any projects,

this respondent indicated spending 8 hours per year on preparing research ideas, 16 hours per year on evaluating proposals, 8 hours per month evaluating progress reports, and 16 hours per year reviewing final reports.

One project manager from the Office of Survey and Mapping reported involvement with one project over the past fiscal year. This manager's responses to the questions pertaining to hours spent on all stages of any projects (Q4-Q11) were all zero.

A more accurate estimate of time spent on the various stages of project management was obtained after filtering out the responses from project managers who did not manage any projects over the past year. Table 3 shows the responses to Q4, Q6, Q8, and Q10 for the 45 respondents that reported involvement in one or more projects over the past fiscal year. Table 4 shows the corresponding information with respect to staff involved in the various stages of project management. Note that twelve of the project managers surveyed reported zero hours of staff assistance at each stage.

Table 3. Time Spent on Project Phases by Project Managers with Current Projects

Question		Mean	Median	Min	Max
Q4	On average, how many hours per year do you spend on preparing potential research projects?	34.15	30	1	130
Q6	On average, how many hours per year do you spend on evaluating proposals for potential research projects?	24.02	20	0	150
Q8	On average, how many hours per month, do you spend monitoring the status of ongoing projects and/or reviewing deliverables?	17.63	8	.5	120
Q10	On average, how many hours per year do you spend on evaluating final reports?	29.71	20	0	120

**Table 4. Time Spent on Project Phases by Staff of Project Managers with Current Projects**

Question		Mean	Median	Min	Max
Q5	With respect to this developmental phase, how many additional hours per year are delegated to your staff?	49.64	9	0	1000
Q7	With respect to the time you spend on evaluating proposals for potential research projects, how many additional hours per year are delegated to your staff?	46.73	3	0	1500
Q9	With respect to the time you spend monitoring the status of ongoing projects and evaluating deliverables, how many additional hours per month are delegated to your staff?	9.84	2	0	100
Q11	With respect to the time you spend evaluating final reports, how many additional hours per year are delegated to your staff?	35.32	3	0	1000

A statistical comparison across divisions of the time spent by project managers is not appropriate given the small number of responses in each division. However, we do note the following:

- On average, project managers in Planning reported spending the largest amount of time on preparing potential research projects.
- Project managers in Structures reported spending the largest amount of time on evaluating proposals, monitoring project status, and evaluating final reports.

The information obtained from the survey is incorporated into our preliminary decision making model as shown in Figure 5 below.

Figure 5: Illustration of Managerial Time and Cost
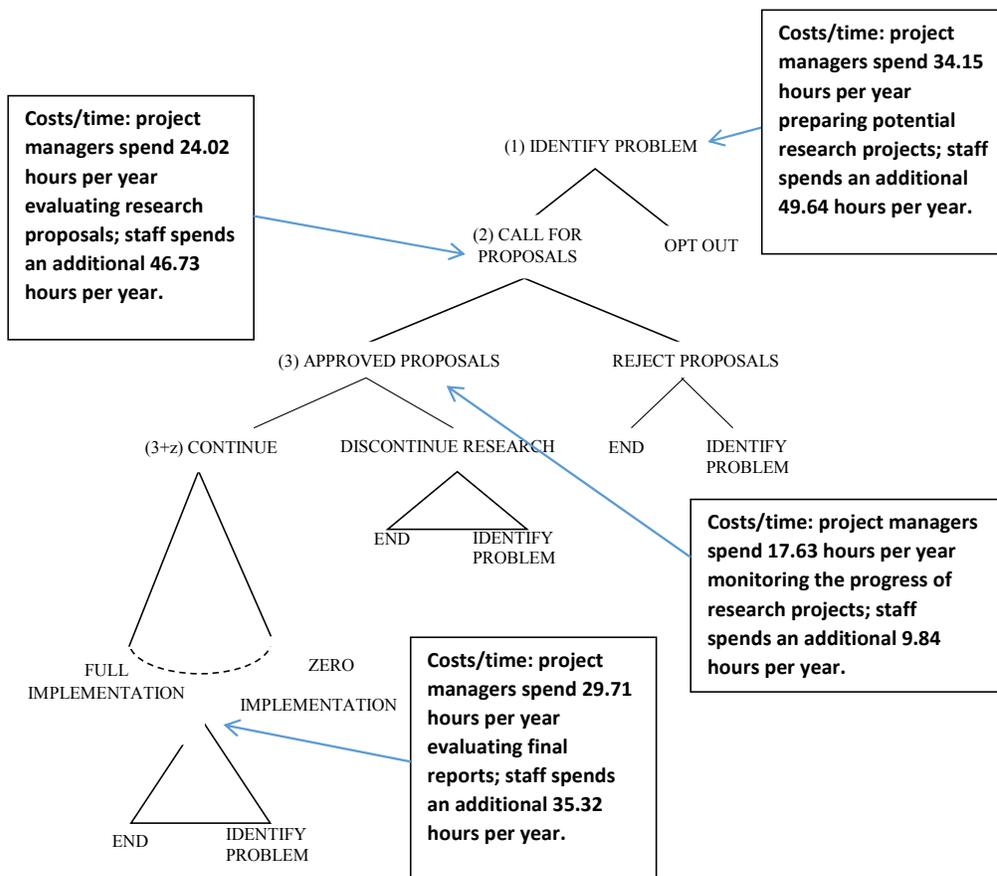
4. APPLICATION OF DECISION FRAMEWORK TO MPSV RESEARCH PROJECTS

