Valuing the Benefits of Transportation Research: A Matrix Approach

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16. Abstract

The purpose of this study was to research, develop, and test various methodologies, approaches, equations and guidelines that could be applied to proposed, existing and completed research projects to provide some measure of the benefit and return on research expenditures.

The approach to the study was to do the following:

- Gain an understanding of the kinds of projects traditionally sponsored by the FDOT Research Center;
- Investigate what work had already been accomplished in the field of quantification of research benefits;
- Determine certain kinds of research best measured by different measurement approaches;
- Gather data on completed projects to test various methods;
- Recommend to the FDOT research department an approach for quantifying the benefits of their research program;

This report begins with the premise that no universal measurement method could be applied to value the economic impact of transportation research and development (TR&D). Accordingly, an alternative TR&D project classification methodology to better match research activity with evaluation methodologies is proposed. Using this alternative classification, an extension of Option Pricing Theory to valuing the economic impact of TR&D and research evaluation is developed. The conditions of limited data availability, commonly found in transportation research agencies, are partially resolved through Monte Carlo simulation. The findings indicate how the Real Option Approach, combined with Monte Carlo simulation, can be adopted to better capture the elements of risk and uncertainty to provide a more accurate economic evaluation of research projects.

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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the author(s) who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Florida Department of Transportation or the Research and Special Programs Administration. This report does not constitute a standard, specification, or regulation.

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Executive Summary

Introduction

State transportation research centers must strike a balance between serving the needs of transportation planners, officials and engineers, and the general public; users of the transportation system. Scrutiny of the use of public funds and the reality of the political environment must also be addressed.

The activity generally defined as *research* encompasses a variety of work types and touches many functional areas. While it is sometimes taken for granted that investments in transportation research should yield positive social and economic benefits, little work has been found that helps a transportation agency to systematically quantify the benefits of its program. State transportation research centers, just as any other research institute, strive to measure their performance activities. Positive economic returns associated with research findings serve as justification for past and future requested research budgets. Programmatic benchmarking and performance measurement take on even greater significance in times of fiscal restraint, when budget cuts might affect research programs significantly.

One of the key problems in research management is that of quantitatively evaluating research, whether completed, planned, or in progress. On the one hand, research managers themselves need to evaluate individual projects to make management decisions relating to the department's (agency) research and development portfolio on the other research program managers are continually under pressure from upper management to explain and defend the value of their programs in financial terms. The latter is particularly true in times when research programs face increasingly reduced budgets, and trade-offs between long-term, basic research, and when short-term, applied research become more necessary.

Current State of Research

Most transportation research programs rely on the few very large and easily quantified success stories to justify their investment levels to decision makers. In the absence of other performance measures, this method is certainly legitimate but not comprehensive. It is difficult to quantify the success of transportation research programs, and traditional economic or financial net present value approaches are not necessarily appropriate. Relatively little work has been undertaken to identify the efficacy of the research activity itself, or to evaluate the research activity on a benefit/cost or return on investment basis.

Extensive research on currently available evaluation methods showed that there is not a universal approach to project valuation. Rather, there are different valuation approaches, which have been applied to tentatively ascribe an economic value to the benefits of transportation research programs. Some of these approaches try to provide quantitative measurements, but most rely on qualitative assessments to overcome what appears to be the main constraint to evaluation: the capability to measure economic benefits of transportation research programs.

Study Objectives

The objective of this study was to develop an approach to measure the value of research projects and to provide some measure of the benefit and return on research expenditures. To achieve these objectives, the Center for Urban Transportation Research (CUTR) initiated a review of the projects sponsored by the Florida Department of Transportation (FDOT) Research Center. CUTR further investigated what had been already accomplished in the field of quantification of research benefits and sought to determine what kinds of research different measurement tools best measured. Finally, CUTR compared traditional measurement tools to the Real Options Approach and found valuable evidence indicating the significant contribution that this alternative approach provides. Under the conditions of limited data availability, commonly found in transportation research agencies, CUTR found that the Real Option Approach, combined with Monte Carlo simulation, could be adopted to better capture the elements of risk and uncertainty to provide a more accurate economic evaluation of research projects.

Recommended Findings

1. ***A "matrix approach" should be applied in creating a research portfolio that includes a mix of high-risk high-potential payoff projects with other research initiatives.***

Among the currently available evaluation approaches, CUTR recognized that no single method is suited to evaluate projects across all proposed categories. Rather, even within one category, one or more approaches may be well suited, their use dependent more on agency constraints and objectives.

This matrix supports the evidence that project evaluation needs to be multidimensional, incorporating not only the project categories but also the dimensions of time, risk, and ease of quantification. Ultimately, CUTR found that in the presence of data availability (and an established collection procedure), for those projects characterized by elements of uncertainty in outcome, the RO Approach (by means of a binomial decision tree), better represents and captures the potential payoffs of a proposed project. The "matrix approach" may also be useful in creating a research portfolio that includes a mix of high-risk high-potential payoff projects with other research initiatives.

	Time of Evaluation		Time to Implement		Risk		Ease of Quantification		Recommended Evaluation Method				
Category	**Early**	**Late**	**Short**	**Long**	**High**	**Low**	**High**	**Low**	**B/C**	**ROI**	**NPV**	**RO Approach**	**Peer Review**
A Develop Product or Procedure													
C Evaluate Product or Procedure													
E Research and Document													
F Technology Transfer													

Figure 1 Matrix Approach to Project Evaluation

2. ***Utilize an extension of the Real Option Approach as a more sophisticated tool for measuring the potential benefits of transportation research.***

The RO Approach can help to provide a better assessment of Research and Development (R&D) projects whenever there is entailed a relevant element of risk and uncertainty. Transportation R&D projects have the potential to produce enormous benefits, but they come with the risk that actual benefits, costs, and other factors affecting implementation may differ greatly from those predicted. Investment in transportation R&D can be regarded as the option, not the obligation to take some action in the future. The option approach shifts this decision-making process from simply choosing whether to invest in a R&D project to a management perspective that considers a range of possible decisions, with the potential value of each decision measured in terms of its option creating value.

Eventually, the option valuation process could be extended to all those project types that, according to CUTR's proposed evaluation matrix, can be valued by means of the RO Approach. Accordingly, the project manager could produce an optimal project portfolio. By allowing a change of input parameters according to project type and category, the research manager could produce an optimal portfolio geared at maximizing returns given annually fluctuating budgetary constraints and relative risk aversion. Furthermore, a better tracking of the project completion phase will eventually supply improved quantitative information to use in the option valuation, or any other process. Ultimately, any synthetic data set created by means of Monte Carlo simulation can be substituted by historical data as data collection on project benefits and implementation costs becomes routine.

3. ***Tracking project success rates, costs, and benefit data must be institutionally integrated if any systematic method of evaluation is to be established. The extent of this effort must be balanced to consider the cost and effort of such a program.***

The FDOT should consider implementing a formal data collection regimen for research projects. Recognition that some projects may be difficult to measure and may not be easily quantified should not be used as an excuse for not embarking on this effort. There is a huge cost of going back to collect this data to quantify research projects, and there appears to be little emphasis on this issue by either Project Managers or Principal Investigators. Tracking of project success rates, costs, and benefit data must be institutionally integrated if any systematic method of evaluation is to be established.

4. ***For R&D programs to continue and to prosper, a change of "mindset" is required.***

The Real Options Approach represents not only a potential method for estimating expected project benefits, but also a way of thinking about research programs. Importantly, the RO Approach sets clearly the concept that research expenditure today is a "call option" on future gains for the FDOT. Universally, sound business practices protect against future losses and plan to be ready to take advantage of future opportunities. As such, research program expenditures are the extent of future losses but are a necessary cost of securing the ability to exploit future opportunities as they arise.

5. ***Incorporate statistical simulation processes to compensate for the current lack of historical data***

The lack of suitable data in the short term for project and program evaluation can be overcome through data simulation. An accepted and commonly used technique is Monte Carlo simulation, which can utilize a small number of data sets to provide valid, robust inferences of program or project value. As program data collection improves, these proxy data sets can be replaced by real data.

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Chapter 1 - Introduction

Background

The Florida Department of Transportation (FDOT) has been involved in transportation research for decades. Each year the FDOT Research Center receives both state and federal funds to conduct research, mostly performed by state universities. In 1999-2000, this funding exceeded $9 million. The Research Center was interested in more fully understanding how the benefits of this research could be better quantified. The management of the department and the Research Center recognize and appreciate the importance of measuring program performance. Programmatic benchmarking and performance measurement take on even greater significance in times of fiscal restraint.

While it seems inevitable that transportation demands will outstrip available resources, the growth in population, vehicle miles of travel, and vehicle registrations in Florida make this perennial problem even more acute. Performance measurement is always a desired management tool and its importance grows as competition for funding intensifies. Recognizing this, the FDOT, specifically the Research Center, embarked on an effort with two university research organizations to attempt to more completely analyze how the benefits of transportation research in Florida could be quantified. This report represents the results of an effort conducted by the Center for Urban Transportation Research at the University of South Florida (CUTR) for the FDOT to assist in providing a framework to capture the benefits of transportation research investments.

1.1 Problem Statement

The activity generally defined as research encompasses a variety work types and touches many functional areas. While it is sometimes taken for granted that investments in transportation research should yield positive social and economic benefits, little is available to help a transportation agency systematically quantify the benefits of research programs.

Most transportation research programs rely on the few very large and easily quantified success stories to justify their investment levels to decision makers. In the absence of other performance measures, this method is certainly legitimate but not comprehensive. The mission of the FDOT Research Center is **"**To improve and protect Florida's transportation system through the ethical scientific conduct of research that increases global knowledge of products, processes, and practices; to transfer information; and to encourage the implementation of research results."

To quantify the success of this mission is difficult, and traditional economic or financial net present value approaches are not necessarily appropriate. Relatively little work has been undertaken to identify the efficacy of the research activity itself and to evaluate the research activity on a benefit/cost or return on investment basis.

Objectives

The purpose of this research was to research, develop, and test various methodologies, approaches, equations, and guidelines that could be applied to proposed, existing, and completed research projects to provide some measure of the benefit and return on research expenditures.

1.2 Study Approach

CUTR's approach to the study was to do the following:

- Gain an understanding of the kinds of projects traditionally sponsored by the FDOT Research Center;
- Investigate what work had already been accomplished in the field of quantification of research benefits;
- Determine certain kinds of research were best measured by different measurement tools;
- Gather data on completed projects to test various methods;
- Recommend to the Department an approach for quantifying the benefits of their research program.

The report is generally organized following this approach. Chapter 2 is a discussion of the premise and findings that various types of research may be best suited for different methods of measuring benefits. This section of the report also addresses the project categorization scheme that was hypothesized as being appropriate by the researchers.

Chapter 3 presents the results of the literature review conducted by CUTR. It summarizes the findings of a review of how the benefits of research are quantified in other industries as well as in the transportation sector. This portion of the report also summarizes a survey of the efforts of state transportation departments to calculate and track the benefits of their research efforts.

Next, the results of the surveys of FDOT project managers and contracted principal investigators are outlined. Chapter 4 details the process used and the results of the survey. The survey was conducted to determine whether detailed data existed on benefits of completed research projects, to test the project categorization scheme that was contemplated by CUTR at the outset of the study, and to obtain detailed information so that various methods of calculating the returns of research could be made.

Chapter 5 presents an analysis of a subset of the projects for which information was gathered through the survey. This additional data provided the input for deriving a proxy base dataset to validate the model detailed in this portion of the report.

Chapter 6, Model Development, includes a discussion of currently available techniques used to evaluate the benefits of research and explores in detail the potential application of the real options approach to estimating the future return of investments in transportation research.

The final section of the report, Chapter 7 includes a discussion of the findings of CUTR's research on this subject, the conclusions reached by the research team, and a set of recommendations for consideration by the Department and the Research Center.

Chapter 2 – Project Categorization

A premise of the researchers at the initiation of the study was that there might be a project categorization scheme that would lend itself to the analysis of projected or real benefits of the projects funded by the FDOT Research Center. The Center's classification of its program has traditionally been along functional lines. While this scheme is appropriate for program management, the researchers felt that it may not be the best way to segregate research projects for the analysis of returns on investment.

2.1 Categorization Hypothesis

After examining over two hundred completed project summaries, the research team proposed that due to the disparity in project focus, approach, timeframe, and expenditure, no single model or equation would likely emerge to effectively predict likely returns on investment.

The suggestion in the request for proposals was that different formulas might, in fact, be appropriate for the research projects in various functional areas (i.e., Construction, Environmental Management, Materials and Testing, Operations, Planning, Public Transportation, Roadway Design, Safety, Structures, Traffic Operations, and University Transportation Centers Research).

CUTR proposed that a more appropriate differentiation of the projects might be based on the research objective. Developing a method to quantify the benefit of a technology transfer initiative seemed to present a different set of questions than did the prospect of evaluating the benefit of developing a new and more easily quantifiable process.

When more than 200 summaries of research projects were examined, the following classification design emerged:

- **Develop** a device or product
- **Develop** a process or procedure (including models)
- **Evaluate** a device or product
- **Evaluate** a process or procedure
- **Research** and document a subject or an issue
- **Conduct** a technology transfer, including training

Applying these classifications to a cursory review of the completed research projects seemed to yield an immediate fit of the projects into the classification system. It was thought these project types would lend themselves more readily to different measures for effectiveness and return on research expenditure than types categorized by the functional area of the research.

Tests of Categorization

The categorization system that was initially developed sought to rank the types of research activities from the easiest to quantify to the hardest to quantify. The development of a product or a device, it seemed, could be quantified if the research effort was successful, the new device was employed, and any productivity gains were measurable.

Conversely, at the other end of the classification system was the technology transfer activity. While the intrinsic value of this very legitimate part of a research program is unquestioned, the quantification of the benefits of this activity seemed far more challenging than in the case of a new product or process. Figure 2.1 illustrates this concept graphically.

Research Type	Perceived Ease of Benefit Quantification
Develop a product	Easy
Develop a process	Easy
Evaluate a device	Moderate
Evaluate a process	Moderate
Research and document	Difficult
Technology transfer	Very Difficult

Figure 2.1. Quantification of Benefits

The proposed classification system would only be valuable if the categorization of research projects left little room for debate. The system should be almost intuitive and, given the classification scheme and a set of projects, researchers and project managers should nearly always agree on the designation. How sensitive the classification system is to subjectivity was tested in two ways.

An internal validation activity was performed at CUTR. Three principal investigators were given a set of research project summary of final reports and asked to independently place each of the over 100 projects into one of the research categories (e.g., Develop a Product, Develop a Process). The independent categorization exercise yielded mixed results. While there was general consistency among evaluators, the distinctions between evaluating a process and evaluating a product seemed difficult to make. Similarly, while projects were grouped as development, the participants did not consistently place the development projects into the "product" or "process" categories.

