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Developing a Framework for Financial Achievability of Department of Transportation Research and Development Projects

Patricia H. Born, Randy E. Dumm, and Robert J. Eger III

A financial analysis framework was developed to allow departments of transportation to assess research projects better. The framework recognizes that the research process contains multiple stages of decision making, and the framework details the information needed at each stage. 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. The framework also considers the decision to implement the research and its potential effects on employees. The application of the framework is illustrated with several Florida Department of Transportation research projects that involve the development of a multipurpose survey vehicle for evaluation of Florida roadways. This illustration allows for an explanation of each step in the framework with actual data from research reports and other internal or external sources. Although the framework is flexible and can be adapted for use in evaluating different types of projects, some judgment will be required when the specific inputs to the model are considered. Successful implementation of the framework will require focused data collection with emphasis on identifying the potential net benefits of research projects.

The purpose of this paper is to develop a financial analysis framework that will allow departments of transportation 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. The authors develop a financial analysis framework using several completed Florida Department of Transportation (DOT) projects as a guide. These projects, which involve the development of the multipurpose survey vehicle (MPSV) to analyze road surfaces, subsequently are used to illustrate the application of the framework.

To comprehensively evaluate the framework, the authors consider five possible measures commonly used to evaluate outcomes or performance. Each measure 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, whereas others use qualitative performance measures either in total (e.g., quality and performance) or in part (e.g., cost-effectiveness analysis). Collectively, these measures provide tools that can be applied across a wide range of situations. The framework considers and incorporates fundamental aspects of all five measures into an integrated decision tool. The measures are (*a*) cost-effectiveness analysis, (*b*) cost–benefit analysis, (*c*) return on investment, (*d*) quality and performance metrics that examine the likelihood of maintaining or increasing quality, and (*e*) management costs, a criterion that examines the types of managerial changes that are likely to be experienced during a research project.

Previous research in transportation has used variations of these five methods to investigate multimodal investment choices (*1*); prioritization of transportation projects (*2*); conceptualization, prioritization, and scheduling of geographic information systems (*3*); and estimation models that enhance the use of historical data (*4*). There is a paucity of frameworks that involve the decision-making process of a project from conceptualization to implementation with a focus on the benefits associated with the project along with the costs.

The authors expand on previous research by recognizing 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 vary according to the type of research project. All proposed research projects have their own costs and benefits, and although most of the costs and benefits can be captured and monetized, there are some that may not be easily identified. In addition, some aspects of a research project may result in improvements in efficiencies and job satisfaction. Although correlated, efficiency measures are easily monetized, whereas measures that capture a perception or feeling can be more difficult to translate into monetary terms. Further, each research proposal to the Florida DOT could or should in part be evaluated at a higher level against the stated mission of the Florida DOT, 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 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 action is not feasible or practical in a world with limited resources; however,

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to ignore the benefit that improved transportation safety provides is also problematic.

Any project has some degree of uncertainty about 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. Decisions to pursue, continue, or reject research projects should be informed to the greatest extent possible to minimize this uncertainty cost-effectively. As such, the initial framework for this project was developed in the context of decision-making under uncertainty.

In addition, it is important to recognize that although 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 require some professional expertise and judgment, at a level that would be expected of a project manager.

THEORETICAL DETERMINANTS OF THE FRAMEWORK

This section provides a theoretical framework for assessing R&D projects; the framework integrates 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 the implementation phase (i.e., how the research is adopted by the current labor force or user). In addition, both phases have a physical and psychic dimension.

Taxonomy of Costs and Benefits

Table 1 introduces a taxonomy of the four primary types of costs and benefits categorized as physical or psychic and research or implementation. Research costs 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 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 and capital equipment, and publication costs. Identifying and quantifying the physical benefits in the research phase may be more challenging than for the implementation phase, in which benefits include, for example, money saved or higher quality.

Psychic costs are typically more difficult to predict and quantify. Because research proposals are often related to some type of application in the field, psychic costs are likely to occur in the implementation phase. Estimating the psychic costs of research is complicated by a lack of clarity in whether the implementation of the research will lead to further costs, produce benefits, or result in both. As an example, the implementation of innovation that automates a dangerous task produces benefits in 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 impose additional costs (physical and psychic) in termination costs and reductions in employee morale. In addition, 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 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.

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 as discussed in the taxonomy. Second, the decision maker does not know the number of possible payoffs or what those payoffs may be. These unknowns represent a different problem than those normally involving risk, in which the decision maker knows the number of 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 decision maker selects subjective probabilities for each possible outcome and chooses the option that provides the highest subjective utility. A subjective expected utility function, SE[U], can be written as

$$\mathrm{SE}[\mathrm{U}] = \sum_{i=1}^{N} \alpha_i U(w_i) \qquad (1)$$

where α_i is the probability of each possible outcome i and $U(w_i)$ is the utility derived from wealth gained in outcome i.