To illustrate the framework, we start with a readily understood structure and discuss how that structure can be expanded such that it is representative of the decision tree. Then, we provide numerical analysis using data collected.

4.1. Approach

To calculate the benefits of implementing the MPSV research, we first take the difference of the profits between the old methodology and the new one that will be replacing it and divide it by one minus the discount rate. If this amount is greater than the total cost of pursuing the project, then the project should be pursued and implemented. Making this decision requires knowing the revenue of the two methodologies along with the cost of their respective inputs as both are required to back out the profit ($\pi_i = R_i - \sum C_i$). Where the revenue of methodology i is (R_i) and the total costs (TC) of methodology i is $\sum C_i$.

$$\frac{\pi_2 - \pi_1}{(1 - \beta)} > TC \tag{28}$$

The one-year benefits of the innovation can therefore be written as the differences between the profits of the two innovations. The total benefit of the research is therefore the discounted total difference in profits between the two (or the amount of substitution between the two) - the exact form of which depends on the life span of the innovation. For simplicity, we will assume the benefits and costs will continue indefinitely (from equation 22) which implies the following equation:

$$\frac{\pi_2 - \pi_1}{(1 - \beta)} = TC \tag{29}$$

Note that the benefits of the project are slightly different than the differences between the two methodologies' profits ($\pi_2 - \pi_1$). Previously we introduced an admittedly nebulous concept of benefits. Here we expand that by defining benefits as the sum of the revenue of the new methodology and costs of the old methodology ($R_2 + C_1$).

$$B(\propto) = R_2 + C_1 \tag{30}$$

In order to capture the cost effectiveness of a given project, we must consider the costs of the new methodology as well. The costs are the forgone revenues of the previous methodology and the cost of implementing the new technology or:

$$C_I(\propto) = R_1 + C_2 \tag{31}$$

Doing so, we are left with the following:

$$B(\propto) - C_I(\propto) = \frac{R_2 - R_1 + C_1 - C_2}{(1 - \beta)} = \frac{\pi_2 - \pi_1}{(1 - \beta)} \tag{32}$$

The difficulty is that only a subset of the costs is known at each stage of the decision process. However, there are some costs that should be known. Generally, these fall into two categories. First the operating costs and benefits of the current methodology are going to be known. The DM will be aware of the worker expenditures, the average level of medical expenditures that will occur, and other costs the DM has experience with. Second, the DM will know the cost of each stage in the research decision tree or will have a well-informed/reasoned estimate. These include the cost of identifying the problem, calling for proposals, reviewing them, and selecting the one that is the most effective. As such, there is only one true unknown – the profit of the new technology.

$$\frac{\pi_2 - R_1 + C_1}{(1 - \beta)} > TC \tag{33}$$

We can simplify this further such that the only unknown to the DM is on the left-hand side of equation 34.

$$\pi_2 > TC(1 - \beta) + R_1 - C_1 \tag{34}$$

This can be rewritten as:

$$\pi_2 > TC(1 - \beta) + \pi_1 \tag{35}$$

Note that these equations are what tie the decision tree to terms that are readily understood by a DM.