Lastly, while there were many instances where "Research and Document" was a part of a more comprehensive research initiative, there were a significant number of projects that were consistently categorized as solely involving this activity.

In addition to the internal CUTR review, the surveyed principal investigators and project managers (discussed in detail in Chapter 4) were asked to categorize their respective projects. Nearly 70 percent of the survey respondents categorized the projects similarly to CUTR. However, due in part to the survey design not forcing a choice for the research category, and perhaps in part to the classification system itself, in only 30% of the cases was there an identical match between the CUTR designation and that of the principal investigator and the project manager. In many cases, the survey respondents marked more than one category regarding the nature of the research project.

As the team contemplated the available measurement tools to attempt to quantify benefits of transportation research, it became apparent that other dimensions, along with the ease of quantification, would also have a significant bearing. One very significant dimension is the time that it takes to implement the research results. Traditional methods that employ some evaluation by means of net present value of the benefit seem to always underestimate the potential benefits of the research if the time to implementation is long.

The project team concluded, based in part on the ability to acquire data for completed research projects (discussed in detail in Chapter 4) combined with the variance in the results of attempting to categorize the research projects, that a modified system would need to be developed. While convinced of the validity of the premise that different research activities might best be measured with different quantification methods, the team worked to develop a better system that would take into account factors beyond the difficulty of quantification of benefits.

2.2 A More Traditional Hierarchy

An alternative approach to group research activities for the purpose of quantifying benefits is through the use of traditional distinctions of research activities. The scale of research activities is often described as moving from *basic* research, to *applied* research, to *development*, to *demonstration*, and, finally, to *technology transfer* to disseminate the new knowledge. This scale or continuum also correlates well to the risk involved with an investment in research. In the case of basic research, there is high risk and low expectation for results, but with the potential of a large return. Once a concept has been developed and demonstrated, there is a high probability that an investment in the dissemination of the new technology will bear a positive result. At this end of the scale the risk is low, as is the potential return on investment. This concept is illustrated in Figure 2.2.

Research Type	Risk of Positive Return	Magnitude of Benefit if Successful	Expectations For Results
BASIC RESEARCH	Very High	Very High	Low
APPLIED RESEARCH	High	High	Moderate
DEVELOPMENT	Moderate	High	Moderate
DEMONSTRATION	Moderate	Moderate	High
TECHNOLOGY TRANSFER	Low	Low	Very High

Figure 2.2. Benefits of research

The exercise of attempting to find the right fit of the research activity with an appropriate measurement approach led the CUTR research team to consider that the element of risk needed to be more explicitly identified when trying to quantify the potential benefits of a research program in its entirety or on an individual project basis. It was also clear from this analysis that the concept of an investment mix in research activities is similar to any investment portfolio in that an appropriate blend of risk and yield is required to attempt to achieve a larger investment goal.

2.3 Profile of FDOT Research Program

- Functional Areas
- Expenditure
- Comparison to other States

2.4 Conclusions

The effort to arrive at a method for classifying research projects in order to apply the most appropriate available measurement tool met with mixed results. While the originally proposed classification system clearly needed to be modified, there are characteristics of the different types of research activities that more appropriately lend themselves to be measured better by some methods than by others. This conclusion is demonstrated and proven in Chapter 6.

The categorization involves more than the originally contemplated "ease of quantification." It is true that the other dimensions (such as time to implement, probability of successful implementation, the point in a project's history when the quantification of benefit is performed, and the availability of data) that need to be considered are related to how easily a project's benefits can be quantified.

The team concluded that a simplified classification system that parallels the generally accepted labels of research activities would be more appropriate for grouping projects for analysis. In addition, the team concluded that a matrix approach to matching research projects with the most appropriate measurement method would also be helpful. For example, it may hold true in most cases that an applied research project is very difficult to measure because of a lack of data or a long lead time to implement the results. If a project in which the data had, in fact, been collected to perform a straightforward benefit/cost calculation were to be analyzed, then it would be pointless to suggest some rigorous and complex methodology. Generally, however, this will not be the case.

A system to classify the research activities with methods to quantify their potential or real benefits did emerge and is outlined in Figure 2.3.

CUTR Classification	Traditional Definition	Ease of Quantification	Time to Implement	Risk of Positive Return
Develop a product or process	Development	High	Short	Moderate
Evaluate a product or process	Demonstration	Moderate	Medium	Moderate
Research & document	Applied	Moderate	Long	High
Technology Transfer	Technology Transfer	Low	Short	Low

Figure 2.3. Research classifications

Chapter 3 – Literature Review

This chapter presents an overview of papers, reports, and studies conducted in the area of research project evaluation. Following the review of available literature, a brief synopsis of efforts by the state departments of transportation is provided.

3.1 Literature Review

This literature review presents a summary of relevant research, involving 15 papers specific to the transportation industry and 15 on other industries. Thirty papers are reviewed out of a total of 32 papers found. Of the 15 transportation-specific papers, five are state department of transportation (DOT) studies, three are university studies, six are private research papers (including TRB), and one is a federal research paper. The literature review identified many different methodologies used for research and development (R&D) analysis. These methodologies include Internal Rate of Return (IRR), Return on Investment (ROI), Benefit-Cost Analysis (BCA), Net Present Value (NPV), Multi-Objective Benefit-Cost Analysis (Multi BCA), Real Option Approach (RO approach), Payback Period calculations, and Utility analysis.

Table 3.1 provides an overview of the literature review as well as details on the various evaluation methods utilized in the reports and studies reviewed for this project. Traditional Benefit/Cost analysis is more common in the transportation studies reviewed. However, it should be noted that the literature review attempted to look outside the traditional areas of research evaluation when reviewing non-transportation reports.

Table 3.1. Overview of Literature Review

Table 3.1

	Methodology							
Project Type	**IRR**	**ROI**	**BCA**	**NPV**	**Multi BCA**	**RO approach**	**Payback**	**Utility**
A: Transportation								
DOT (5)			☑☑☑☑☑	☑☑	☑			
University (3)								
Private Research (5)			☑☑☑	☑☑				
Government (1)		☑	☑				☑	
B: Non-Transportation								
Telecommunication (1)						☑		
Agriculture (2)	☑							
Medical Technology / Health Sciences (3)			☑					☑
Chemical (1)		☑						
Park Management (1)								
Pharmaceutical (1)						☑		
Personal Products (1)				☑		☑		
Several or Non-specific Industries (5)		☑		☑		☑☑		

3.1.1 Summary of Literature

Absher, James D. McCollum, Daniel W., and J.M Bowker. The Value of Research in Recreation Fee Project Implementation. *Journal of Park and Recreation Administration*, Fall 1999.

This paper describes how a Forest Service team of managers developed a system to measure how research information had been used in the development of required business plans for existing fee projects. Through a survey of all Forest Service fee project managers, key questions about business planning, communication efforts, fiscal issues, and use of research data were investigated.

Ardis, Colby. *Evaluation of ODOT Research and Development Implementation Effectiveness*. Final Report. Ohio Department of Transportation, University of Toledo, July 1989.

The objectives of this research report were:

- Determine the effectiveness of the initiation and review process for research problems.
- Compare research results of completed ODOT research and development projects with initial ODOT research objectives.
- Determine the extent of implementation and effectiveness of research results.
- Identify implementation success factors associated with ODOT research.
- Develop a methodology to ensure better implementation effectiveness of future projects.
- Develop a method to measure the effectiveness of future ODOT research and development.

The paper relates the importance of research in the corporate world, with testimonials from ITT, Xerox, Honeywell, and Northern Telecom. The ODOT recommends that researchers access the technology available through the Transportation Research Board, other in-house research, and other DOTs.

The report concludes that R&D is important and cost effective; however, implementation procedures must be improved. To improve the research capabilities of the ODOT, the report recommends full participation of R&D research engineers and that the research committees must improve internal and external communication, along with various administrative improvements.

Brand, Daniel, S. R. Mehndiratta, and T. E. Parody. Options Approach to Risk Analysis in Transportation Planning. In *Transportation Research Record 1706*, TRB, National Research Council, Washington, D.C., 2000, pp.54-63.

This paper focuses on the implementation of the real options approach to transportation planning projects. The authors state that the Net Present Value (NPV) method, a traditional project evaluation tool, works well in situations with little risk involved. Therefore, projects that are obvious "winners" or "losers" for further investment can be easily evaluated with NPV. However, if uncertainty about future outcomes is present, a more sophisticated evaluation technique, the Real Options Approach, is recommended. Just as financial options represent a right, not an obligation, transportation investment opportunities are options, not obligations, to take some action in the future. This type of option is called "real option."

Brand et al. demonstrate how delaying a certain investment to the future can be of enormous financial benefit. Instead of making a commitment in a time of uncertainty, and therefore risking a negative monetary outcome, it might be advisable to wait until the first uncertainties have vanished. Then managers have a better picture of the realistic benefits from the project implementation and can act accordingly.

It is suggested to clearly identify and analyze the risks and uncertainty of each project. If the project is risky, management should develop and implement a risk management plan to mitigate the risk. Unfortunately, there is no general recipe that can be utilized in all cases. The transportation sector is simply too complex and managers need to develop an exact understanding of the risks of individual projects and act according to special circumstances.

The real options approach provides management with a new way of thinking and analyzing uncertain future situations. This allows for improved planning. The authors conclude that the application of the new tools of risk analysis and risk management can lead to significant changes and improvements in the transportation planning process.

Carter, Robert and D. Edwards. Financial Analysis Extends Management of R&D. *Technology Management*, Sep-Oct 2001.

This article applies corporate financial analysis to research, development, and acquisition (RDA) investments. It demonstrates how resources in RDA projects should be allocated in a portfolio in order to achieve the optimal risk-return tradeoff.

The authors introduce the valuation concept of Real Options. Four types of options are introduced: the option to defer, the option to preempt, the option to discontinue the research, and the option for flexible response. These options are especially valuable if there is uncertainty in future outcomes. They provide an objective, quantitative guide to strategic judgments that heretofore were mostly subjective. Their recommendation is to start many research projects that are potentially extremely significant if successful, to discontinue the ones that do not show promise, and to harvest the unexpectedly successful research option payoffs. A shortcoming of this approach is that potential projects with smaller, though still significant and important payoffs would be less likely to be funded.

***Assessing the Value of Research in the Chemical Sciences*. Chemical Sciences Roundtable: Report of a Workshop. National Research Council, 1998.**

This report is a collection of short papers presented by various academicians and professionals at a workshop in Washington, D.C. in 1998. The authors discuss different methods of research valuation and implementation. Many of the papers include the transcription of roundtable discussions held by the Chemical Sciences Group, a science-oriented, apolitical forum for leaders in the chemical sciences.

Four of the papers are particularly relevant for their different approaches toward research. David Hounshell of Carnegie Mellon describes the importance of ROI analysis in the corporate research setting. He writes that R&D valuation is critical in any organization, and chooses DuPont as the standard of ROI analysis in the scientific community. James Mitchell of Lucent Technologies explains the phase transitions of research projects and how prioritization analysis should effectively balance short-term and long-term R&D. The author concludes that high-risk, breakthrough research has the highest priority in any valuation study.

Truman Parish of Eastman Chemical Company writes about developing the Technology Value Pyramid (TVP) and how it helps balance research creation and integration. The TVP includes 50 metrics that assist in calculating the value of R&D.

Patricia Dehmer of the U.S. Department of Energy (DOE) assesses the value of research at the DOE with a performance measurement matrix. The matrix assists in the prioritization of funding allocation decisions, and includes the following factors:

- Excellence in basic research
- Relevance to the energy mission of the agency and, moreover, to a comprehensive national energy agenda
- Stewardship of research performers, essential scientific disciplines, institutions, and scientific user facilities.

Group consensus from the workshop concluded that research has significant value and that there are many different methods to improve research valuation.

Cohen, Linda R., G. J. Fielding, J. F. Nolan, and G. C. Smith. Appraising Transportation Research. In *Transportation Research Circular*, Number 426. TRB, May 1994.

This study examines the importance of transportation research, how best to measure its value, and the best way to promote it efficiently. The authors discuss various public strategies that would promote research and development:

- Direct funding of research activities
- In-house research
- Prizes for innovation
- Market guarantees

The authors discuss issues that could make research more efficient by creating a fair and consistent BCA using NPV. Goals should be pre-established with the rate of return for decision makers, all benefits (direct and indirect) should be identified, all costs should be included, all benefits and costs should be projected for the duration of the longest proposal under review, and finally, results should be tested against the most likely range of critical assumptions. The authors use a study from the California Department of Transportation on high-speed rail as a case study, to clearly demonstrate the use of BCA as a research evaluation tool.

Cohen, Linda R., and G. J. Fielding. *New Technology Research: Costs and Benefits*. California Department of Transportation, UC Irvine, June 1993.

The objective of this research study is to develop a methodology by which the California Department of Transportation (CALTRANS) evaluates research and develops a portfolio of research proposals for consideration. Increasing productivity is emphasized as the priority goal because CALTRANS considers that research should be appraised in terms of its contribution to economic efficiency.

The study emphasizes BCA and the maximization of monetary return for a given investment. Quantitative and qualitative estimates are both used. The qualitative estimates include the value of life, environmental benefits, and the value of time. The authors prefer the NPV method, because it emphasizes the discounting of costs and benefits to current values that are frequently omitted in BCA ratios.

The study concludes that NPV methodology is the most flexible and useful guide to project evaluations. Proposals can be ranked in terms of the magnitude of benefits, or they can be placed in an array/matrix representing their contribution to other goals and various modes. The goal should be to construct a portfolio of proposals that are economically efficient and that satisfy the predetermined priority goals set by the agency.

Copeland, T. and Antikarov, V. *Real Options: A Practitioner's Guide*. Texere, New York, 2001.

This book summarizes experiences in the application of RO approach to several cases. It describes several extensions to the approach with the intent of providing the practitioner a "how to" guide. Among the many example applications tested, an extension of the RO approach to R&D was considered. It also contains a detailed description of the Net Present Value approach and its shortcomings.

Doctor, R.N., D. P. Newton, and A. W. Pearson. Managing Uncertainty in Research and Development. *Technovation*, Vol. 21, 2001.

In this paper, the issues of decision-making under uncertainty are considered in the R&D context. Several techniques are considered including the decision tree approach and the option pricing theory. In the option pricing theory, uncertainty and risk analysis are modeled through simulation processes, which include Monte Carlo experiments. The paper recognizes the existence of analysis constraints in the form of a lack of data availability and documentation of R&D projects.

"Exploring the Application of Benefit/Cost Methodologies to Transportation Infrastructure Decision Making." Searching for Solutions, A Policy Discussion Series Number 16, July 1996.