TABLE 1 Taxonomy of Cost and Benefits

	Research		Implementation	
	Cost	Benefit	Cost	Benefit
Physical	Labor or capital expenditures Publication expenditures	New methods and capital	Labor or capital expenditures Additional management or staff time Temporary workload increases	Money saved Higher-quality good or service
Psychic	Stress Project failure	Knowledge spread Higher-skilled labor force Identification of other research topics	Project failure Morale drops from temporary workload increases	Project success Increased team mentality Increased feeling of "safeness"

Because there are N possible outcomes, the probabilities of each possible outcome must sum to one, as shown in Equation 2.

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

The authors 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 decision maker knows there are multiple possible outcomes when the research is implemented. In some cases the maximized expected profit may be extremely low; in others it will be much greater. The authors posit that the decision maker assigns a subjective probability to each possible outcome. Consequently, the subjective expected profit of research (SE[π]) can be written as shown in Equation 3.

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

where

$\pi_i = B_i(\alpha) - C_{Ii}(\alpha)$,
$B_i(\alpha)$ = benefits of outcome i as a function of implementation level α, and
$C_{Ii}(\alpha)$ = cost of implementation level α.

If outcome i is realized, then the decision maker 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:

$$\frac{\partial\pi}{\partial\alpha}=\frac{\partial B(\alpha)}{\partial(\alpha)}-\frac{\partial C_I(\alpha)}{\partial(\alpha)}=0 \tag{4}$$

Multiple optimal implementation levels (α_i^*) may or may not be identical, and α will always be strictly positive because any level of implementation that leads to less than a zero profit should not be implemented. Thus, the worst case scenario is truncated.

Intermediate Versus Final Profit

It is necessary to differentiate between the different types of profit. The final profit of implementation of research is denoted 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 decision maker maximizes as a function of α to gain the most from the research. Because of the nature of fixed costs, the costs associated with pursuing the research (sunk costs) do not affect the level of implementation because they have already been paid.

However, the subjective expected profit (SE[π]) 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 decision maker 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 decision maker simply ceases work on the research project and incurs no new costs because the fixed costs have already been incurred.

Decision Framework

The subjective expected profit function introduced in the previous section is a fundamental input to the decision tree presented in Figure 1. It is assumed that at each stage shown on the decision tree, the decision maker gains additional information and that this new information reduces uncertainty. In the absence of any uncertainty, the decision maker's profit function could be written as

$$\pi=B(\alpha)-C_I(\alpha)-(N\gamma+\mu+\delta+C_r) \tag{5}$$

where

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

In a real-world setting, the decision maker does not know the ex ante outcomes of the research and therefore a decision tree is useful because 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 decision maker. It is assumed for the purposes of the narrative that the decision maker is a single person, but the decision maker also could be a committee or even a number of committees.

As with any large-scale public works entity, it is assumed that the Florida DOT 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 6). It is also assumed that new projects may fill a variety of roles or complement existing technologies.

$$\prod(\alpha)=\sum_{i=1}^{n}\pi_i+\sum_{j=1}^{z}\pi_j \tag{6}$$

In the framework identified in Figure 2, the primary concern is the decision about the implementation of a new project. The first stage of the process is the identification of an existing problem that could be addressed through a successful research project. In this first stage, a problem can be identified by researchers, the decision maker, or politicians, or it can be identified through the failure of a previous project. Although costs may be incurred in clarifying and developing the problem statement, the decision maker is not required to make a decision in Stage 1.

Equation 7 describes the subjective expected profit (SE[π]) 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).

$$\mathrm{SE}[\pi]=\sum_{i=1}^{N}\alpha_i(B_i(\alpha)-C_{Ii}(\alpha))-(E[N\gamma]+\delta+\mu+E[C_r]) \tag{7}$$

Once the problem is identified, the decision maker 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