We apply the decision tree and assume reasonable parameters in order to illustrate how the decision tree can be used. At this point, the project has been completed and pursued. We understand that the MPSV was introduced as an innovation to reduce roadway assessment times, enhance evaluation methods, and to reduce potential harm associated with having survey crews exposed to highway traffic.

We back out the total profit (π_T) of the application of the MPSV which will be a function of the time frame (t) and its level (α) of implementation. We identify π_T as a function of the inputs of the survey crews and coring, the prior methodology to evaluate roads, and the MPSV along with the total revenue of the MPSV and the survey crews and coring (SC).

The next step is to compare the costs of SC with the new MPSV. To do so requires that we calculate the monetary savings based on paying SC workers (S_w) and the medical savings associated with the change in worker exposure to highway traffic (S_m). For simplicity, we assume the differences in the "revenues" ($R_2 - R_1$) can be captured with an "other benefits" variable or (OB) that may (or may not) be known. As such the total profit of the MPSV can be written as a function of the cost savings and increases in revenues. We will focus primarily on two types of cost savings. The first (S_w) are cost savings associated with worker hours (or wages) while the second, (S_m), are the savings accrued by medical spending reductions. As such, the total yearly profit π_T can be written as:

$$\pi_T(\alpha, t | Pursued) = S_w(miles) + S_m(miles) + OB \tag{36}$$

We begin by calculating (S_w) and (S_m). S_w is a function of the SC's cost and the MPSV's cost. We denote this with the general notation as C_o indicating the cost per mile of SC and C_n as the

per-mile cost of the MPSV. To calculate the total benefit realized, we can proxy for the level of implementation by using the number of road miles the MPSV will survey.

Assuming a fixed number of miles that must be completed, the cost savings from switching from SC to the MPSV as it pertains to worker payments can be written as:

$$S_w = (C_o - C_n) * Miles \tag{37}$$

There are a handful of variables needed before we can calculate the cost savings pertaining to worker cost: the worker's hourly wage (W_i), the time it takes for a survey crew to cover one mile (D_i), the crew size ($Crew_i$), and other costs (OC). The cost per mile for the SC can be written as:

$$C_o = W_o * E[Crew_o] * E[D_o] + OC \tag{38}$$

While MPSV worker costs can be written as:

$$C_n = W_n * E[Crew_n] * E[D_n] + OC \tag{39}$$

Without further information, it is difficult to back out all the final costs of the project. Primarily this is due to the level of implementation. Two costs that are difficult to identify are medical and managerial costs. For example, when switching from the coring and surveys to the MPSV it is reasonable to assume that the probability of having an injury is greater for workers on a road survey site than for the workers in the MPSV vehicle. That is:

$$EPr[injuries|SC] > EPr[injuries|MPSV] \tag{40}$$

However, the introduction of the MPSV might be a sufficient enough improvement that it is used significantly more often. Although the number of injuries per worker hour decreased, the number of observed injuries might increase through the increased number of miles covered.

Another example of this case involves managerial oversight. Because the MPSV requires fewer workers than the survey crews, it is reasonable to assume that the ratio of managers (or oversight) per work crew is greater for survey crews than it is for the MPSV. At a cursory glance, one may assume that the comparative efficiency of the MPSV would lead to a decrease in managerial costs. However, because of the increased efficiency, the MPSV might be used more often or lead to the construction of more vehicles. Both of these occurrences would normally imply an increase in the amount of managerial oversight. So although the ratio of MPSV workers to managers might be smaller than what is seen in other methodologies, there still might be an increase in managerial costs because of the increased usage.