At a conference on Benefit Cost (BC) analysis, various civil engineers from around the world presented papers on the application of BC analysis to transportation infrastructure. Jan A. Martinsen, Public Roads Administration of Norway, introduced the advantage of BC analysis in the Norwegian transportation sector. He claims benefits of BC analysis for decision-making on three levels:

- Deciding best alternative/standard on the project level.
- Deciding priority between projects on the program level.
- Deciding priority between transport modes and/or sectors.

However, he also points out the drawback of excluding environmental and regional impacts in BCA. This is a major reason why BC analysis plays an insignificant role at the political decision-making level in Norway.

Fan, Shenggen. Research Investment and the Economic Returns To Chinese Agricultural Research. *Journal of Productivity Analysis*, No.14, 2000, pp. 163-182.

This paper measures the economic return of research investment in Chinese agriculture using the Production Function approach. The author's goal is to measure the economic impact of Chinese R&D investments, while taking care to control other sources of output growth that could potentially bias such rate of return estimates.

The study calculates the IRR to research by comparing the benefits of research to the cost. Using the production function, the marginal output value of research can be calculated along with the IRR. Using various lag times for the research stock of knowledge variable, the estimates of IRR to agricultural research range from 73.8% to 32.8%, for the years 1975-1997. The study concludes that rates of return are increasing over time. Total research benefits from 1975-1997, in terms of output, vary from 1,831.8 B Yuan to 3040.1 B Yuan, which represents 13.22% to 22.04% of output value.

G.D. Love. Value of Transportation Research: Federal Perspective. *In Transportation Research Record 829,* TRB, National Research Council, Washington, D.C., 1980, pp.54-63.

This essay reviews various ideas and concepts related to research at the U.S. Department of Transportation. The author emphasizes the need to distinguish between short-term problem solving research and long-term fundamental research.

The author describes many factors that are involved in the decision-making process, such as risk factors, payoffs, and measurements of value. The author concludes, "Research must be viewed as a systematic cumulative procedure wherein individual studies contribute to the final objective as the nature and the multiple facets of the transportation problem become more precisely defined and understood." The crucial factor is to recognize the importance of quantifying the potential value of research. Only then can decision makers determine the allocation of critical research funding.

Gosling, James J., and Lowell B. Jackson. Getting the Most Out of Benefit-Cost Analysis: Application in the Wisconsin Department of Transportation. *Government Finance Review*, Vol. 2, No. 1, February 1986.

According to the authors, "benefit-cost analysis compares all of the relevant direct and indirect costs and benefits associated with a project, permitting comparison of the respective benefit-cost ratios for a determinate number of alternatives." The projects where benefits exceed costs should be undertaken. This study seeks to determine if this type of analysis is an efficient way to make policy decisions. The authors use various case studies by the Wisconsin Department of Transportation (DOT) to present their case.

Herath, H. S. B., and C. S. Park. Economic Analysis of R&D Projects: An Option Approach." *The Engineering Economist,* Vol. 44, No. 1, 1999.

This paper considers the Real Options Approach (ROA) in evaluating R&D. A valuation model is considered for application to the R&D investment decision of Gillette, for the development of the MACH3 razor. The ROA is compared to Discounted Cash Flow Analysis.

Hickling Corporation. *Cost Benefit Analysis of the ATRC Research Program, Fiscal Year 1992*. Final Report not yet published, Hickling Reference: 5731, December 22, 1994.

This report applies the benefit-cost criteria of an effectiveness evaluation to six research projects completed for the Arizona Transportation Research Center (ATRC) during the fiscal year 1992. For the analysis of the sample projects, published data from ATRC research reports was utilized in conjunction with an economic, transportation user cost model developed by the Hickling Corporation. The projects were evaluated by the following criteria:

- Cost
- Safety
- Vehicle operating cost
- Value of time savings
- Productivity cost
- Maintenance cost
- Environmental cost
- Length of the implemented period
- Lag time before measurable economic effects

Out of the six projects reviewed, two indicated obvious net benefits (benefits minus costs) over a 25-year period. In addition, the study found that for cost-benefit purposes uncertainty tends to inhibit the economic effects of research and that quick implementation periods tend to produce larger economic benefits than implementation with a longer time frame.

The main conclusion was to consider the application of the benefit-cost framework as a tool to manage the conduct of research from an economic perspective rather than to identify winners and losers.

Hood, Jacqueline and D. Albright. Assessing the Benefits and Costs of Research. In *TRB*, National Research Council, January 2002.

This paper presents a model for assessing the benefits and costs of research activities. The purpose of the paper is to review the literature on assessing benefits and costs for research projects prior to implementation, proposes a template for benefit-cost analysis for the outcomes of transportation research, and discusses implications for the future of transportation research.

To determine the costs and benefits of an investment in research, the authors consider two methods: the payback method and Return on Investment (ROI). The Payback method is calculated by dividing annual cash flows into the original investment.

The ROI is divided into several steps, of which the first is to calculate the Benefit/Cost (B/C) ratio, which is Program Benefits, divided by Program Costs. Next, ROI is calculated by taking the Net Benefits divided by Program Costs and multiplying the result by 100. ROI is results-based and measures specific contributions of each research activity. The authors also developed a survey designed to gather information on the B/C analysis of research products used by research organizations.

Jensen, Kjeld and Warren, P. The use of options theory to value research in the service sector. *R&D Management,* Vol.31, No.2, 2001.

This study examines the practicalities of applying real options theory to valuing research in the service sector. The authors use an option-pricing model based on a three-phase lifecycle consisting of research, development, and deployment.

Real options theory proposes to value current projects or activities based on mathematical models using interest rates, volatilities, cash flows, and probabilities to derive a 'fair value'. The authors use a case study approach, examining an e-commerce project at British Telecom (BT) as an example of a multistage real options experiment.

The study concludes that the present value of the BT research project is thirteen times the cost of research. As the option-pricing model can be adjusted for different volatilities and cash flow projections at any stage, it is a flexible tool for valuating research projects. Although it is not a precise science, this study explores the influence of different value drivers on the value of research activity. The authors believe this technique is best used for key projects, not a total research portfolio.

Kentucky Transportation Center Staff. *Value of Research*. Kentucky Transportation Center, College of Engineering. University of Kentucky, October 1991.

This report describes the Kentucky Transportation system of management as a five-step process:

1. Select the project
2. Design the experiment
3. Supervise the project
4. Implement the results
5. Evaluate the benefits

Members of a research advisory committee rank proposed studies according to their priorities. Study findings are implemented as the study progresses and information is developed. Study benefits are evaluated depending on the nature of the study. The report contains real examples of transportation projects in Kentucky divided into eight functional areas:

1. Pavements
2. Geotechnology

3. Materials
4. Testing
5. Structures
6. Traffic
7. Safety
8. Bituminous materials

Using a number of case studies, the authors provide a general description of the project, state the implementation steps, and describe the cost effectiveness of each project. In other examples, projects are described as ‘problems’, with particular research solutions and monetary benefits. Transportation research, the report concludes, brings great value to the state of Kentucky.

Levi≅kangas, Pekka and L≅hesmaa, Jukka. Profitability Evaluation of Intelligent Transport System Investments. *Journal of Transportation Engineering*, Volume 128, May-June 2002, Number 3, pp. 276-286.

The authors discuss the limitations of conventional Benefit-Cost analysis (BC) for certain investment evaluations and introduce alternative evaluation tools. Their primary example is ITS (Intelligent Transport Systems) investment in Finland.

According to USDOT, ITS financing differs from conventional infrastructure financing in the following ways:

- ITS financing includes significant participation from the private sector
- ITS reduces adverse environmental effects
- ITS improves performance by implementing new technologies

In addition, there are numerous differences in the cash-flow profile; e.g., shorter lifetime and lower investment cost for ITS investments. While BC analysis is a widely respected and used evaluation method, it experiences certain shortcomings, such as the omission of risk-return trade-offs. Therefore, BC analysis in certain instances can provide managers with the wrong decision rule. Multi-criteria Analysis (MCA), risk-adjusted discounting rates, and real options are introduced as potential alternatives. MCA, which is the ability to deal with two or more criteria measured in different units, includes non-monetary factors in investment evaluations, while risk-adjusted discounting rates take different time risk profiles into account, and real options weigh the impact of future decisions on uncertain cash flows.

The authors conclude that none of the evaluation tools should be used exclusively, due to their inability to capture all aspects of investment evaluations. Instead, they recommend that by “using a suitable set of different methods depending on the decision situation and by comparing the results, a wider and more realistic picture of investments can be obtained."

Liddle, Jeannine, M. Williamson, and L. Irwig. *Method for Evaluating Research Guideline Evidence (MERGE*). New South Wales Health Department, December 1996.

This paper details an evaluation method of research and scientific evidence in the medical and health care industry.

The authors propose an evaluation checklist that reviews various risk factors and statistical models. The paper lists various reasons for using the Method for Evaluating Research Guideline Evidence (MERGE). The authors encourage various applications of the study, such as incorporating evidence from individual studies into a review of evidence, evaluating the quality of scientific evidence for clinical interventions, and ensuring important methodological aspects of study design and performance that are reported in journal articles. The paper includes copies of all the necessary checklists and review sheets.

Loch, Christoph H. and K. Bode-Greuel. Evaluating Growth Options as Sources of Value for Pharmaceutical Research Projects. *R&D Management*, No. 31, 2001.

This paper presents an approach to analyze R&D in the pharmaceutical industry through growth option theory. The authors seek a flexible way to value research and to determine whether risk, volatility, and uncertainty influence the value of R&D projects.

Growth options are financial instruments that attempt to value a particular asset today at a certain point in the future, by incorporating elements of private and market-priced risk. The authors take three pharmaceutical projects and apply their theories and methodologies.

The paper concludes that growth options, using a binomial model, are the best way to evaluate research. Due to the flexibility and transparency of the binomial model, and the use of risk-aversion analysis that can be built into the study, managers can analyze the value of R&D projects with better accuracy and visibility than by utilizing other methods.

Luce, Bryan R. and A. Elixhauser. Outcomes Research: Documenting the Value of a Medical Device. *Medical Device and Diagnostic Industry Magazine*, January 1999.

The authors state that manufacturers of medical devices should determine the value of their products during the planning stages to help in product development, marketing, and acceptance. Outcomes-based research, according to the authors, should be the standard to analyze this industry. The authors describe a 'value equation' as a tool in determining evidence of value. This type of BCA is one of many outcomes-based research tools that can be used in the medical device industry.

The authors describe how BCA can assist in equivalent effectiveness studies and strategic outcomes research planning and execution. Outcomes research can be used in both early and later clinical studies. A research group can create a model to determine the effectiveness of a product launch by demonstrating health, economic, and quality-of-life value.

The authors conclude that integrating outcomes research into the product development process will allow manufacturers to better satisfy the demands of the marketplace.

McFarland, William F. *A Method for Evaluating the Benefits of Research Projects*. Texas State Department of Highways and Public Transportation, November 1988.

This study evaluates methods and data used for measuring the benefits of research projects. The authors discuss historical and predictive studies and provide several case studies, divided into five groups categorized by project type or purpose.

The authors outline BCA, along with different measurements for accidents, motorists, and vehicles. The report gives detailed formulas for B/C ratios and NPV analysis. The benefits and costs are estimated for each implementation unit. The case studies demonstrate a high return on research and also show the need to develop better information in research implementation. The appendices include estimated values of time and vehicle operating costs, accident costs, and various case study data utilized in the study's methodology.

Newton, D.P. and A.W. Pearson. "Application of option pricing theory to R&D." *R&D Management*, 1994.

The article illustrates how Option Pricing Theory (OPT) provides value to management. In particular, the authors explain the OPT method, detail the required information, and provide an overview of practical implementation. A simple numerical example is used to illustrate the potential superiority of the OPT over conventional valuation techniques for R&D projects. The volatility of the expected future cash flows is the only variable that is difficult to estimate. Forecast data for those cash flows and their probabilities have to be converted into an estimated cash value and associated volatility. It is known that volatility increases with time, which causes the value of the option to increase as well.

Peterson, Dale. Measuring the Effectiveness of a Research Program. *Research Record No. 738*, TRB, Utah Department of Transportation.

The purpose of this paper is to present techniques used to measure the effectiveness of a research program and to identify steps that can be used to improve its efficiency. The author reports that B/C ratios in transportation research are approximately 9 to 1. However, B/C ratios are only one measure of effectiveness. Other measurements include the number of awards, the number of implementation packages, and the size of the research budget.

The author presents various methods to address research problems and their necessary solutions. A transportation problem is a potential research project. Three questions must be answered: How critical is the problem? What are the chances of success? What is the expected B/C relationship? In order to answer these questions, a researcher must have the necessary technical and administrative skills. The author identifies six steps to efficiently implement the solution:

1. Identification
2. Planning
3. Packaging
4. Promoting
5. Adoption
6. Evaluation

This paper concludes by stating that if key personnel are involved throughout all phases, then there should be agreement on the implementation of the program. If research is planned and conducted with clear implementation goals, the program should be successful.

Pozdena, Randall J. *Selecting Public Transportation Projects: Informational Requirements*. Conference on Information Requirements for Transportation Economics Analysis, ECO Northwest, August 1999.

This paper examines the informational requirements of the decision-making process in transportation projects. The author depicts the process as a hierarchy that includes policy objectives, data and analysis, political and social goals, programs, project selection methodology, and project design. In this process, decision makers face a variety of challenges: constitutional and legislative constraints, income redistribution goals, financing considerations, status quo considerations, power barriers and power vacuums, and social planning objectives for transportation.

The author discusses project evaluation and selection in a cost-benefit context. This paper includes a helpful description of ‘the time value of money’, essential in calculating NPV for BCA. The study concludes that transportation decision processes have many informational requirements.

Rose, Geoffrey and D. Bennett. Benefits from Research Investment: Case of Australian Accelerated Loading Facility Pavement Research Program. *Transportation Research Record 1455*, Pavement Management Systems.

This Australian Research Board program project focused on the Accelerated Loading Facility (ALF), a mobile road-testing machine that applies full-scale rolling wheel loads to a test pavement. The purpose of this study was to produce a credible, justifiable evaluation of the ALF trials on the basis of dollar value assessments of benefits and costs.

The authors examine a project in Benalla, Victoria, conducted between June 1985 and February 1986. The ALF trial helped determine the best pavement for the highway system in Victoria; the benefit of this trial was the expected savings in costs resulting from continued use of the low-cost granular pavement. The researchers used a decision tree to represent the uncertainty associated with the different choices of pavement. The decision tree includes probabilities and discounted life cycle costs.

The report includes a helpful overview of individual ALF trials and lists primary outcomes and primary benefits, along with assumed duration of benefits. The overall conclusion is that the ALF program is economically viable.