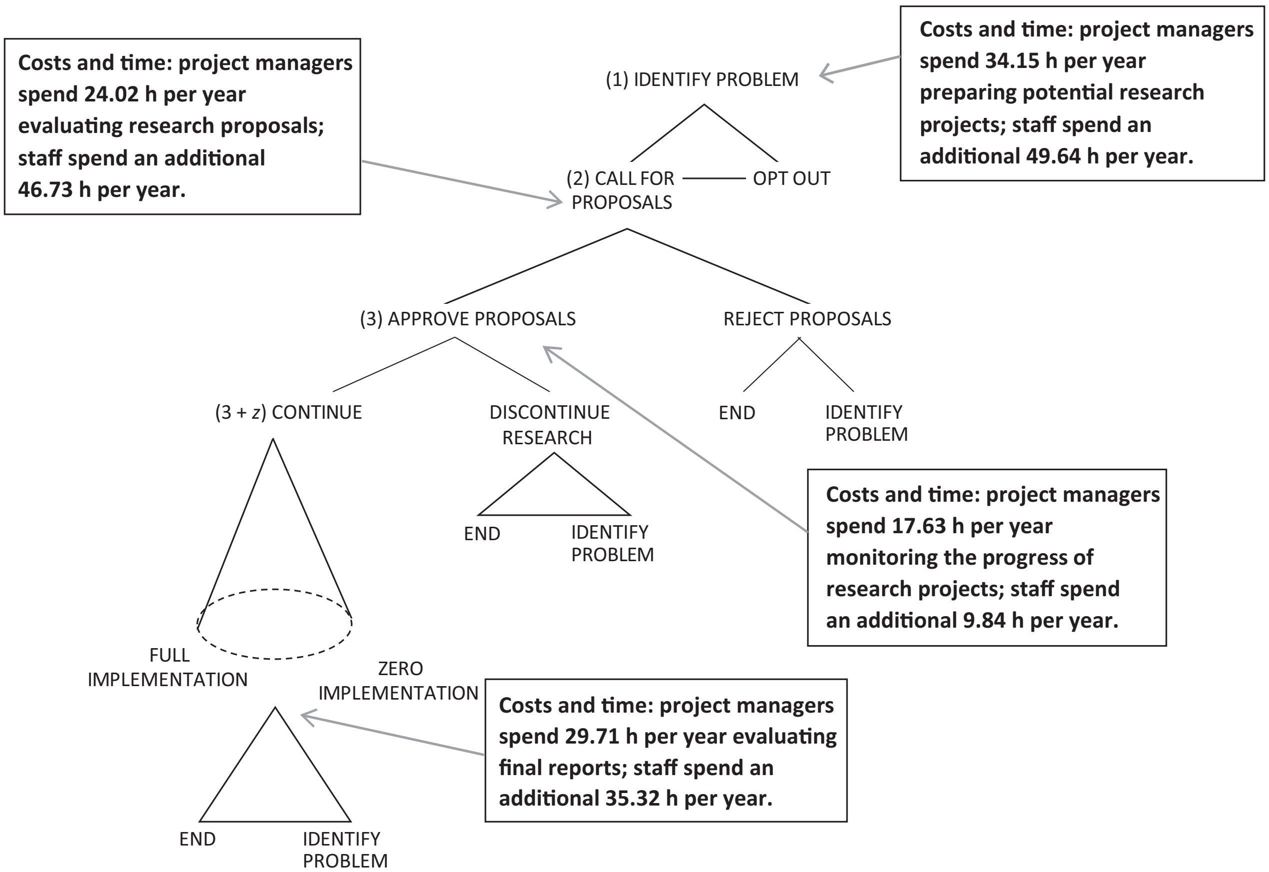

FIGURE 1 Managerial time and cost.

or that it would not be feasible. If no RFP is pursued, the decision maker incurs only cost δ. Equation 8 shows this binary decision:

$$\text{if}\left\{\begin{array}{ll}\sum_{i=1}^{N}\alpha_i\pi_i-(E[N\gamma]+\delta+\mu+E[C_r])\geq-\delta & \text{pursue}\\ & \rightarrow\\ \sum_{i=1}^{N}\alpha_i\pi_i-(E[N\gamma]+\delta+\mu+E[C_r])<-\delta & \text{end}\end{array}\right\}\quad(8)$$

If the decision maker selects to pursue the research, the decision maker accrues cost $N\gamma$ (i.e., the cost of reviewing all the proposals) and the cost of requesting proposals (μ). If all proposals are rejected, the decision maker faces a total loss equal to the costs associated with Stage 2 ($N\gamma+\mu$), plus the identification costs (δ) in Stage 1.