We also can perform a similar process with work site injuries. However, in this case the calculation is significantly more complicated. We start by assuming the savings with respect to worker injury costs is equal to the difference in the medical expenditures per mile under SC minus the expected per mile medical expenditures of MPSV workers. To get the total expected savings, we simply multiply the difference by the number of miles that are planned to be covered by the MPSV and the average medical expenditures for an injured worker.

$$S_m = \left(E\left[\frac{M_o}{Miles}\right] - E\left[\frac{M_n}{Miles}\right]\right) * miles * E[medical] \tag{41}$$

On the surface this may seem relatively unassuming; however, it is complicated. First, we must calculate the expected probability of injury. A naïve approach would be to divide the observed number of injuries by the number of workers. This would overestimate the expected probability of injuries as it would not account for the total number of hours that have been worked. As such, the expected probability of injury should be estimated with the following equation:

$$EPr[injuries] = \frac{Injuries}{Workers * hours} \tag{42}$$

Next, we calculate the expected number of worker hours per mile. This is simply equal to the expected crew sizes multiplied by the time it takes for them to survey a mile of road. We then

31

multiply the expected worker hours times the expected probability of injury. This gives us the expected number of worker injuries per mile worked. To find the amount saved, we multiply the difference in expected worker hours by the total number of miles surveyed and the average medical expenditures per worker injury.

$$S_m = (E[Crew_o] * E[time_o] - E[Crew_n] * E[time_n]) \\ * EPr[injuries] * miles * E[medical]$$

(43)

4.2 Numerical application of formulas

Prior to the start of the call for proposals, there are several known variables in regard to the functions above – most of which are associated with the costs of SC. For simplicity, we will assume that the differences between the revenues of the two projects is equal to X, where X is strictly greater than or equal to zero. We would argue that this is a reasonable assumption as it is unlikely that decision makers will pursue innovations that make current projects more expensive.

To further simplify the problem, since 2003, we found that approximately $46,000 was spent on worker compensation claims. We will ignore the medical costs of survey crews by assuming medical expenditures of survey crews will be equal to the medical costs of the MPSV users. We believe the medical costs in this example should be lower per mile but that does not necessarily translate to lower medical costs as the MSPV is likely to be deployed more often. As such, the probability of injury per mile may decrease but we may observe an increase in worker injuries if the miles associated with the MPSV are large.

We note that according to the information provided, SC sizes generally range from three to four workers with costs ranging between $140 and $225 per hour. This implies an average wage of about $52.29 per worker hour. The SC teams can cover anywhere between .02 and .028 miles per hour. As such, we can assume it takes between 34.71 and 50 hours for a SC crew to cover one mile of road. From equation 38 we know the operational cost associated with SC workers is:

$$C_o = W_o * E[Crew_o] * E[D_o] + OC$$

Given that the average survey crew is approximately 3.5 members, an average per hour wage of $52.29, and an average coverage speed equal to .024 miles per hour, we can estimate the cost of a survey crew to be about $7,843 per mile plus the OC. In this case, the other cost (OC) is the analysis of the digital terrain map. The map analysis is estimated to cost around 1/3 the of project cost. This can be found with the equation below:

$$x + \frac{(x + y)}{3} = x + y$$

This simplifies to:

$$\frac{x}{2} = y$$

Where x is the cost of the SC and y is the cost of the digital map. This allows us to find the cost of the digital map.

$$\frac{\$7,843}{2} \approx \$3921$$

And implies the total cost per mile is:

$$\$3921 + \$7,843 = \$11,764$$

At this point, we have calculated the per mile costs of the survey crew and now we need the cost saving required to make the MPSV financially viable. As a reminder of the decision tree, the following parameters are defined as follows: (1) $N\gamma$ is the cost of reviewing N proposals, (2) δ is the cost of identifying the problem, (3) μ is the cost of sending out a request for proposals, and (4) C_r is the cost of the selected proposal.