Salter, Ammon J. and B. R. Martin. The Economic Benefits of Publicly Funded Basic Research: a Critical Review. *Research Policy*, Vol.30, No.3, March 2001.

This article reviews the literature on the economic benefits of publicly funded basic research. Basic research includes ‘strategic’ and ‘curiosity-oriented’ research. The authors note the numerous benefits from this type of research, but acknowledge the various flaws and gaps in the evidence. They also review the methodological issues concerning the approaches employed for analyzing and assessing the benefits from research. The authors analyze three methodological approaches: econometric studies, surveys, and case studies. They also assess different measurements of return to investments in basic research in a variety of industries (pharmaceutical and agricultural, among many).

The authors conclude that one can try to estimate the rate of return but only on the basis of very questionable assumptions. They acknowledge that there are good returns to research investment, but that it is not possible to model the economic benefits of basic research. A portfolio-based approach is best when drawing upon the many different technological and product developments that one research project may have.

Schmitt, Robert P. and, E. A. Beimborn. "Examination of Techniques to Enhance the Utilization of Research Results." ***Transportation Research Record 738*****, University of Wisconsin.**

This paper examines the research process and the major problem areas that hamper implementation within this process. The authors present eight basic principles relevant to the process of research implementation.

The utility of any research project depends on how these steps are followed. The authors give three axioms of research utilization. First, the probability of research utilization is inversely proportional to the distance between researchers and users of the research. Second, the probability of research utilization is inversely proportional to the degree of formality between researcher and user. Third, probability of research utilization increases with the degree of understanding that the researcher and user have of each other's problems and motivation. The paper also discusses various barriers to research utilization.

Tavakoli, Amir and Collyard, Cynthia. ***Benefit-Cost Analysis of Transportation Research Projects.*** **Case Western University, Ohio Department of Transportation (ODOT), May 1992.**

This study discusses the evaluation of completed research projects and it develops a methodology, system, and computer application based on BCA and multi-objective analysis techniques. The report describes the four phases of this project:

1. Review of current ODOT evaluation techniques
2. Review of current and recent ODOT research projects
3. Literature survey and questionnaire survey of best practices and techniques
4. Development of a research project evaluation methodology and system

Surveys were sent to the larger Departments of Transportation in the country. With this data, the researchers developed a model based on BCA, multi-objective benefit analysis, performance evaluation, and utilization. The evaluation model has technical and performance sections, with quantitative and qualitative measurements.

The study concludes that this tool should be used to address projects on an individual basis, as well as to provide ways for comparative review between projects by a variety of descriptive categories. The authors include a number of case studies for further analysis, as well as many useful appendices.

Thomsen, Leon. The Current, Direct Value of Internal Research. ***The Leading Edge*****, September 1993, Amoco Production Company.**

In order to understand why companies should invest in research, the author proposes that the answer is more than just a quest for better technologies. Research is an integral part of the commitment to technology, upon which corporations depend for profitability today. According to the author, "the role of internal research is an integral part of a company's commitment to technology itself and constitutes its primary, current, direct value."

Zilberman, David and Amir Heiman,. The Value of Economic Research. *American Journal of Agricultural Economics*, Vol. 79 No.5, 1997.

The authors claim that the impacts of research depend on the transmission of results and the capacity of users to take advantage of them. In other words, the productivity of economics research depends on the quality of extension and economic literacy.

This paper classifies the products of economic research into three groups—new economic information, products contributing to technological change, and products contributing to policy. In order to quantify the benefits from economic research, the authors also cite various studies on dimensionality and uncertainty in an economic framework.

The authors conclude that economic research generates many benefits in terms of information, technological change, and improved policy. More importantly, the productivity of economic research is determined by its transmission and the capacity of users to implement the methodology.

3.2 Other state departments of transportation research evaluation efforts

All US state departments of transportation (or their equivalents) were surveyed as to their efforts in evaluating transportation research and transportation research programs. Out of 50 State DOTs contacted, 37 replied, a response rate of 74%. Fifteen states indicated that they had never been involved with the evaluation of research projects, while one state (New Mexico) specifically indicated that they had conducted research in this area before. The respondents provided several references for research evaluations, which are listed in the appendix with reference title and author.

The most quoted article was "Performance Measures for Research, Development, and Technology Programs" by Scott Sabol of Vermont Technical College (this has been subsequently published on TRB 300). Respondents also noted that another study on the evaluation of the benefits of transportation research was nearing completion by the Kansas DOT. The findings of that study recommend a "case-by-case" proposition when estimating research benefits. Additional comments and concerns from those surveyed were that this project had the potential to stir great controversy about the evaluation of research, the problem of valuing a human life, and the idea that research should not be undertaken with an expectation of return. Six states specifically asked for a copy of the final report of this study when completed. A brief summary of responses, including contact names, is presented in Appendix C of this report.

Chapter 4 – Survey of Selected Projects

The Florida DOT Research Center funded almost $30 million worth of projects between July 1998 and June 2001, and since 1989, when the center was established, fostered over 300 final reports. The Research Center made available project summaries and details of Project Managers (FDOT staff) and Principal Investigators (contracted researchers) for many of these projects. The availability of project summaries was not manipulated or controlled by the Research Center in any way.

4.1 Project Selection

CUTR analyzed the project listing from the *FDOT closed project database*. Those projects represented all FDOT specified functional areas and were not sorted or selected according to the CUTR categorization outlined in Chapter Two. Projects were omitted from the survey process if the responsible Project Managers (PM) and Principal Investigators (PI) were no longer available at their respective departments.

4.2 Survey Process

First, a sample of projects was selected for a survey evaluation. The initial sample consisted of 281 completed projects from the FDOT database for the time period January 1991 to June 2001. The intention of that broad sample selection was to evaluate projects independently of the FDOT's functional classification scheme. Two different sets of surveys were designed, one for the Project Managers, another for the Principal Investigators. The purpose for this differentiation was to solicit a cross-dimensional perspective on the projects and obtain sample data for statistically robust analysis. The overall survey objective was to obtain a general perception of project benefits together with qualitative and quantitative information for use in validating models under development for project evaluation.

The surveys were distributed electronically via email as well as by fax[1]. A cover letter from Mr. Richard Long, Director of the FDOT Research Center, accompanied each survey packet; outlining the need for and importance of the survey in assisting the department to better evaluate the Research Centers' efforts. Templates of the surveys are provided in Appendices A and B.

4.3 Survey findings

Each project was the subject of both a Project Manager (PM) and Principal Investigator (PI) survey. Accordingly, the selected 281 projects resulted in 562 surveys distributed. Almost twice as many PM's (46) as PI's (24) replied to the survey, a response rate of

[1] Before distributing the survey, CUTR obtained the necessary Independent Research Board approval

16.4% for the PM's and 8.5% for the PI's. The overall participation rate in the survey was 12.5%. A summary of the PM's survey results is included in Table 4.1. Table 4.2 reports the results for PI's. An unabridged table of responses is provided in Appendices A and B.

Respondents were asked to provide their perceptions of project success, knowledge of implementation, and, where possible, quantitative data on their projects. Table 4.2 shows that out of the 70 projects evaluated, project managers and principal investigators considered 24 projects (34.3%) as extremely successful, 28 projects (40.0%) as very successful, 9 projects (12.9%) as successful, 3 projects (4.3%) as unsuccessful, 1 project (1.4%) as very unsuccessful, and 2 projects (2.9%) as failures. Three projects were not identified for their success rates. Of these projects, a total of 40 projects (57.1%) were implemented. The percentages of successful projects and implemented projects are incorporated later in Chapter 6 as an input assumption of the real option binomial tree.

Respondents were asked to classify their projects in accordance with the proposed CUTR project classifications. The majority of the projects were classified as development projects (48.6%), followed by evaluation projects (25.7%), solely research projects (21.4%), and solely technology transfer (4.3%). Since the survey did not force a single choice for the research category, the general tendency of project managers was to classify a given project under two or more subcategories, thus reinforcing the evidence that a modified categorization scheme needed to be developed.

The reported average time frame for project completion appears to be 24 months for all 70 projects. The time frame of two years was also consistent in each of the project categories, with the exception of technology transfer. This variation might have resulted from the small number of observations in this category. On average, projects were completed six months after their original due date.

Table 4.1 Project Manager Survey- Success and Implementation

Project	Total Annual Cost $	Successfulness (on a scale from 1 to 5)	Riskness(on a scale from 1 to 5)	Projected Time Frame (months)	Actual Time Frame(months)	Implementation	Project Classfication
1	50,000	4	1	18	39	No	D, E
2	55,000	0	2	18	25	No	C, E
3	70,000	3	2	18	19	No	E
4	250,000	4	2	24	18	No	A, B, E
5	126,000	4	2	12	36	Yes	A
6	200,000	5	1	12	24	Yes	B
7	45,000	5	1	24	24	Yes	A, C, E, F
8	50,000	3	2	12	18	Yes	B, D
9	98,584	5	1	24	24	Yes	E
10	150,000	5	1	18	24	Yes	C
11	N.A.	3	2	12	24	Yes	A
12	200,000	3	1	24	48	Yes	A
13	80,000	4	1	24	30	Yes	D, E, F
14	39,337	5	1	4	4	Yes	E
15	58,800	5	1	3.5	4	Yes	E
16	299,979	4	2	36	48	No	A
17	150,000	4	1	24	48	Yes	B, D
18	55,000	4	1	12	16	Yes	E
19	99,420	4	2	12	18	Yes	D
20	63,363	N/A	1	16	18	Yes/Somewhat	E
21	N.A.	N/A	2	12	12	Yes/Somewhat	E
22	32,000	3	2	15	15	No	B
23	105,325	5	1	24	24	Yes	B, E, F
24	100,000	5	1	18	24	Yes	C, F
25	449,982	4	1	24	not yet completed	Yes/Somewhat	E
26	95,000	5	1	24	36	Yes/Somewhat	E
27	N.A.	5	1	N.A.	N.A.	Yes	C
28	N.A.	4	2	N.A.	N.A.	No	A
29	N.A.	4	2	N.A.	N.A.	Yes/Somewhat	C
30	N.A.	4	2	N.A.	N.A.	No	C
31	N.A.	4	3	N.A.	N.A.	No	C
32	N.A.	4	1	N.A.	N.A.	No	D
33	N.A.	5	1	N.A.	N.A.	Yes	E
34	N.A.	5	1	N.A.	N.A.	Yes	C
35	N.A.	4	1	N.A.	N.A.	Yes	D
36	N.A.	5	1	N.A.	N.A.	Yes/Somewhat	A
37	270,000	5	4	12	12	Yes	F
38	142,800	4	4	12	12	Yes	F
39	30,000	5	1	36	36	Yes	A, B, F
40	249,554	5	1	30	40	No	E
41	149,900	5	1	29	60	Yes	E
42	200,000	4	1	26	60	Yes	E
43	122,418	5	1	30	34	Yes	A
44	132,970	4	1	27	31	No	C
45	178,034	4	1	18	21	No	A, B
46	39,970	3	2	18	42	No	C
Average	***130,542***	***4***	***1***	***20***	***27***		

Table 4.2 Principal Investigator Survey: Success and Implementation

Project	Total Annual Cost $	Successfulness (on a scale from 1 to 5)	Riskness to Sponsoring Agency (on a scale from 1 to 5)	Projected Time Frame (months)	Actual Time Frame(months)	Implementation	Project Classfication
1	272,000	0	3	36	48	NO	B, D
2	110,000	5	1	15	21	NO	B, E, F
3	75,000	4	1	15	18	NO	C, E
4	100,000	4	2	18	24	NO	B, E
5	70,000	4	2	12	18	YES	B, E
6	191,500	3	2	24	24	NO	A, C
7	118,000	4	1	18	18	NO	F
8	60,000	4	1	16	16	NO	B, E, F
9	142,800	4	1	11	11	NO	B, E, F
10	21,000	5	1	7.5	12.5	YES	A, B, C, D, E
11	87,000	3	1	12	12	NO	C
12	100,000	5	1	24	30	YES	A, C, E
13	57,435		1	15	15	NO	E
14	238,224	5	1	36	38	YES	B, C, D, F
15	72,260	5	1	12	12	YES	C, D
16	136,600	1	2	24	24	NO	A, B
17	45,150	2	2	24	not completed yet	NO	B, F
18	30,000	4	1	12	12	YES	A, C
19	29,531	3	2	17	17	NO	B, E
20	137,707	2	2	24	24	YES	B, E, F
21	79,913	2	2	13	13	NO	A, F
22	87,500	4	1	11	11	NO	B, D
23	63,363	4	1	16	18	YES	E
24	135,000	5	2	18	29	NO	A, B, E, F
Average	***233,042***	***4***	***1***	***37***	***47***		

4.4 Additional anecdotal information

Many Project Managers and Principal Investigators found completing the surveys to be quite a challenge. The initial mindset for many was that "this cannot be done," that many successful projects have significant qualitative benefits and are difficult to quantify. In many instances, this perception was reinforced by a lack of formalized data retention or tracking of project outcome. That the survey required more than a cursory review, and that many Project Managers or Principal Investigators received more than one survey to complete (requesting information on more than one project), tended to exacerbate this perception. CUTR underestimated the impact that the extensive survey, meant to evaluate program efficiency, would have on the respondent's tasks at hand. Survey recipients were concerned by the manner in which any data might be used, as well as how successful project types with little quantitative data might be measured.

Another factor that emerged from the survey findings was the projected time versus actual time to completion for many projects. Respondents reported an average delay of project completion of approximately 6 months. Some factors for consideration from this finding are the opportunity costs of resources committed to a project, and the control and expectations of a project's progress and outcomes.

If cost opportunity issues are to be considered, such as the benefit of other research that can be conducted for every month of delay, then a substantial economic value is forgone due to delay in project completion. This would be true even if the annual allocated budget from FDOT were fixed, and researchers would not be allocated more money for completing projects at an earlier date. The issue becomes more problematic if we apply the forgone opportunity to invest this amount at the currently accepted discount rate.

Chapter 5 - Candidate Project Evaluation

Introduction

The data collection process as discussed in Chapter Four provided useful insight into the extent and accuracy of project information retained by Project Managers and Principal Investigators. Additionally, the process further defined those project types that might best be measured in a quantifiable manner, and which might be a source of baseline metrics for evaluation of the FDOT Research Program. In developing a model or set of equations to evaluate research expenditure, our proposed approach included a "validation" of our methodology.

5.1 Data Collection for Model Validation

From the original data set of 281 responses, 15 projects were selected for an additional survey. This additional survey, and the data collected, is presented in Appendix A. A limitation of no more than two projects per Project Manager was applied to alleviate the demands on PMs for responses, as well as to diversify the sources of data. The projects were not selected by functional areas; rather, they were selected insofar as they lent themselves to a quantification of benefits or insofar as the Project Managers appeared to have good data or sound recollections of outcome.