Once all the proposals have been reviewed, the cost of the selected project is known. In Stage 3, a proposal has been accepted and the decision rules can be rewritten as shown in Equation 9. The left side of the equations is the expected final profit of the research; the right side is the loss suffered if the research is ended.

$$\text{if}\left\{\begin{array}{ll}\sum_{i=1}^{N}\alpha_i\pi_i-(N\gamma+\delta+\mu+C_r)\geq-N\gamma-\delta-\mu & \text{pursue}\\ & \rightarrow\\ \sum_{i=1}^{N}\alpha_i\pi_i-(N\gamma+\delta+\mu+C_r)<-N\gamma-\delta-\mu & \text{end}\end{array}\right\}\quad(9)$$

In Stage 3, the decision maker is fully aware of the research costs and breaks them into z parts. Each part represents a point at which the decision maker reviews the approved project's progress (e.g., through task reports). If sufficient progress has not been made 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.

$$C_r=\sum_{i=1}^{z}C_i\quad(10)$$

As such, the decision rules for i RFP renewals may be rewritten as

$$\text{if}\left\{\begin{array}{ll}\sum_{i=1}^{N}\alpha_i\pi_i-\left(N\gamma+\delta+\mu+\sum_{i=1}^{z}C_i\right) & \\ \qquad\geq-\sum_{i=1}^{i}C_i-N\gamma-\delta-\mu & \text{pursue}\\ & \rightarrow\\ \sum_{i=1}^{N}\alpha_i\pi_i-\left(N\gamma+\delta+\mu+\sum_{i=1}^{z}C_i\right) & \\ \qquad<-\sum_{i=1}^{i}C_i-N\gamma-\delta-\mu & \text{end}\end{array}\right\}\quad(11)$$

Thus, the total costs for ending the project at point i are the accrued costs in Stage 3 plus the costs of Stages 1 and 2.

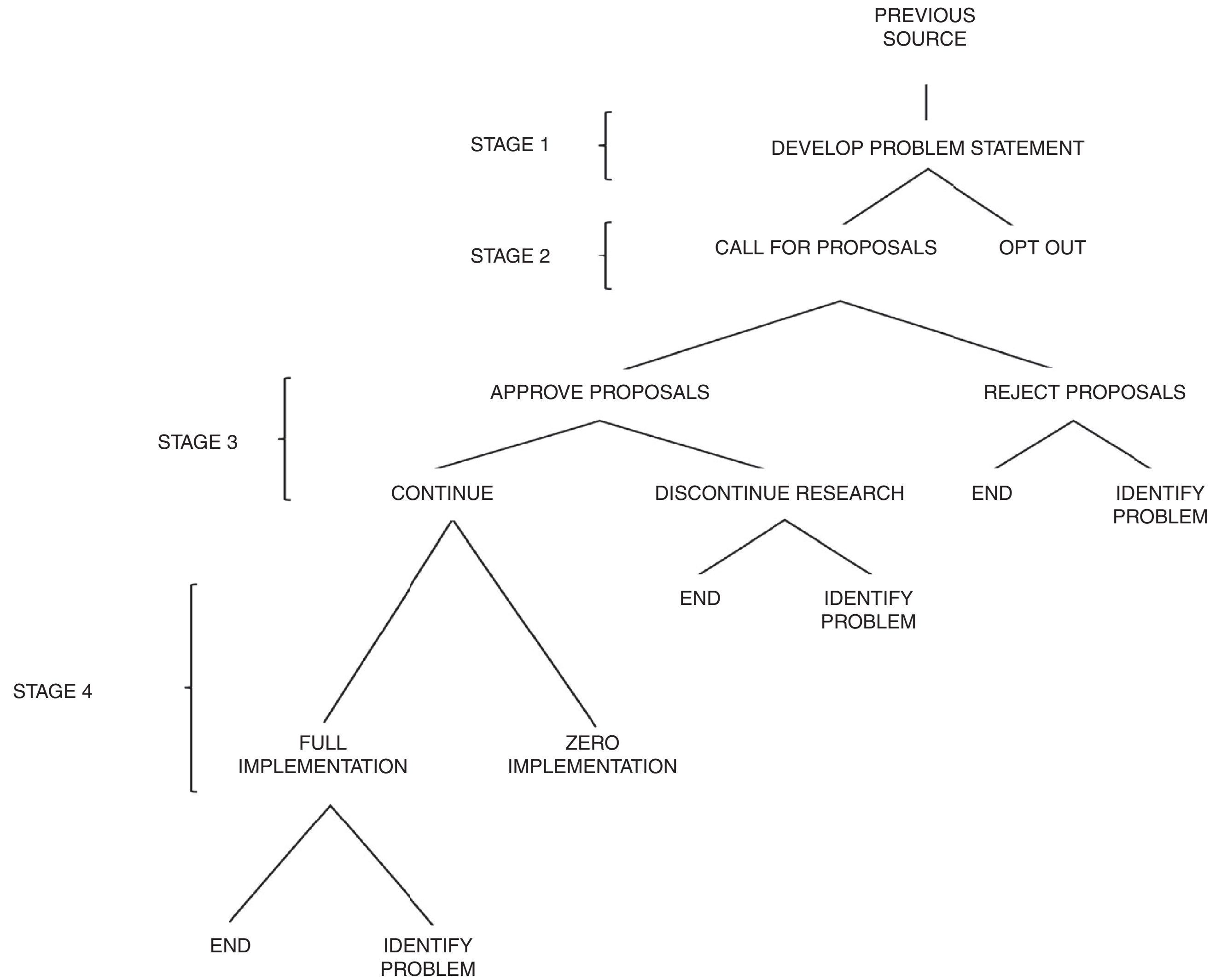

FIGURE 2 Decision framework.