As we have already shown, a project should be pursued past the identification stage if the following equation holds:

$$\pi = B(\propto) - C_I(\propto) - (N\gamma + \mu + \delta + C_r) > -\delta$$

In the case of a project having benefits that continue indefinitely into the future, this equation is modified as:

$$E[\pi_2] - \pi_1 - (E[N\gamma] + \mu + \delta + E[C_r^a])(1 - \beta) > -\delta(1 - \beta)$$

For simplification, let's make the naïve assumption that the DM is only concerned with the cost savings potential of the MPSV. Therefore, the DM assumes the revenues would be identical in both technologies. Given that the MPSV was introduced in 2001, some savings might have accrued from its usage. However, beginning in 2003, there were significant reductions in the FDOT workforce. The surveying and mapping office lost approximately 50% of its field staff and 25% of its office staff due to state personnel reductions. Separating the cause of these reductions from the state mandates and the innovation from the manual survey collection using the SCs to the automated survey innovation of the MPSV is extremely difficult. This leads us to assume the revenues are identical between the SC and the MPSV. That is the MPSV and SC would be able to do the same job while keeping the quality constant. This cancels out the revenues of the competing technologies and leaves us with the equation below.

$$\$11,764 * Miles - C_2 * Miles - (E[N\gamma] + \mu + \delta + E[C_r^a])(1 - \beta) > -\delta(1 - \beta)$$

The addition of the $(1 - \beta)$ term, seen on both sides of the equation, reflects that these costs are non-recurring and can be spread out over the innovation's life cycle. Using the results of our survey of project managers (PM), we know that the average PM spends 32.87 hours per year identifying the problem (δ), 23.34 hours on reviewing proposals ($N\gamma$), and the cost for the call for proposals (μ) appears to be minor since information regarding these costs were not available. The PM survey provided us with the PM's perspective on administrative staff time required for identifying the problem (47.48 hours) and reviewing proposals (44.7 hours). In addition, the PM's provided information that, on average, they manage 2.53 projects per year. Although the number of projects may underestimate the number of proposals, we use the number of projects managed per year to allocate the time spent by both the PM and administrative staff in the 1st and 2nd stages of the decision tree, the costs associated with identifying the problem and the costs of

evaluating proposals. This provides for an overestimation of the costs per proposal, a conservative estimation technique.

Using data from FDOT, we find that the average engineer's annual salary is about $72,767 and the average administrative staff's annual salary is about $30,507. Using the averages provided in the PM survey, the costs allocated to the MPSV for identifying the problem (δ) is $455 for the PM and $275 for the administrative staff. Since the MPSV was implemented, we know that the DMs correctly identified the value of improvements and thus moved to the second stage where they determined whether or not the costs of sending out a proposal satisfied the equation:

$$\$11,764 * Miles - C_2 * Miles - (E[N\gamma] + \mu + \$730 + E[C_r^a])(1 - \beta)$$
$$> (E[N\gamma] + \mu + \$730)(1 - \beta)$$

In the 2nd stage, the additional costs of reviewing proposals are assessed by the DM. Using the PM survey, allocating costs to reviewing the proposals, $N\gamma$, leads to $323 for the PM and $259 for administrative staff. Assuming that the call for proposals cost (μ) is insignificant leads to:

$$\$11,764 * Miles - C_2 * Miles - (\$1312 + E[C_r^a])(1 - \beta) > (\$1312)(1 - \beta)$$

At this point the DM enters into the 3rd stage, selecting the final project. The DM knows how much the research costs are. In the case of the MPSV, R&D costs come out to approximately $636,674 in real dollars which are derived from FDOT projects BC965, BD544-11, BD544-36, and BDK05.[4] From this we know that the project will proceed so long as per mile costs of the MPSV (C_2) are less than $11,764 plus the one-time costs associated with the R&D for the MPSV.

$$\$11,764 * Miles - C_2 * Miles - (\$1312 + \$636,674)(1 - \beta) > (\$1,312)(1 - \beta)$$

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[4] The total cost of the four projects was approximately $1,284,621 in real dollars; BC965 included an additional $625,560 capital cost in real dollars, which we do not include in the R&D costs.

To derive the costs for the MPSV (C_2), we need at minimum the following costs: all costs underlying the operations and management of the MPSV, a measure of the quality of the MPSV data as compared to the SC, a measure of the impact on employees with the introduction of the MPSV, and the lane miles covered by the MPSV. Table 5 presents the utilization of the three survey vehicles by year, which we used to derive our estimate of annual lane miles.