It was the intention of the CUTR team that the sample data points from this additional survey would form the basis for a proxy data set representative of the FDOT Research Program activities. The sample data points would utilize the information requested in the survey regarding the possible ranges of completed project economic benefits, in terms of cost-savings, and related implementation costs. The ultimate objective was to create a synthetic sample using the sample data points and a statistical process named Monte Carlo simulation. The synthetic sample would have represented an approximation of the population distribution underlying that of the sample data points, thus compensating for the lack of historical data. Unfortunately, from the additional 15 surveys, only 4 respondents partially reported responses, thus rendering the Monte Carlo simulation impractical. Therefore, the CUTR research team opted for an application example to demonstrate the validity of the proposed model. The example is explained in detail in Chapter 6.

5.2 Proxy Data and Monte Carlo Simulation

The lack of data available to facilitate the Monte Carlo simulation of a proxy dataset is not an indication that this process is unsuitable for FDOT use. To the contrary, Monte Carlo simulations are particularly valid because they can utilize a relatively small dataset and provide robust statistical output. The challenges that CUTR experienced in obtaining data would be easily overcome with a more thorough explanation of the Research

Center's intent and with buy-in from a limited number of Project Managers. Without the need for an extensive and lengthy data collection process, The Research Center would be able to derive proxy datasets with minimal effort.

The survey respondents were asked to report a range of cost savings the completed project might have realized on an annualized base. They were also asked to provide implementation cost estimates in terms of ranges. A sample survey is available in Appendix B. Considering the lack of a formalized data collection and project evaluation process at FDOT, as well as the large number of functional areas under which FDOT research is classified (or even the smaller number of categories used to classify research projects detailed in Chapter 2), obtaining a statistically sufficient number of datasets suitable for robust statistical analysis is highly unlikely. Hence, a procedure was needed that could utilize the limited data effectively and provide a basis for future project evaluation.

A statistical process known as Monte Carlo simulation facilitates this. The Monte Carlo technique takes its name from the famous gambling center, due to the randomness involved in game outcomes. The application of Monte Carlo simulation is particularly appropriate to the situation presented by the FDOT Research Office; there is a need for several parameters to produce estimates of the economic benefits of a research project but insufficient data to undertake statistically robust analysis. Further, data from the surveys supports the assumption that some of these parameters cannot precisely be quantified for the lifetime of the project. This is due to several reasons, the most significant of which is the lack of readily available quantitative information/estimates on economic returns from the implementation phase of research findings.

Monte Carlo Simulation makes it possible, using a small number of data points, to estimate the mean and standard deviation of a derived dataset of interest and to support statistical inferences of the necessary parameters. Monte Carlo simulation analysis has become established as a financial tool to aid in risk analysis, particularly in investment decision-making (e.g., range of investment levels, implementation costs, defining possible benefit streams). The fundamental concept is that a computer can be used to simulate a large number of outcomes, each representing a probable future path. The values generated will be found most frequently near the most likely outcome (e.g., the most likely range of economic returns) and less frequently for values further removed from that outcome. The simulation typically undertakes over 1,000 runs.

5.3 A Simulation Example

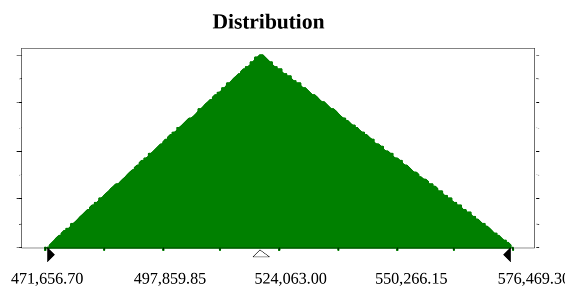
The objective of the additional survey was to obtain a small data point sample from which to run a Monte Carlo experiment. Using a relatively small dataset from the second survey, in terms of project cost savings and implementation costs, the CUTR research team intended to create a synthetic sample to simulate the availability of a larger database (although the team recognized that not all project categories will be conductive to qualitative measurement, those that are require some level of baseline data).

PM's were asked to provide three possible ranges of various cost-savings and implementation costs: Lowest, Highest, and Most Likely. An underlying assumption has to be made regarding the data generating process (DGP) for the observation at hand. In this example, we assume that the distribution underlying the DGP is a triangular one. That is, the three values provided by the respondents are assumed to originate from a distribution where, if they were to be drawn again and again, they would take any value, at random, within the open-end intervals of the least and most likely values. Furthermore, it is assumed that the most likely occurring event reflects the most likely value. Using this assumption and the provided ranges, a synthetic sample of 1,000 observations is created. The figure below provides a computer snapshot of the Monte Carlo run. Figure 5.2 displays the results of a Monte Carlo run, with an underlying truncated lognormal distribution.

Assumption: Cost-Savings Distribution

Triangular distribution with parameters:

Minimum	471,656.70
Likeliest	520,000.00
Maximum	576,469.30



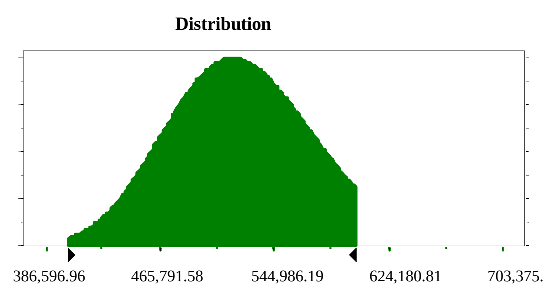
Selected range is from 472,000.00 to 576,000.00

Figure 5.1 Monte Carlo Simulation, all data in $

Assumption: Cost-Savings Distribution

Lognormal distribution with parameters:

Mean	524,063.00
Standard Dev.	52,406.30



Selected range is from 401,379.96 to 602,006.31

Figure 5.2 Monte Carlo Simulation; all data in $

The objective of the survey of selected projects was to obtain a small data set from which to conduct sample drawing with replacement[1] and create a synthetic data set of new observations able to provide a proxy for expected benefits and costs a given project category might actually produce. Project Managers were asked to provide estimates of the ranges of savings (or benefits) that a project might have achieved in the areas of Construction, Maintenance, Administrative, and Technology savings. PMs were also asked to provide an estimate of the costs of implementing the findings of the research project. Once this is done, the data can entered in the option validation model as described in the example application of Chapter 6.

[1] Sampling with replacement is the first step in Monte Carlo simulation. From a give sample, one observation is extracted and replaced with an out-of-sample randomly generated observation.

Chapter 6 - Model Development

Introduction

Extensive research on currently available evaluation methods showed that there is not a unique approach to project valuation. Rather, there are different valuation approaches, which have been applied to tentatively ascribe a quantitative economic value to the benefits of transportation research programs. Some of these approaches try to provide quantitative measurements, while most rely on qualitative assessments to overcome what seems to be the main constraint to evaluation - the inherent incapability to accurately measure economic benefits of transportation research programs.

The objective of this task was to develop a model or an approach to provide a quantifiable economic measurement of the value of research projects, aimed at recognizing and summarizing benefits for which a consensus on dollar value may not be easily recognized. Using the CUTR proposed project classification, option pricing theory is applied to valuing the economic impact of Transportation Research and Development (TR&D), and extended to transportation research project evaluation. The conditions of limited data availability, commonly found in transportation research agencies, are partially resolved through Monte Carlo simulation.

Option pricing theory (and the undergirding philosophy, generally) is currently applied in various R&D programs in the private sector, such as the oil exploration, pharmaceutical, telecommunication, and service industries. This approach has found support in that it is somewhat different from other financial techniques and is particularly suited to the nature of research programs [i.e., medium to long-run project duration, uncertainty of outcome, implementation of findings delayed at some point in the future, and the general recognition that risk varies throughout the overall process, and finally the need to have a portfolio of research projects with an ideal mix of short-run, low-risk and medium-long run, high risk research projects (e.g., applied vs. basic type of research)].

The Real Option Approach, combined with Monte Carlo simulation, can be adopted to better capture the elements of risk and uncertainty to provide a more accurate economic evaluation of research projects. Ultimately, the goal was to provide the program managers with a set of suggested measurements of the value of research projects for each of the categories and, at the same time, to optimize their potential for economic returns under a set of yearly fluctuating budgetary constraints. Furthermore, given limited initial data, a Real Options approach provides the setting for considering the entire FDOT Research Center *program* more as an investment for future gain, as opposed to tracking and attempting to select individual projects based on likelihood of success and payoff.

In the first part of this chapter, an overview of the currently available evaluation methods, including a short background on Net Present Value (NPV) and Real Options evaluation methods is presented. In the second part, an extension of the Real Option approach to value research projects is provided. Finally, an example application to show how this approach can supply transportation research managers with a new tool to value their projects is demonstrated. Data constraints are overcome with Monte Carlo simulation processes (as explained in Chapter 5) and data from the PM survey as discussed in the previous section of this report.

6.1 Current evaluation methods

There exists an extensive body of literature covering the benefit-cost analysis of transportation improvement projects. As a consequence, there is general agreement within the transportation research community on key variables such as travel time-savings, accident costs, and, to a certain extent, proper discount rate. Conversely, there are only a limited number of studies that actually address the specific issues of estimating the economic benefits attributable to transportation research projects. Table 6.1 provides an informational summary of the techniques currently available.

Benefit/cost ratios have been popular for some time, since they provide a simple and relatively easy way of attempting to understand the potential gain of transportation research projects. In performing a simple benefit/cost analysis, it is necessary for the decision maker to provide quantitative information in order to ascribe value to a project. When this has been done, the project can be viewed as a relatively simple financial investment and, therefore, be subject to measurement with more standard financial investment tools (e.g., net present value).

Table 6.1. Project Evaluation Techniques-Overview

METHOD	MEASURE	PRO	CON
Benefit-Cost Analysis	In terms of direct user benefits and project costs. The B/C ratio measures the ratio of projects benefits to project costs	Widely known and used technique. Relatively easy to compute and implement	Overestimation of cost/benefits. Subjectivity of attributions / assumptions about externalities of costs. Mainly considers direct user benefits. General disagreement upon hurdle rate for discount
Net Present Value (Discounted Cash Flow)	Measured in dollars, it estimates the actualized difference between expected benefits and costs associated to the research project	Conventional type of investment analysis. Widely accepted	Discount rate often includes conservative estimates of perceived risk. High discount rates contribute to unwarranted risk aversion to making long-term/high risk investments
Payback Method	Ratio of Investment over Annual Cash Flows	Easy to compute and understand	The longer the payback period, the higher the risk. Not well suited to evaluate long-term basic type of research. Does not measure the returns from cash flows for the life of the project
Return on Investment	Measures economic benefits of in terms of a ratio	It assists in in planning and decision making for future investments and priority setting	As with NPV, it fails to deal explicitly with the implications of not pursuing the research project
Real Option Valuation	Similar to NPV, but through a bionomial decision tree, which accounts for the element of uncertainty peculiar to the project	The higher the uncertainty of project's outcome, the higher the potential payback from investment. Very well suited to track project development from approval to post-implementation phase. Well suited to value medium and long-term, high risk research projects	None in particular. Additional information in the form of estimated project related probabilities need to be gathered or simulated
Peer Reviews	Qualitative assessment through anecdotal stories of project success.	Can capture all qualitative externalities not measured by all other traditional valuation methods. Can be used without extensive data.	Not particularly useful for project prioritization/evaluation purposes, especially under budgetary constraints

6.1.1 Current Evaluation Methods Shortcomings

As outlined in Table 6.1, the various readily available project evaluation techniques have a number of shortcomings. Such shortcomings impact the measure of economic benefits and the discounting of future benefits, and ignore the basic economic principle of sunk cost.

Economic Benefits

The major limitation common to all currently available evaluation methods is the assessment and definition of what constitutes an economic benefit. While it is relatively easy to resolve the issues of defining research costs (conversely, it is difficult to identify the costs associated with the implementation of research findings), to assess the benefits a particular research project will produce is by far the most difficult task in determining the value of an investment in a research. Usually, benefits are assumed to take the form of tangible and intangible benefits. Tangible benefits (e.g., cost savings accrued by the development of a more durable type of asphalt) are easier to quantify, while intangible benefits (e.g., an increment in labor productivity due to technology transfer) are difficult to identify and capture.

While tangible benefits tend to provide hard data to the researcher and are more objective in their own assessment, intangible benefits usually incorporate a certain degree of subjectivity in their definition and are difficult to measure and quantify directly. As seen previously in Chapter Four's interpretation of survey findings, the limited availability of hard data impairs any attempts to ascribe quantifiable estimates to transportation research projects. Within the boundaries of current statistical techniques, CUTR compensates for this lack of data by employing data simulation procedures to provide meaningful ranges within which to estimate economic benefits.

Excessive or too conservative discount rate

Even if economic benefit assessment issues are resolved, the particular evaluation method and metric used in evaluating a research project have their own limitations. Table 6.1 summarizes the pros and cons of the most widely used evaluation methods. In particular, Benefit Cost analysis (BC), Discounted Cash Flow (DCF) analysis, and Internal Rate of Return (IRR) fail to treat the research investment as a series of separate decisions (Research, Develop, Implement). Furthermore, the discount rate is typically applied to the entire research project, while the actual level of risk may vary substantially in the different phases (Research, Development, and Implementation). To compensate for these shortcomings, discount rates are often inflated, resulting in an undervaluation of the project.

Research expenditure as a sunk cost

All methods, with the exception of the Real Option Approach fail to take into account that research projects (such as basic research) can be assumed as a sunk cost by the sponsoring agency. That is, a research project may have embedded a high element of uncertainty with respect to its outcome, but also provides the opportunity to reap great benefits. By applying NPV or DCF, the research manager might fail to deal explicitly with the implications of not pursuing the research project if the initial NPV is negative and the project is rejected altogether. This is especially true for basic research, which is prone to return a negative NPV the longer the temporal horizon of the research phase. As a consequence, NPV and DCF approaches seem to favor applied, short-term, low-risk transportation research at the expense of basic, long-term, high-risk transportation research. This, in turn, affects research programs at a programmatic level, where the portfolio composition tends to be biased towards low-risk, applied research.

6.1.2 Matrix approach

Among the currently available evaluation approaches, CUTR recognized that no single method is suited to evaluate projects across all proposed categories. Rather, even within one category, one or more approaches may be well suited, their use dependent more on the agency constraints and objectives. Multiple possibilities are due to the fact that the choice of the most suitable approach depends on three main factors: time or duration of the research project, the project's relative risk, and the program managers' level of risk aversion. Limited data availability represents a constraint to traditional evaluation approaches as well as the RO Approach. Figure 6.1 provides a quick reference as to the suggested use of the various evaluation methods as well where the RO Approach stands. This matrix supports the evidence that project evaluation needs to be multidimensional, incorporating not only the project categories but also the dimensions of time, risk, and ease of quantification. Ultimately, CUTR found that in the presence of data availability (and an established collection procedure), for those projects characterized by elements of uncertainty in outcome, the RO Approach (by means of a binomial decision tree) better represents and captures the potential payoffs of a proposed project.