In the final stage, the approved research has been completed and the final research costs have been paid. The decision maker'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.

$$\pi(|\text{pursued}) = \sum_{i=1}^{N} \alpha_i \pi_i \quad (12)$$

or

$$\pi(|\text{pursued}) = \sum_{i=1}^{N} \alpha_i (B_i(\alpha) - C_{Ii}(\alpha)) \quad (13)$$

Because costs have been realized, the decision maker 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.

$$\pi(|\text{pursued}) = B_i(\alpha) - C_{Ii}(\alpha) \quad (14)$$

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

$$\frac{\partial \pi}{\partial \alpha} = \frac{\partial B(\alpha)}{\partial \alpha} - \frac{\partial C_I(\alpha)}{\partial \alpha} = 0 \quad (15)$$

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

Although one may expect that at this point all projects that are implemented will be financially profitable, that 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 14 is greater than zero. Total profit may be less than zero because the net benefits conditional on implementation may be modest and the other costs associated with the research may outweigh the net benefits. The equation can be rewritten as

$$\pi = B(\alpha^*) - C_I(\alpha^*) - (N\gamma + \delta + \mu + C_r) \quad (16)$$

which will be less than zero if Equation 17 holds:

$$B(\alpha^*) - C_I(\alpha^*) < (N\gamma + \delta + \mu + C_r) \quad (17)$$

Although this type of case is possible, the potential for underestimating benefits makes it unlikely to occur.

The benefit–cost equation, Equation 18, is separated into four parts that are a function of the new innovation's revenue and costs and (if applicable) the technology it is replacing.

$$B(\alpha) - C_I(\alpha) \quad (18)$$

The decomposition of Equation 18 (essentially the increase in profits as a result of the innovation) yields Equation 19. 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.

$$B(\alpha) - C_I(\alpha) = R_2 + C_1 - R_1 - C_2 \quad (19)$$

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, whereas in others, the new technology may be only partially implemented. Some technologies are used in tandem or to supplement existing technologies, and the proposed framework accommodates those situations.

The paper highlights only a few stages of the framework. Assuming the structure stays the same, the addition of new stages does not alter the primary conclusions of the decision model. That is, the decision maker does not let previous spending influence the propensity to pursue the next stage (sunk costs fallacy); conditional on reaching the final stage, the decision maker selects the optimal level of implementation such that the level of implementation is greater than or equal to zero; and the project may still generate a significant loss even if the level of implementation is nonzero.

Benefits

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

Three types of benefit streams are (*a*) those that continue indefinitely, (*b*) those that stop at time T and (*c*) those that continue as foundations for future projects. The various benefit streams are shown in Figure 3.

The benefit stream that continues indefinitely can be written as follows:

$$\pi_L(\alpha, t|\text{pursued}) = \pi + \beta^1\pi + \beta^2\pi + \beta^3\pi + \beta^4\pi + \cdots + \beta^n\pi \quad (20)$$

where $\beta \in (0, 1)$.

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

$$\pi_L(\alpha, t|\text{pursued}) = \frac{\pi}{(1-\beta)} \quad (21)$$

However, in many cases, the benefits are relatively short-lived, as shown in Figure 3*b*, and 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). The equation is as follows:

$$\pi_L(\alpha, t|\text{pursued}) = \pi + \beta^1\pi + \beta^2\pi + \beta^3\pi + \beta^4\pi + \cdots + \beta^t\pi \quad (22)$$

where $t < \alpha$.