We collected information on many of the operational costs (excluding training costs associated with the driver, analyst, and any additional employees cross-trained for the MPSV) and much of the management oversight estimated costs (we lack information on FDOT overhead allocation but assume it is similar to SC). We have been unable to acquire data related to the impact on employees, such as employee satisfaction or employee performance evaluation, but have been able to find some evidence that the MPSV data are similar to SC data collected (see FDOT BD544-36). Using the average US Treasury 10 year yield of 3.5043% for the 2001-2013 time-periods and assuming that the innovations associated with the MPSV have a similar life-cycle as that of the capital assets for the MPSV, we annualize the costs for the MPSV. We show the annualized costs for the MPSV in Table 6. In Table 6, PM oversight is the average amount of time spent by project managers (45.84 hours) and administrative staff (43.19 hours) annually monitoring the progress of research progress and evaluating final reports. All other costs are derived through FDOT subject matter experts.

Table 5: Utilization of Multi-purpose Survey Vehicles, June 2005 – July 2013

Vehicle	1	2	3	Total
2005*	106			106
2006	19			19
2007	79	225		304
2008	0	1518		1518
2009	1501	973		2474
2010	677	507		1184
2011	1192	1281		2473
2012	510	1557		2067
2013*		120	166	286

* Denotes years which are partial

36

Table 6: Average Annual MPSV Costs

PM Oversight	$1,135
External Operating	$14,610
Labor*	$118,058
Capital	$122,187
Maintenance	$7,572
Total	$263,562
Lane Miles[+]	1,227
Cost per lane mile	$215

*Labor cost includes one driver and one analyst
[+]Based on the annual average lane miles from 2006 – 2013

To explore the benefit associated with the MPSV, we evaluate the costs of the alternative, the SC with that of the MPSV per mile. Above, we established that the costs per lane mile of the SC at $11,764. In table 6 we show that the annualized costs of the MPSV per lane mile at $215. Assuming no additional adverse effects or costs associated with MPSV in training or employee morale, the difference per lane mile is considered the financial benefit of the MSPV. This amount of "savings" is about $11,550 per lane mile. The initial known investment into the innovation in R&D for the MPSV is estimated at $636,674. Using this estimate, it takes the MPSV approximately 55 lane miles to return the costs of the R&D associated with the MPSV. A caveat is in order here. We are assuming that the technology placed on the MPSV capital asset has the identical life-cycle as that of the capital asset, the vehicle. Technology may or may not need replacing at shorter or longer intervals than that of the capital asset. Therefore, we are assuming that the technology and the capital asset have no salvage values and are both replaced simultaneously at the end of the MPSV's life cycle. In addition, we are assuming that the MPSV continues to provide the same number on lane miles as was found for the time period 2006-2013 for each and every year of its life-cycle. Changes in any of our assumptions will change the "savings" associated with the MPSV.

Using our analysis derived to date, ignoring overhead, training, and the effect on employees, our model indicates that $C_2 < C_1$, making the MPSV a profitable innovation under these constraints. Note the final implication of the model. The project will end in a loss if the following equation holds:

$$C_2 > \frac{(E[N\gamma] + \mu + \delta + E[C_r^a])(1 - \beta)}{Miles} - C_1$$

Policy makers may then note that the equation above is more likely to hold if the new innovation does not enjoy wide spread use. In other words, employee acceptance of the innovation is a critical aspect of successful full implementation of the innovative practice.

5. DISCUSSION OF FRAMEWORK STRENGTHS AND CHALLENGES

In this section, we provide a discussion of the strengths and challenges of using the framework to evaluate research projects and we provide this against the backdrop of the MPSV project.

5.1 Strengths of the proposed framework
As noted above, the successful application of the framework requires sufficient data related to costs and benefits. For the MPSV project, we identified multiple sources of publicly available data, as shown in Table 7.

Table 7. Data

Centerline Miles per county	Road Crew Cost
Crash Statistics per county	Registered Vehicles per county
Daily Vehicle Miles Traveled per county	Research Project Cost
Lane Miles per county	Road Construction Cost
Licensed Drivers per county	State employee salaries
Maintenance Records	Work Zone Fatalities
MPSV Vehicle Usage Statistics	Worker Compensation claims
Populations per county	Worker Compensation injuries
Public Road Mileage	

*see the Codebook in the Appendix to this report for more details.