		Time of Evaluation		Time to Implement		Risk		Ease of Quantification		Recommended Evaluation Method				
Category		Early	Late	Short	Long	High	Low	High	Low	B/C	ROI	NPV	RO Approach	Peer Review
A	Develop Product or Procedure													
C	Evaluate Product or Procedure													
E	Research and Document													
F	Technology Transfer													

Figure 6.1 RO and Matrix Approach

6.2 Real Options Approach (ROA)

CUTR researchers recognize that the RO Approach has a great potential for extension to transportation project evaluation. It could reasonably provide a means of not only quantifying their intrinsic benefits, but also providing a tool for research portfolio decision-making under budgetary constraints.

Recently, Real Options has emerged as a potentially useful technique complementing traditional approaches to R&D evaluation. Option Theory to value financial assets was originally formalized in a theoretical and mathematical framework in the 1970s thanks to the work of Black & Scholes (1973) and Merton (1973). The early insight that Options Theory could be applied to non-financial settings, (or real options) as described in

Trigeorgis (1996), coupled with the realization that the real value of investing in research is equivalent to the purchase of a real option, led to attempts to extend this approach to value research. To date, much of the practical application of Options Theory has been in the pharmaceutical and biomedical industries, and, to some extent, in the service and telecommunications sectors.

The main advantage of the RO Approach lies in its capacity to capture the value of flexibility in R&D projects. It presents research program managers with the option to abandon a project if the results of R&D are not promising, thus limiting losses to the amount originally invested in the R&D phase. By applying the RO Approach, the research project is regarded as a series of sequential options where information enters the process as it becomes available to the analyst.

R&D is characterized by uncertainty, and the effective assessment of R&D programs requires a complex interaction of variables. It requires the balancing of strategic management (how to properly allocate R&D resources) with operational management (execution of projects) while facing budgetary constraint issues. The strategic aspect of R&D management alone requires the resolution of some very important questions such as the following:

- Do we have the right total R&D budget?
- Are we allocating it to the right research areas?
- Do we have the right mix of risk and returns of long and short-term projects, of basic verses applied research?

This chapter addresses the manner in which the conditions of limited data availability, commonly found in transportation research agencies, are partially resolved through simulation techniques. The following sections will demonstrate that the Real Option Approach, combined with Monte Carlo simulation, can be adopted to better capture the elements of risk and uncertainty to provide a more accurate economic evaluation of entire research programs.

6.2.1 Explanation of RO Approach

Definition of option

An option is a financial product constantly used in the daily financial decision-making process. The kinds of options that are traded today come in many forms. The type that is most relevant to Research and Development (R&D) is the "call option." A call option is a contract that gives the purchaser the right but not the obligation to buy a certain asset at a specific future date. When the future date comes, the purchaser of the option will "exercise" this right if the market price of the asset is higher than the price specified in the option contract, and will make a profit proportional to the price differential. If the market price of the asset is lower than the option contract price, the option holder will allow it to "expire", and his loss will be limited to the original amount paid for the option. Two interesting characteristics of a call option are that its potential value is a function of future uncertainty and time to expiration, and that there is a limit to the downside risk to which the option holder is exposed. Increases in uncertainty about the future asset price increase the value of the option.

The general concept is that R&D is closely analogous to an investment in a call option. An R&D investment gives the right to decide, at some future date, whether or not to "exercise" that R&D investment. At the end of the R&D phase, the uncertainty that is intrinsic to research will be resolved and the outcome can be assessed. If the outcome looks promising and external conditions are favorable (political, economic), the R&D will be exercised in terms of implementing the R&D findings. It if does not look promising, the R&D option will "expire" (or an option to postpone will be exercised) and the loss will be limited to the amount of the initial R&D investment.

The extension of the use of options from financial assets to real assets happened quite recently, when corporations strived to find more flexible methods than discounted cash flow analysis in the evaluation of investment opportunities in very uncertain environments. Only recently, the approach has been extended to Research and Development (R&D) to aid in the assessment of research projects, particularly in medical and biological research, due to the high uncertainty of outcome.

As we will show in greater detail in the next sections, the parallels between the option price and an R&D option can be seen by the following comparisons:

- The price of an option is analogous to the cost of the R&D project
- The exercise price is analogous to the cost of the future investment needed to implement the R&D findings
- The value of the stock is analogous to the returns that the R&D investment will produce. It is the uncertainty in these returns that gives value to the option

6.2.2 Real Options Applications

To date, much of the practical application of the RO Approach has been to the oil exploration, pharmaceutical, and biomedical industries, although increasingly to the service and telecommunication sectors. In the service sector, recent applications deal with electronic commerce projects evaluation or decisions of companies to invest in Internet retail services.

Typically, R&D is divided into three main phases, each one characterized by its own timescale: 1) Research; 2) Develop; 3) Launch the product. At the end of each phase a decision has to be made on whether or not to continue for the next phase. The research and development phases are also characterized by costs. The last phase is characterized by expectations of economic returns. Under this scheme, the research phase buys the option to launch the development phase, which in turn buys the option to launch the implementation phase. The choice of model depends upon the compromise between capturing as many aspects of the decision problem as possible while being able to reasonably estimate the parameters of the model.

6.2.3 Relevance of Real Options Theory to Transportation Research

Investments in transportation research programs have potential benefits, but they come with the risk that their actual benefits, costs, and other factors affecting implementation may differ greatly from those predicted. Investment in transportation R&D can be regarded as the option, but not the obligation, to take some action in the future. However, the decision whether to invest in a given R&D project, once made, is irreversible.

The option approach shifts this decision-making process from simply choosing whether to invest in a R&D project to a management approach that considers a range of possible decisions, with the potential value of each decision measured in terms of its option creating value. By allowing the incorporation of improved information, the RO Approach allows program managers to positively incorporate those risk elements inherent to transportation R&D, better capturing their potential value in term of economic benefits.

Importantly, the RO Approach sets clearly the concept that research expenditure today is a "call option" on future gains for the FDOT. Universally, sound business practices protect against future losses and plan to be ready to take advantage of future opportunities. As such, research program expenditures are the extent of future losses, but are a necessary cost of securing the ability to exploit future opportunities as they arise. The fundamentals of the RO Approach are easily extended from individual project evaluation to program evaluation, again along the lines of a "portfolio mix" of research investments. Certain projects lend themselves more easily to quantifiable outcomes, others more to qualitative measurement. The portfolio approach would allow program managers to consider that an appropriate portion of research expenditure be in the harder-to-quantify types of activity, balanced by those in the easier-to-quantify categories for which an RO Approach can be applied to value a research program's overall activity.

6.3 ROA Model Selection

There exist several methods to evaluate a real option, most of which directly follow the approach initially formalized by Nobel Prize recipients Black, Scholes, and Merton, which developed the theoretical and mathematical framework for financial option valuation. The Black-Scholes partial differential equation (PDE) represents the basis of valuation of many different types of option. The solution of this equation provides the value of the option, which can be exercised (or not) at one specific date in the future.

CUTR found that the nature of transportation research lends itself well to an alternative approach defined as the Binomial Option Valuation Model in valuing transportation research projects because this approach requires the construction of decision trees, which by their graphical nature help to convey a direct understanding of the basic outline of the project path from inception to completion. Furthermore, the use of the decision tree approach addresses the element of project risk in a manner that cannot be modeled by applying the Black-Scholes equation. In fact, in financial markets, where the Black-Scholes equation is mostly used, the calculation of volatility of a given assets takes the form of a log-normally distributed continuous variable, while in R&D risk takes the form of a discrete variable. Hence, the Binomial Option value model provides a better statistical fit to predicting likely of outcomes for research project valuation.

6.3.1 Black Scholes

The Black-Scholes pricing method requires the solution of a system of equations, whose necessary inputs are those defined in the following section. Although the formula itself is complex, it can be programmed into a computer. The complexity of the formula, however, means that the Black-Scholes will appear as a "black box" to most research managers. The mathematical manipulations that take place are not easily understood and the results are often counterintuitive, thus presenting a significant challenge to the acceptance of Black-Scholes model adaptations. For convenience and for a more thorough discussion of the Black-Scholes approach and base formula, please refer to Appendix E of this report.

6.3.2 Decision Trees

Decision trees have been discussed in many papers in terms of the principle and method of construction and use. Real option valuation by means of decision or binomial trees can be shown to be a direct adaptation of the Black-Scholes model and that it can yield the same results. The decision trees can help project managers to do the following:

- Understand the basic outline of the project path from inception to completion. The construction of the tree can help the project manager to understand the sequence of events that will have to be developed as the project progresses. It can also help project managers to reduce the likelihood of unpredicted events in downstream activities (for example, project activity delays).
- Identify and understand the probability of success along the project path. By designing a decision tree for each project, project managers could begin to track historical information on probability of success peculiar to each project category. As historical data is accumulated, their reliance on simulation processes is reduced and option value calculation becomes more accurate.

The ability to lay out on a single sheet of paper the key elements of a project can prove useful in project selection, project management, and project portfolio composition decisions. Considering the degree of risk aversion of the programming agency and its correlation to the annual budgetary constraint, transportation research agencies can utilize decision trees to construct an optimal portfolio capable of maximizing returns. The actual construction of a decision tree can be a time consuming process for each project, but can be considered a useful investment in time by the project evaluator. Figure 6.2 displays an example of a decision tree that can used to value a given R&D project.

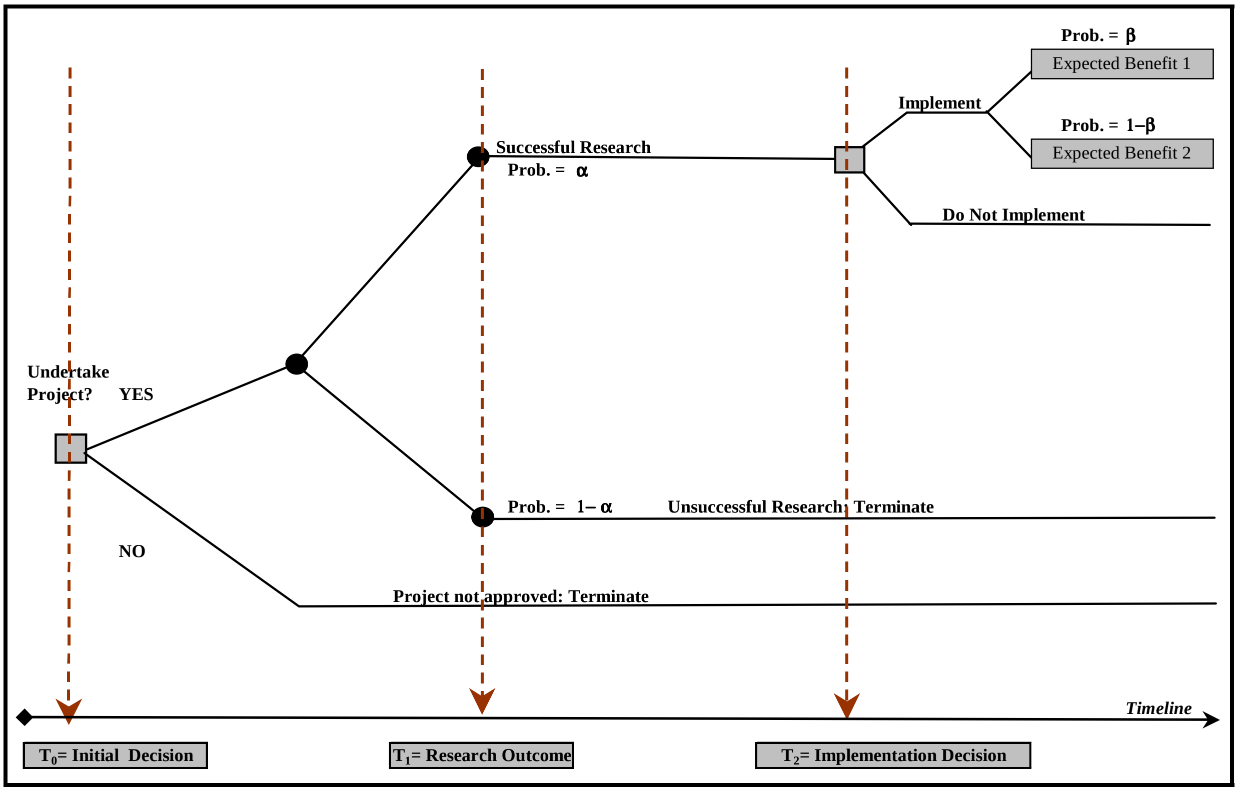


Figure 6.2 Binomial Decision Tree

Explanation of the binomial tree

An R&D investment can be viewed as a cost (I_0) of a real option in which the project proceeds only if the R&D succeeds. More specifically, the cost to implement the R&D findings can be viewed as the exercise price (I_c), and the present value of the future expected benefits (EB) from implementation could be viewed as the asset value for a typical real option framework. A successful R&D outcome has probability ($P(S) = \alpha$), whereas an unsuccessful R&D outcome has probability ($P(F) = 1-\alpha$). Alpha can be considered as a measure of technical risk peculiar to the project being valued. In this example, to value the option of an R&D project, we assume that the expected benefits (which can take the form of cost savings) assume one of the two values. They take the form of EB_1 with probability (β) if the economic conditions are favorable, and a value of EB_2 with probability ($1-\beta$) if the economic conditions are unfavorable.

At each point in time along the timeline, the project manager is faced with a decision. At T_1, when the outcome of the research is known, the project manager must decide whether or not to implement the project findings. In doing so, the manager will have to rely on the expected benefits. At this point, newly available information can be incorporated in the decision making process, leaving the project manager with the option to interrupt or proceed to the implementation phase. At T_2, the research project will start producing benefits.

Eventually, the process is one of back folding values from T_2 to T_0. The first decision is whether or not to buy the option (invest in R&D), which depends on the value of the option itself. This value is based on estimates of uncertain future benefits.

While the project manager does not know exactly what the future benefits will be, the range and likelihood of these benefits using a probability density function can be modeled. The research manager is also faced with the uncertainty surrounding the expected implementation costs. Thus, in order to make a decision about the R&D project, the manager must use two models of uncertainty: one for the expected benefits and one for the expected implementation costs. To resolve this problem, accrued by the lack of historical data, in Chapter 5 we proposed to utilize Monte Carlo simulation. Eventually, due to the fact that Monte Carlo experiments entail a high number of runs, the resulting option value will be in the form of an inference interval, with attached confidence bounds. This will be seen in greater detail in the example application.