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

Alternatively, as indicated in Figure 3*c*, some projects would not be possible without an innovation or findings provided by previous research. In this case, the benefit stream continues as long as the new project continues. For example, imagine a previous project that has the following benefit stream:

$$\pi_l^o = \pi + \beta^1\pi^o + \beta^2\pi^o + \beta^3\pi^o + \beta^4\pi^o + \cdots + \beta^n\pi^o \quad (23)$$

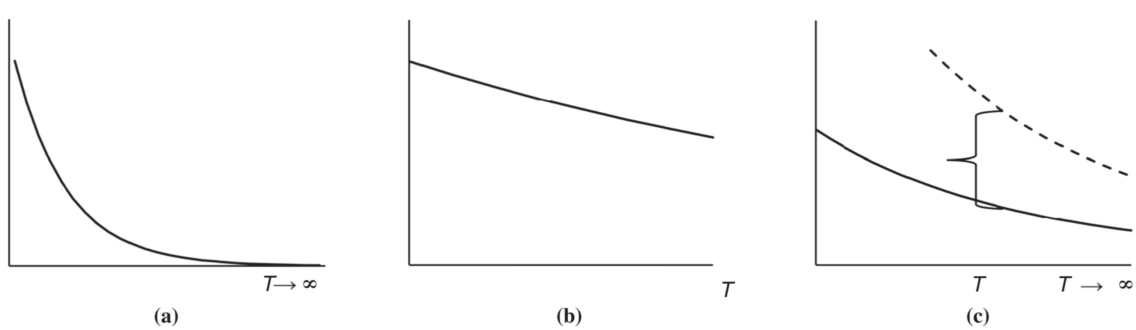

FIGURE 3 Types of benefit streams: (*a*) continues indefinitely, (*b*) stops at time *T*, and (*c*) continues with new project.

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

$$\pi_t^n = \pi_t^n + \beta^{t+1}\pi_t^n + \beta^{t+2}\pi_t^n + \beta^{t+3}\pi_t^n + \cdots + \beta^{t+n}\pi_t^n \qquad (24)$$

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

$$\pi_t^n = \pi_t^n + \beta^{t+1}\pi_t^n + \cdots + \beta^{t+n}\pi_t^n - (\beta^t\pi^o + \beta^{t+1}\pi^o + \cdots + \beta^{t+n}\pi^o) \qquad (25)$$

Before a decision maker 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, the authors argue that 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 (*3*).

The choice of discount rate presents a series of important issues related to the projects under evaluation. Certain projects will have a depreciation 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 midterm life cycles that do not exceed 20 years. The common discount rates associated with these short and midterm capital assets are U.S. Treasury, U.S. agency, or municipal bond yields. The investment grade on these debt instruments coincides nicely with many state restrictions on investments, for which 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 U.S. Treasury 10-year bond yield is both defensible and prudent given the grade of U.S. Treasury bonds.

An alternative to 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. 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 26). All of these potential rates are explicitly decided by the decision maker in conjunction with information from the financing professionals in the organization. Some states use a fixed annual rate for analysis, and some states use the current market rate that coincides with the innovations life cycle.

$$\beta = f(\rho_1, \rho_2, \rho_3, \ldots, \rho_n) \qquad (26)$$

APPLICATION OF DECISION FRAMEWORK TO FLORIDA DOT's MPSV RESEARCH PROJECTS

In collecting data for the application of the framework, the authors used a variety of data-gathering efforts. To learn about the MPSV project, the authors met with the Florida DOT project management team. Two main benefits were identified: (*a*) a reduction in the time required to analyze a section of road and (*b*) a reduction in worker injuries or fatalities.

Using research projects available on the Florida DOT research website, the authors reviewed projects related to the MPSV to determine the extent to which costs and benefits were provided in a relevant sample of the project reports. After this review, the authors identified four projects. To allow for comparability, the project costs were discounted with the U.S. Treasury 10-year yield average for 2001 through 2013. The yield average was calculated by taking the U.S. Treasury 10-year rate on January 1 of a given year over the 13-year time period; the result is an average nominal discount rate of 3.50%. The authors used the 10-year U.S. Treasury rate under the assumption that the innovation has a similar life cycle to that of the capital associated with the MPSV, as reflected in discussions with the Florida DOT. The first MPSV was retired after 10.3 years of service, providing support for the assumption of a 10-year life cycle.

To address the capital costs in the projects, capital costs associated with the MPSV are depreciated by using a straight-line depreciation method based on a 10-year service life. This depreciation follows the Governmental Accounting Standards Board Statement 34, which gives governments 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.

The next step was to identify all other relevant available costs related to the development and subsequent use of the MPSV. First, basic information was obtained on the number of survey vehicles in service and acquisition and maintenance costs for each vehicle. 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 a reduction in the number of survey points of 566% for urban use, 485% for rural use, and 782% for Interstate use. Florida DOT personnel reported an average savings of $375 per lane mile. Although the process described above is specific to MPSV, it 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.

After attempting to identify available relevant costs, the authors collected worksite statistics. A list of Florida DOT predesign coordinators for each project was obtained, and an e-mail questionnaire was distributed to these coordinators to gain a better understanding of the process of determining actual benefits and data availability. The 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 authors requested information and received data from the Florida DOT project manager about the actual use of the MPSV, maintenance records, operational cost, vehicle equipment, and driver and crew information. To collect data on worker injuries, statewide injury reports from the past 10 years were obtained from the Office of the General Counsel of the Florida DOT. These data were analyzed and filtered to include only those injuries involving survey crew members.