Based on our review of data sources and collection efforts, we believe there are both a sufficient number of data sources available to the project manager or research team and a sufficient quantity and quality of data needed to use the framework as a decision tool.

5.2. Data Collection Challenges
While we suggest the data required to apply the framework are readily available, we recognize that there may be significant costs associated with these collection efforts both in terms of time and expertise. One could argue that each data collection effort includes some form of learning or

experiential cost where these costs decline through multiple or ongoing use of a specific data source. When using cost/benefit data that is unique to a specific project, the project manager has no opportunity to experience these types of efficiency gains.

One challenge is that data on the time spent by FDOT personnel at each stage of the research process is not currently collected within FDOT. We collected this information through our survey of project managers, described above. While this survey enabled us to estimate an allocation of project manager and staff time to each stage of the decision framework, a more accurate accounting of time could be obtained.

Data collection may require contacting multiple offices in order to obtain usable measures for the framework. In one situation, one may need to contact multiple offices for multiple measures, while in other situations, one may need to contact multiple offices in order construct a specific measure for the framework. For example, it was necessary to contact the Florida Department of Transportation to get worker injury statistics, but in order to obtain the actual workers compensation claim it was necessary to contact the Division of Risk Management.

Another acquisition issue that may impact on the viability of the framework involves the quality or consistency (e.g., comparability over time and across organizations) of the data. While data quality and consistency may be of a concern within FDOT, this is especially true for data that must be obtained outside of FDOT where the long term availability, reliability, and consistency of the data may be more problematic. Problems in this area may lead to additional costs in the form of data manipulation and analysis or additional data validation efforts. Significant data quality or consistency problems could adversely impact the reliability of the framework results.

5.3 Challenges to Implementing the Framework
The feasibility of implementing our proposed framework depends not only on the availability of data, but the ability of FDOT project managers and staff to identify the appropriate data collection activities at each step of the research process, and perform the relevant comparisons. The equations we provide at each stage are straightforward, but we assume that some technical expertise and judgment are necessary for identifying the relevant costs and benefits at each stage.

Table 8 provides a simplified "generic" process to illustrate the data gathering efforts at each stage of the process, but we note that the actual data items collected at each stage will be specific to each project. For each stage of the decision process, the table illustrates the data that should be collected because the information is known, and the additional information that must be estimated before proceeding to the next step. Some judgment will be necessary to determine whether certain costs and benefits are relevant and should be included in the framework. In addition to developing and revising the subjected expected profit from the research, other inputs to the decision framework that require the DM's judgment include, for example, the extent to which the costs of prior research projects should be included in the model, the expected duration of costs and benefits, and the appropriate rate for discounting future costs and benefits.

Table 8: Generic Illustration of Data Gathering Process

Phase	Data that must be collected in each phase, and important calculations
1 Identify Problem Statement	Cost of developing problem statement (δ - known) Calculate subjective expected profit: $SE[\pi]$ = a function of the expected benefits of implementation (B_i – estimated), expected costs of implementation (C_{Ii} – estimated), the implementation level (α – estimated), and other costs associated with the research process See equations 1-8 for guidance on the calculation.
2 Call for Proposals	Cost of identifying problem (δ - known) Cost of requesting proposals (μ - known) Cost of reviewing proposals ($N\gamma$ – estimated, depends on # proposals submitted) Cost of research (C_r – estimated) Reevaluate $SE[\pi]$ See equation 9 for decision rule for going forward.
3 Monitoring selected project (repeated for each part of the project)	Cost of identifying problem (δ - known) Cost of requesting proposals (μ - known) Cost of reviewing proposals ($N\gamma$ – known) Total cost of research (C_r – known) Reevaluate $SE[\pi]$ Calculate cost of research to date ($\sum C_i$ – known at each stage) See equation 10 for decision rule for going forward to next part.
4 Implement	Cost of identifying problem (δ - known) Cost of requesting proposals (μ - known) Cost of reviewing proposals ($N\gamma$ – known) Total cost of research (C_r – known) Benefits of implementation at a given α ($B_i(\alpha)$ – known) Costs of implementation at a given α ($C_{Ii}(\alpha)$ – known) Calculate optimal implementation level See equation 15 & 16 for calculations

The framework we developed is flexible and can be adapted for use in evaluating different types of projects. Successful implementation of the framework within FDOT will require focused data collection efforts throughout the research process with emphasis on identifying the potential net benefits of research projects at the outset.