6.3.3 Binomial Tree Real Options Equation

Inputs details and constraints

The inputs needed to run the RO Approach and evaluate an option on an R&D project are:

- The initial investment cost, I_0 (Value of the underlying asset, V_0)
- The implementation cost to implement findings, I_c (Exercise price)
- Time to the decision date (option expiration date), T
- Risk free interest rate, r
- Probabilities, α and β (volatility of the underlying asset, σ)

The parallel between the option price of a stock and an R&D option can be seen if we substitute the above factors for the analogous elements in parenthesis.

Expected Benefits (The current value of the underlying asset V_0)

For an option on a stock, this is just the current stock price. For a real asset, calculations have to be made. When V_0 cannot be directly established, a comparable asset is used instead. For example, in valuing an Internet start-up the value can be obtained using the V_0 of comparable firms already established.

In the traditional Black-Scholes option valuation approach, V_0 follows a geometric process. V_0 moves up or down by multiplying it by an up/down movement factor. The magnitude of the up/down movement factor depends on the volatility of the underlying asset. By estimating movements of V_0, the analyst is able to compare it to the exercise price at the time the option expires. If V_0 is greater than the exercise price, then the option will be exercised. Therefore, the greater the volatility, the greater the changes V_0 could incur in each period, thus leading to a potentially higher option value.

In transportation R&D, V_0 is the value of the benefits coming from the implementation of the research findings discounted to their actual value. Together with implementation cost, it is the most difficult input to assess. Very little quantitative information can be currently obtained on this input across all project categories. The difficulty is mainly due to the fact that a system that tracks the post-implementation phase of research findings must be in place to record any historical data on accrued benefits. As discussed in greater detail in Chapter 4, the survey demonstrated the difficulty of obtaining even rough estimates, in terms of ranges, of benefit attributable to a given research project. In Chapter 5, CUTR provides an alternative method to deal with this lack of information.

Implementation Cost (the exercise price)

In R&D, the exercise price is the equivalent to the cost of the future investment needed to implement the R&D findings, I. As in the case of V_0, the main problem is to identify what costs will have to be associated to implement the findings of a given R&D project. If proxy data are available from similar completed and implemented projects, this information can be entered in the option valuation process. The application example provides a clear idea of how to partially overcome lack of information on implementation costs.

Project Specific Probabilities (the volatility of the underlying asset)

Volatility in the Black-Scholes model is derived from the "price relative" (final stock price divided by initial stock price) and obtained from historical data. Volatility expresses the inherent risk associated with the traded asset. This usually does not apply to R&D projects.

In R&D, volatility takes the form of probability that an event will occur, such as the probability that the research will be successful in attaining the objective stated in the initial scope of work. Probability can also express the risk associated with the implementation of findings, which embeds elements of uncertainty exogenous to the project. In our case this can be related to the probability of success of research projects. Success could be estimated by using the rate of project approval by FDOT through the years, as well as the rate of success in research, e.g. successful project completion.

In order to capture project volatility, CUTR proposed using the analog of the Black-Scholes financial option pricing formula to understand the effect of volatility. This approach is useful to qualitatively understand the determinants of project value. However, it relies on the assumption of variance growing continuously over time or more information being gained every day. Additionally, the variance is often assumed to grow at a pace following a random walk[2]. This does not fit a research environment, where information becomes available at discrete points in time (e.g., after a research phase has been completed). To remedy to this limitation, several authors have proposed jump process models, in which discrete value changes are superimposed on a Brownian value process following exponentially distributed intervals.

6.3.4 The equation

The value of the R&D option at the completion of an R&D project is equivalent to the stock option on the exercise date. When the decision is made to invest or not invest in a given R&D project, the value of that R&D project is the difference between the net present value of the anticipated or expected benefits and the net present value of the implementation costs. If the anticipated benefits exceed the costs, then the R&D project has a positive value. Otherwise, the project has no value. Since the research manager does not have to make the additional investment (in implementation costs) if costs exceed benefits, the research manager will never realize a loss from this decision.

The value of an R&D project at completion is:

$$V = \max [0, B-C]$$

Or

[2] A random walk is a time series in which an observation at T_2 takes a value which is independent of the value of observation at T_1

$$\begin{Bmatrix} B - C, & if \quad B > C \\ 0, \; if & B \le C \end{Bmatrix}$$

where: V= value of the R&D at completion

B= net present value of future benefits

C= net present value of implementation costs

The value of the R&D project at the beginning of the project would be V discounted back to time T_0. Of course, the project manager does not know what V will be until the end of the project, so the expected value of V must be used as an estimate. Let X be the net flow of benefits, X= B – C, then the expected value of the project at completion is given by:

$$E\,[V] = \int_0^\infty x f_x(x)dx$$

Where $f_x(x)$ is the probability density function of the net expected benefits. As shown in Chapter 5, and in the example application of Chapter 6, if some underlying DGP for both expected benefits and implementation costs is assumed, it is easy to derive $f_x(x)$ from the distribution of B and C. In particular, it can be shown that, by using relatively few data points for a sample of historical data on benefits and implementation costs of similar projects, one can obtain a distribution of outcomes of E [B].

While the anticipated costs will always be greater than zero, the net benefits can be positive or negative. The model can now be used to determine how much one would be willing to pay for R&D at the beginning of the project, given a discount rate of *r*:

$$V = e^{-rt} \int_0^\infty x f_x(x)dx$$

In this model, the two uncertainties of benefits and implementation costs are combined into one probability model describing net benefits. In Chapter 5, two different distributions to describe the underlying DGP of expected benefits and expected implementation costs were used. It is common practice to assume expected benefits to be log-normal distributed. Depending on the characteristic of the project in question, a triangular distribution can be fitted instead.

6.3.5 Applied Example with Monte Carlo Simulation

An example of a ROA application to value a given R&D project follows. The example shows how the value of the project increases as its relative uncertainty accrues, while NPV fails to do so. Given that in order to value the option all of the inputs described in the previous section are needed, researchers at CUTR utilized a simulation procedure to compensate for the lack of quantitative data from past completed projects. The initial objective was to utilize information from a set of selected completed projects (as described in Chapter 5) to create a portfolio of projects capturing all of the proposed categories. Since only two or four PMs provided partial answers to the selected questionnaire, CUTR could not collect enough information to attempt to construct a FDOT research portfolio able to produce meaningful insight.

Instead, an application example to explain how the RO Approach can help to better evaluate a given R&D project is examined. The following example is intended solely for explanation purposes. It by no means represents an attempt to ascribe a value to a specific FDOT project. Some of the parameters needed for RO Approach analysis were obtained using information from the initial survey of the 281 completed projects.

Example

Highways are repaved on a regular basis to guarantee a sufficient thickness of asphalt. This helps to avoid road wear as well as expensive repair work and assures continued road usage. However, some highways need more maintenance than others. The research project deals with the construction of a prototype device to measure the thickness of asphalt. The successful prototype should provide a means to accurately assess asphalt thickness, so that roads are not repaired prematurely or unnecessarily. Such a successful research project could result in significant annual cost savings in terms of dollars saved in asphalt expenditures. Figure 6.3 depicts the Binomial Tree approach to value this research project.

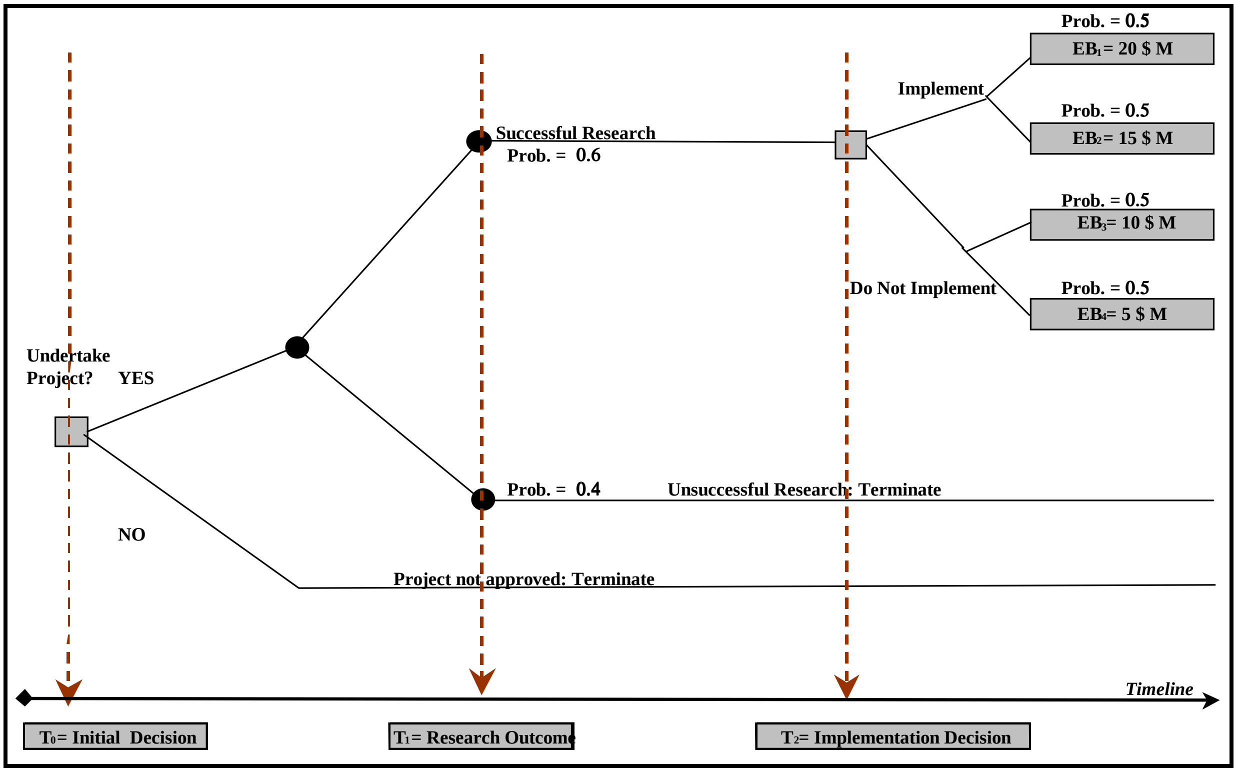


Figure 6.3 Example Application: Binomial Tree.

Inputs and Assumptions

The research and development of such a device will take one year and cost $7 million. At the end of this phase, if the research is successful and no particular events suggest a delay in implementation, the results can be implemented. The costs associated with the implementation are not known at the moment the research project is approved, but previous historical information on similar devices helps to provide some estimates. Projected implementation costs (I_c) could range between $15 and $30 million with a mean value of $20 million. Such costs are assumed to be log-normally distributed, with a standard deviation of 3%. Figure 6.4 depicts the distribution of implementation costs.

It is also assumed that the device will be in use starting in the third year after the implementation phase. Expected benefits in terms of cost savings will start that year and are projected to last for at least five years. Given the current economic conditions, and information on similar and previously completed projects, we estimate that annual cost savings will range between $15 million and $20 million a year, in a best-case scenario. In a less than optimistic scenario, annual cost savings will be between $10 million and $5 million. It is assumed that the expected benefits are exogenous to our analysis, since there is no direct control on their future values. For this example, it is considered that these expected benefits are log-normally distributed with a standard deviation of 20%. Figure 6.5 shows the relative distribution.

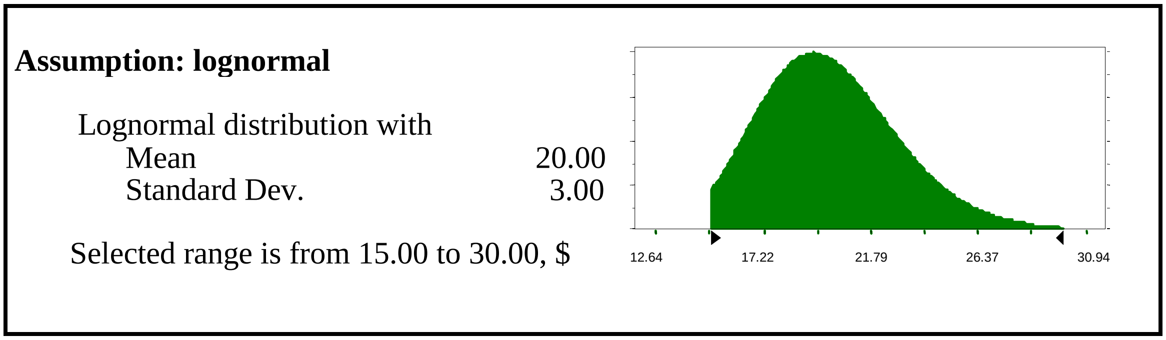


Figure 6.4 Implementation costs distribution

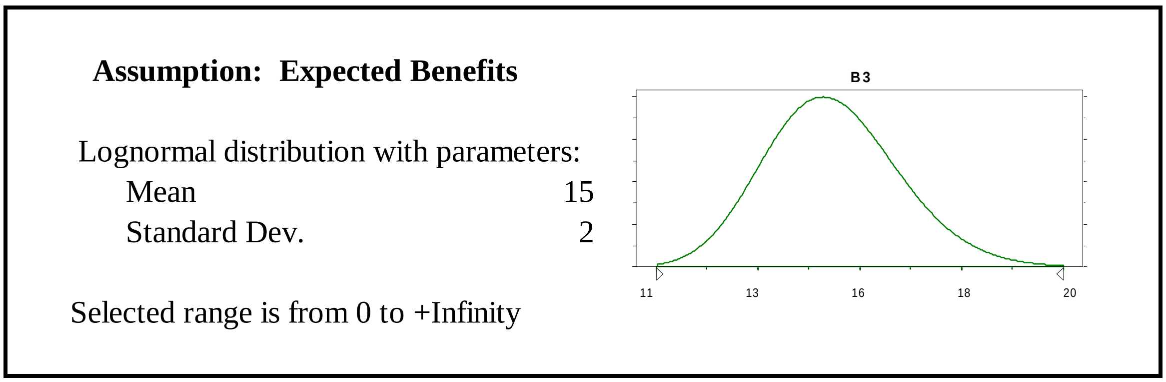


Figure 6.5 Expected benefits distribution

If the research phase is unsuccessful (the prototype is not developed), the device will not be built. Therefore, there will be neither implementation cost nor annual cost savings. As reported in Chapter 4, the survey on completed projects revealed that out of all research projects considered successful, 60% get implemented. This value is used as input for our project-related probability. Furthermore, the assumed risk-free interest rate is 7%.

Results

These inputs are entered into a Monte Carlo simulation model for a 1,000 runs of sampling with replacement. The target variable is the option value itself. After 1,000 runs a distribution of this value upon which to make some inference is produced. Table 6.3 provides the descriptive statistic.