The data obtained to use in the decision framework as applied to the MPSV included research cost of the project; acquisition cost of the new equipment; cost to run a survey crew, including wages of employees, injuries related to the task at hand, and the time frame of completion of a survey; and the cost of operating new equipment, including external operational cost, maintenance cost, service life, salaries of operators of new equipment, and the time frame of completion of a survey by the vehicle. The authors provided a guidebook to the Florida DOT on data accumulation for the project.

To collect data for Stages 1 and 2 of the framework (costs of problem statement development and call for proposals), the authors solicited information from project managers about the time that is spent on all phases of a research project. Because 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. Forty-seven project managers completed the entire survey. Responses were obtained from project managers in 11 divisions of the Florida DOT. Figure 1 identifies and illustrates the results from the survey.

Numerical Application

Before the call for proposals, there are several known variables, most of which are associated with the costs of the survey crew. For simplicity, it is assumed that the differences between the revenues of the two projects is equal to *X*, where *X* is strictly greater than or equal to zero. This assumption is reasonable because it is unlikely that decision makers will pursue innovations that make current projects more expensive.

The authors found that since 2003 approximately \$46,000 was spent on worker compensation claims. To further simplify the problem, it is assumed that the medical expenditures of survey crews will be equal to the medical costs of the MPSV users, and the medical costs of survey crews will be ignored. The authors believe the medical costs in this example should be lower per mile, but that does not necessarily translate to lower medical costs because the MPSV is likely to be deployed more often. As such, the probability of injury per mile may decrease, but an increase in worker injuries may be observed if the miles associated with the MPSV are large.

According to the information provided, the size of a survey crew is generally three to four workers, with costs from \$140 to \$225 per hour. An average wage of about \$52.29 per worker hour is implied. The survey crew teams can cover between .02 and .028 mi per hour, so it takes 34.71 to 50 h for a survey crew to cover 1 mi of road. The operational cost associated with survey crew workers is

$$C_o = W_o * E[\text{crew}_o] * E[D_o] + \text{OC}$$

where

C_o = cost per mile of the survey crew,
W_o = worker's hourly wage,
D_o = time it takes a survey crew to cover 1 mi,
crew_o = crew size, and
OC = other costs.

Given that the average survey crew is approximately 3.5 members, the average wage per hour is \$52.29, and the average coverage speed is .024 mph, the cost of a survey crew is estimated to be about \$7,843 per mile plus the other costs. In this case, the other cost is the analysis of the digital terrain map. The map analysis is estimated to cost around one-third of the project cost. This value can be found with the equation below:

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

This equation simplifies to

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

where *x* is the cost of the survey crew and *y* is the cost of the digital map. This equation leads to the cost of the digital map:

$$\frac{\$7{,}843}{2} \approx \$3{,}921$$

and implies that the total cost per mile is

$$\$3{,}921 + \$7{,}843 \cong \$11{,}764$$

At this point, the costs per mile of the survey crew have been calculated and now the cost saving required to make the MPSV financially viable is needed. As a reminder of the decision tree, the following parameters are defined: (*a*) $N\gamma$ is the cost of reviewing *N* proposals, (*b*) δ is the cost of identifying the problem, (*c*) μ is the cost of sending out an RFP, and (*d*) C_r is the cost of the selected proposal.

A project should be pursued past the identification stage if the following equation holds:

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

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

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

For simplicity, it is assumed that the decision maker is concerned only with the cost savings potential of the MPSV. Therefore, the decision maker 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 Florida DOT workforce. The surveying and mapping office lost approximately 50% of its field staff and 25% of its office staff as a result of state personnel reductions. Separating the cause of these reductions from the state mandates and the innovation from the manual survey collection by the survey crews from the automated survey innovation of the MPSV is extremely difficult and leads to the assumption that revenues of the survey crew and the MPSV are identical. That is, the MPSV and the survey crew would be able to do the same job while keeping the quality constant. This assumption cancels out the revenues of the competing technologies and leaves the following equation:

$$\$11{,}764 * \text{miles} - C_2 * \text{miles} - \left(E[N\gamma] + \mu + \delta + E[C_r^a]\right)(1-\beta) > -\delta(1-\beta)$$

The addition of the $(1 - \beta)$ term, seen on both sides of the equation, reflects that these costs are nonrecurring and can be spread out over the innovation's life cycle. The results of the survey of project managers revealed that the average project manager spends 32.87 h per year identifying the problem (δ) and 23.34 h reviewing proposals ($N\gamma$), and that the cost for the call for proposals (μ) appears to be minor because information about these costs was not available. The project manager survey provided perspective on administrative staff time required for identifying the problem (47.48 h) and reviewing proposals (44.7 h). In addition, the project managers indicated that, on average, they manage 2.53 projects per year. Although the number of projects may underestimate the number of proposals, the number of projects managed per year was used to allocate the time spent by the project manager and administrative staff in Stages 1 and 2 of the decision framework, the costs associated with identifying the problem and the costs of evaluating proposals. This number provides for an overestimation of the costs per proposal, a conservative estimation technique.