APPENDIX: Data Sources – Code Book

Panel A. Data Sources within Florida Department of Transportation	
Measure(s)	**Source/Contact Information**
Research Project Cost	Transportation Statistics Office http://www.dot.state.fl.us/research-center/documents.shtm Phone: 850-414-4848
Road Construction Cost	Office of Work Program and Budget Dan Cashin – (850) 414 - 4428 - Daniel.Cashin@dot.state.fl.us Kendra H. Sheffield – (850) 414 – 4627 - Kendra.Sheffield@dot.state.fl.us
MPSV Maintenance Records	Materials Office Abdenour (Nour) Nazef, P.E. - (352) 955-6322 Abdenour.nazef@dot.state.fl.us
MPSV Vehicle Usage Statistics	Materials Office Abdenour (Nour) Nazef, P.E. - (352) 955-6322 Abdenour.nazef@dot.state.fl.us
Population per County	http://www.dot.state.fl.us/planning/statistics/sourcebook/
Centerline Miles per County	http://www.dot.state.fl.us/planning/statistics/sourcebook/
Lane Miles per County	http://www.dot.state.fl.us/planning/statistics/sourcebook/
Daily Vehicle Miles Traveled per county	http://www.dot.state.fl.us/planning/statistics/sourcebook/

Road Crew Cost	District Coordinators
	• District 1
	   o Debra Childs – (863) 519-5848
	    debra.childs@dot.state.fl.us
	   o Marlene Herbert – (863) 519-4267
	    marlene.herbert@dot.state.fl.us
	• District 2
	   o Chad Townsend – (386) 961-7844
	    chad.townsend@dot.state.fl.us
	   o Belqis Majboor – (386) 961–7444
	    belqis.majboor@dot.state.fl.us
	• District 3
	   o Samuel Weede – (850) 330-1621
	    Samuel.weede@dot.state.fl.us
	• District 4
	   o Eva Campello – (954) 777-4458
	    eva.campello@dot@state.fl.us
	• District 5

	o Tim Keefe – (386) 740-3512 timothy.keefe@dot.state.fl.us
	• District 6
	o Nereida Canjura – (305) 470-5127 nereida.canjura@dot.state.fl.us
	o Tim Albury – (305) 470-5262 tim.albury@dot.state.fl.us
	• District 7
	o Pedro Lopez – (813) 975-6789 pedro.lopez@dot.state.fl.us
	• Turnpike
	o Christopher NeSmith – (407) 264-3482 Christopher.nesmith@dot.state.fl.us
	o Eduardo Hernandez – (954) 444-4571 Eduardo.hernandez@dot.state.fl.us
Worker Compensation Injuries	General Counsel http://www.dot.state.fl.us/generalcounsel/PublicRecords/PRRHomePage.shtm Tonya Granger – (850) 413-1709 Mark Eacker – (850) 414-4176 Mark.Eacker@dot.state.fl.us
Public Road Mileage	Transportation Statistics Office – John H. Taylor, P.E. – (850) 414-4930 John.Taylor@dot.state.fl.us

Panel B. Data Sources outside of Florida Department of Transportation	
Licensed Drivers per county	Florida Department of Highway Safety and Motor Vehicles http://www.flhsmv.gov/html/safety.html
Registered Vehicles per county	Florida Department of Highway Safety and Motor Vehicles http://flhsmv.gov/html/reports_and_statistics/reports_and_statistics.html
Crash Statistics per county	Florida Department of Highway Safety and Motor Vehicles http://www.flhsmv.gov/html/safety.html Appriss – (866) 495 - 4206
Work Zone Fatalities	National Work Zone Safety Information Clearinghouse http://www.workzonesafety.org/crash_data/
State employee salaries	Florida Governor's Office of Open Government www.floridahasarighttoknow.com
Worker Compensation Claims	Florida Department of Financial Services Ms. Sam Walker - (850) 413-4808 Sam.Walker@myfloridacfo.com