Data from the Florida DOT show that the average engineer's annual salary is about $72,767 and the average administrative staff's annual salary is about $30,507. From the averages provided in the project manager survey, the costs allocated to the MPSV for identifying the problem (δ) are $455 for the project manager and $275 for the administrative staff. Since the MPSV was implemented, the decision makers correctly identified the value of improvements and moved to the second stage to determine whether the costs of sending out a proposal satisfied the following equation:

$$\$11{,}764 * \text{miles} - C_2 * \text{miles} - \left(E[N\gamma] + \mu + \$730 + E[C_r^a]\right)(1-\beta) > \left(E[N\gamma] + \mu + \$730\right)(1-\beta)$$

In Stage 2, the additional costs of reviewing proposals are assessed by the decision maker. From the project manager survey, allocating costs to reviewing the proposals, $N\gamma$, leads to $323 for the project manager and $259 for administrative staff. Assuming that the call for proposals cost (μ) is insignificant leads to

$$\$11{,}764 * \text{miles} - C_2 * \text{miles} - \left(\$1{,}312 + E[C_r^a]\right)(1-\beta) > (\$1{,}312)(1-\beta)$$

At this point the decision maker enters Stage 3, selecting the final project. The decision maker knows how much the research costs are. In the case of the MPSV, R&D costs come to approximately $636,674 in real dollars; these costs are derived from Florida DOT projects BC965, BD544-11, BD544-36, and BDK05. From this information, it is known that the project will proceed as 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.

$$\$11{,}764 * \text{miles} - C_2 * \text{miles} - (\$1{,}312 + \$636{,}674)(1-\beta) > (\$1{,}312)(1-\beta)$$

To derive the costs for the MPSV (C_2), the following costs are needed: all costs underlying the operations and management of the MPSV, a measure of the quality of the MPSV data compared with the survey crew, a measure of the impact on employees of the introduction of the MPSV, and the lane miles covered by the MPSV.

Information was collected 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 (information on the Florida DOT overhead allocation was lacking but assumed to be similar to that for a survey crew). The authors have been unable to acquire data related to the impact on employees, such as employee satisfaction or employee performance evaluations, but have been able to find some evidence that the MPSV data are similar to survey crew data collected (see Florida DOT BD544-36). Using the average U.S. Treasury 10-year yield of 3.5043% for the 2001 to 2013 and assuming that the innovations associated with the MPSV have a similar life cycle as that of the capital assets for the MPSV, the authors annualize the costs for the MPSV. Project manager oversight is the average amount of time spent by project managers (45.84 h) and administrative staff (43.19 h) annually monitoring the progress of research progress and evaluating final reports. All other costs are derived through Florida DOT subject matter experts.

To explore the benefit associated with the MPSV, the authors evaluated the costs of the alternative, the survey crew, with that of the MPSV per mile. The cost per lane mile of the survey crew was established at $11,764. The annualized cost of the MPSV per lane mile was derived 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 MPSV. This amount of savings is about $11,550 per lane mile. The initial known investment in the innovation in R&D for the MPSV is estimated at $636,674. Therefore, 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: it is assumed that the technology placed on the MPSV capital asset has the identical life cycle as that of the capital asset, the vehicle. Technology may need to be replaced at shorter or longer intervals than the intervals of the capital asset. Therefore, it is assumed that the technology and the capital asset have no salvage value and are replaced simultaneously at the end of the MPSV life cycle. In addition, it is assumed that the MPSV continues to provide the same number of lane miles as for 2006 to 2013 for every year of its life cycle. Changes in any of the assumptions will change the savings associated with the MPSV.

Data Collection Challenges

Although it is suggested that the data required to apply the framework are readily available, it is recognized that there may be significant costs associated with these collection efforts, in both time and expertise. One could argue that each data collection effort includes some form of learning or experiential cost that declines through multiple uses or ongoing use of a specific data source. When using cost–benefit data that are unique to a project, the project manager has no opportunity to experience these types of efficiency gains.

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