Table 6.2 shows how the regular NPV method suggests a negative value of about $7.2 million for this project. This is because the NPV considers the project as a "now or never" investment decision. In doing so, a fixed discount rate is applied and the present value of the difference between benefits and cost is computed.

Conversely, if the RO Approach is implemented, the research project will be, on average, worth about $8 million at the time the decision will be taken. Table 6.3 shows that the resulting option value is in the form of an inference interval, with attached confidence bounds. This is due to the fact that a sampling with replacement for a run of 1,000 was conducted.

Table 6.2 NPV Method

	EB_1	EB_2	EB_3	EB_4
	20	15	10	5
	PV			
Year 1	16	12	8	4
Year 2	15	11	8	4
Year 3	14	11	7	4
Year 4	13	10	7	3
Year 5	12	9	6	3
Total	72	54	36	18
I_C	-24	-24	-24	-24
Present Value (PV) of Cost Savings	**47**	**29**	**11**	**-7**
Probabilities	*0.6*	*0.5*		
	0.4	*0.5*		
Net Present Value	**-7.2**			
Real Option	***8.6***			

Research Project Costs	
I_0	7
I_C	30.00
PV (I_C)	24
Total	**31**

Assumptions

I_0 = Initial Research Cost
I_C = Implementation Cost
Risk Free Interest Rate = 7%

A confidence interval can be applied to this distribution, and the confidence level can be intended as a proxy for risk aversion. By setting a stricter confidence interval, the project manager is more conservative in valuing the chance that the project will produce an expected level of economic benefits. Figure 6.6 displays the results for confidence interval of 80%.

Stated differently, out of the 1,000 possible values of the option, 80% of the time its value will lay within $5.2 and $10.7 Million. Since the research result is implemented only if the cost savings turn out to be higher than the implementation cost, the real options approach yields a higher result. It can be shown that increasing the risk of outcome plays a positive role in option valuation, while it tends to produce an even greater negative value in NPV.

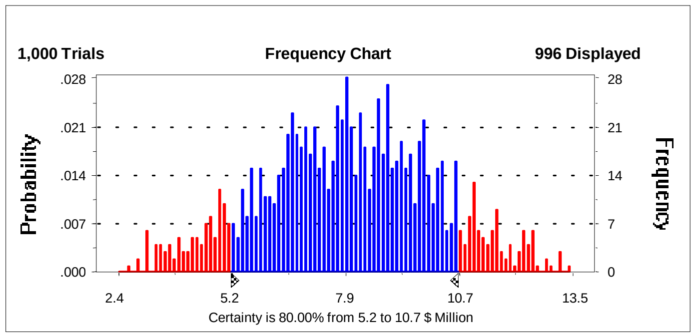
Table 6.3 RO Approach and Monte Carlo Simulation: Results for a 1,000 run

Real Option Value: Monte Carlo Simulation

Summary:

Certainty Level is 80.00%
Certainty Range is from 5.2 to 10.7 $ Million
Display Range is from 2.4 to 13.5 $ Million
Entire Range is from 1.2 to 13.7 $ Million
After 1,000 Trials, the Std. Error of the Mean is 0.1

Statistics:	**Value**
Trials	1000
Mean	8.0
Median	8.0
Mode	---
Standard Deviation	2.1
Variance	4.5
Skewness	-0.08
Kurtosis	2.73
Coeff. of Variability	0.27
Range Minimum	1.2
Range Maximum	13.7
Range Width	12.5
Mean Std. Error	0.07



Conclusions

The RO Approach can help to provide a better assessment of R&D projects, whenever there is entailed a relevant element of risk and uncertainty. Transportation R&D projects have the potential to produce enormous benefits, but they come with the risk that actual benefits, costs, and other factors affecting implementation may differ greatly from those predicted. Investment in transportation R&D can be regarded as the option, not the obligation to take some action in the future. The option approach shifts this decision-making process from simply choosing whether to invest in a R&D project to a management approach that considers a range of possible decisions, with the potential value of each decision measured in terms of its option creating value.

Eventually, the option valuation process could be extended to all those project types that, according to CUTR's proposed evaluation matrix, can be valued by means of the RO Approach. Accordingly, the project manager could produce an optimal project portfolio. By allowing change of input parameters according to project type and category, the research manager could produce an optimal portfolio geared towards maximizing returns given annually fluctuating budgetary constraints and relative risk aversion. Furthermore, better tracking the project completion phase will eventually supply improved quantitative information to use in the option valuation or any other process. Ultimately, any synthetic data set created by means of Monte Carlo simulation can be substituted by historical data as data collection on project benefits and implementation costs becomes routine.

Project classification by research activity rather than functional area will facilitate a more effective means to evaluate project and program benefits. Incorporating a Real Options approach to project and program evaluation will better incorporate the unique qualities of transportation research and assist both mangers and practitioners in evaluating project potential, acting as a more refined and effective decision support tool. An options approach will also better communicate to sponsors of research programs the nature of and rationale for investing in transportation research.

However, it is also important to recognize that this approach is not a "fits-all" solution to project evaluation; oftentimes, simple approaches are still quite relevant. The place of the RO Approach is to serve as an evaluation tool that incorporates uncertainty into the evaluation process, focusing on future gains. It is a phased and adaptive approach that recognizes that political and economic conditions may change. This approach incorporates three fundamentals of transportation research projects: high implementation costs, uncertain future value, and medium to long research phases.

Chapter 7- Conclusions and Recommendations

Public agencies are perhaps more closely scrutinized as to the effective and judicious use of revenues than are private agencies. The existence of public funding obliges agencies to full accountability; however, relevant tools are difficult to identify and develop. In contrast to such typical measures as returns on investment, share prices, and market share, public agencies must also be seen to be "serving the public".

The importance of measuring the return from public expenditure becomes even more visible in times of fiscal restraint. In the case of a Research Program, the danger is that activity will cluster toward easily measurable low-risk types of projects with easily measurable outcomes and, accordingly, low returns. Fundamentally, however, "research" by definition should be an activity in which risks are high, outcomes unknown, and benefits difficult to quantify until the project is complete.

The difficulty in measuring the return from research expenditure is that a historical lack of emphasis on quantification of the benefits of transportation research has led to data gap that makes estimating those benefits today very difficult. Data collection of outcomes and implementation is not routine, and an institutional resistance to measurement often prevails. Furthermore, the timeframe from the original research idea to eventual implementation is typically quite long, the outcomes are uncertain, and there is a broad lack of agreement on what a "benefit" is. Changes in the way that research is viewed could help follow projects from inception to implementation. Additionally, anecdotal success stories will only carry a research program so far. Without an organizational gauge of progress, and lacking the ability to quantify the benefits of previous expenditures, the risk of a loss of attention and subsequent loss of funding are a very real and rational response.

In this study, CUTR examined seven industry types and discovered that a common denominator in the difficulty of Research and Development (R&D) evaluation is that of uncertainty. Additionally, there is a need to better match evaluation tools to address the fundamental elements of transportation R&D, which include the following:

- Projects are rarely short term
- Outcomes lead to subsequent decisions
- Outcomes are uncertain
- Outcomes are difficult to quantify

CUTR also found a need to communicate that research programs are by their nature risky and exploratory. If answers were known with certainty, there would be no need to do research, and project ideas could proceed directly to implementation. Importantly, without R&D today, the option of being able to proceed with certainty in the future is not created.

Hence, for R&D programs to continue and to prosper, a change of "mindset" is required. It is widely understood that research is the first phase of a project, however, by formalizing not just the recognition of this concept but also adopting a tool to measure and evaluate this phase, research can be better seen as the first step in an "option chain." CUTR's adoption of the Real Options Approach (RO Approach) represents not only a potential method for estimating expected project benefits, but also an alternative way of viewing the activity of research programs. Consequently, time becomes a creator of value, as opposed to traditional evaluation approaches that place a cost on time.

The Real Options approach has particular relevance to transportation research, as it incorporates into the evaluation process the very nature of many of FDOT projects including the following:

a. Historical difficulty in Quantifying benefits
b. High Uncertainty of Research (risk)
c. NPV no appropriate for long payoff periods

Effectively, a RO Approach provides a more refined decision support system and has the potential to assist in predicting project benefits in advance. Additionally, the RO Approach implicitly incorporates the element of uncertainty and focuses on future gain, recognizing that political and economic conditions may change. This emphasis on uncertainty and focus on future gain rather than future loss facilitates an adaptive phased approach to research program management. Additionally, the RO Approach mindset helps identify the program mix better by highlighting distinguishing between Project Investments (low risk, committed timeframe projects) & Options Investments (higher risk, more exploratory types of projects). The value of the research itself then can be seen as analogous to a call option.

The findings of this study supports that the RO Approach be an element of a matrix approach to evaluate some, but not all, R&D projects. Project evaluation needs to be multidimensional, incorporating not only the project categories developed by CUTR in this study, but also the dimensions of time, risk, and ease of quantification. The RO Approach is not a "fits all" solution, but one that has a place in a decision matrix for project and program evaluation. The "matrix approach" may also be useful in creating a research portfolio that includes a mix of high-risk high potential pay off projects with other research initiatives.

Data needs are not an insurmountable problem. New, though common, techniques in data simulation can assist. Monte Carlo simulation can utilize a small number of data sets to provide with valid, robust inferences of program or project value. As program data collection improves, these proxy data sets can be replaced by real data.

Recommendations as to the Florida Department of Transportation Research Program's next step in assessing the economic value of the program include the following:

1. ***A "matrix approach" should be applied in creating a research portfolio that includes a mix of high-risk high-potential payoff projects with other research initiatives.***

Among the currently available evaluation approaches, CUTR recognized that no single method is suited to evaluate projects across all proposed categories. Rather, even within one category, one or more approaches may be well suited, their use dependent more on agency constraints and objectives.

This matrix supports the evidence that project evaluation needs to be multidimensional, incorporating not only the project categories but also the dimensions of time, risk, and ease of quantification. Ultimately, CUTR found that in the presence of data availability (and an established collection procedure), for those projects characterized by elements of uncertainty in outcome, the RO Approach (by means of a binomial decision tree), better represents and captures the potential payoffs of a proposed project. The "matrix approach" may also be useful in creating a research portfolio that includes a mix of high-risk high potential payoff projects with other research initiatives.

		Time of Evaluation		Time to Implement		Risk		Ease of Quantification		Recommended Evaluation Method				
Category		Early	Late	Short	Long	High	Low	High	Low	B/C	ROI	NPV	RO Approach	Peer Review
A	Develop Product or Procedure													
C	Evaluate Product or Procedure													
E	Research and Document													
F	Technology Transfer													

Figure 2 Matrix Approach to Project Evaluation

2. ***Utilize an extension of the Real Option Approach as a more sophisticated tool for measuring the potential benefits of transportation research.***

The RO Approach can help to provide a better assessment of Research and Development (R&D) projects whenever there is entailed a relevant element of risk and uncertainty. Transportation R&D projects have the potential to produce enormous benefits, but they come with the risk that actual benefits, costs, and other factors affecting implementation may differ greatly from those predicted. Investment in transportation R&D can be regarded as the option, not the obligation to take some action in the future. The option approach shifts this decision-making process from simply choosing whether to invest in a R&D project to a management perspective that considers a range of possible decisions, with the potential value of each decision measured in terms of its option creating value.

Eventually, the option valuation process could be extended to all those project types that, according to CUTR's proposed evaluation matrix, can be valued by means of the RO Approach. Accordingly, the project manager could produce an optimal project portfolio. By allowing a change of input parameters according to project type and category, the research manager could produce an optimal portfolio geared at maximizing returns given annually fluctuating budgetary constraints and relative risk aversion. Furthermore, a better tracking of the project completion phase will eventually supply improved quantitative information to use in the option valuation, or any other process. Ultimately, any synthetic data set created by means of Monte Carlo simulation can be substituted by historical data as data collection on project benefits and implementation costs becomes routine.

3. ***Tracking project success rates, costs and benefit data must be institutionally integrated if any systematic method of evaluation is to be established. The extent of this effort must be balanced to consider the cost and effort of such a program.***

The FDOT should consider implementing a formal data collection regimen for research projects. Recognition that some projects may be difficult to measure and may not be easily quantified should not be used as an excuse for not embarking on this effort. There is a huge cost of going back to collect this data to quantify research projects, and there appears to be little emphasis on this issue by either Project Managers or Principal Investigators. Tracking of project success rates, costs, and benefit data must be institutionally integrated if any systematic method of evaluation is to be established.

4. ***For R&D programs to continue and to prosper, a change of "mindset" is required.***

The Real Options Approach represents not only a potential method for estimating expected project benefits, but also a way of thinking about research programs. Importantly, the RO Approach sets clearly the concept that research expenditure today is a "call option" on future gains for the FDOT. Universally, sound business practices protect against future losses and plan to be ready to take advantage of future opportunities. As such, research program expenditures are the extent of future losses, but are a necessary cost of securing the ability to exploit future opportunities as they arise.

5. ***Incorporate statistical simulation processes to compensate for the current lack of historical data***

The lack of suitable data in the short term for project and program evaluation can be overcome through data simulation. An accepted and commonly used technique is Monte Carlo simulation, which can utilize a small number of data sets to provide valid, robust inferences of program or project value. As program data collection improves, these proxy data sets can be replaced by real data.

Appendix A

Project Manager Project Survey:

Template and Results

Project Manager Project Survey Template

INTRODUCTION

The Center for Urban Transportation Research (CUTR), at the University of South Florida, is conducting a study on behalf of the Florida Department of Transportation Research Center. This study is indented to develop and test various methodologies to provide some measures of the benefits and returns on research expenditures.

The information collected from you will remain strictly confidential, and your name or other identifying information will not appear on any survey reports. Only aggregate data will be analyzed and reported. As a project manager or principal investigator responsible for the projects in question, you can help us by answering a few questions about the research projects you have performed or managed. Your input is very important to us, and it will help us to assess and document the benefits of transportation research in Florida. This survey will take just a few minutes to complete and your participation is completely voluntary. Thank your for your assistance.

Should you require any assistance in completing the survey, please contact Mr. Stephen L. Reich (813-974-3120, reich@cutr.usf.edu) or Mr. Sisinnio Concas (813-974 -7760, concas@cutr.usf.edu) at CUTR.

Sincerely,

Stephen L. Reich
Principal Investigator

RESEARCH PROJECT IDENTIFICATION

Research Project Title	Contract	Principal Investigator

SECTION A: GENERAL INFORMATION

A 1. Please state when and if research results of this project were first implemented.

A 2. Clients or sponsors using the research results. Please list the primary contact person for each agency or organization using the research results of this project.

SECTION B: ECONOMIC ASSESSMENT OF PROJECT

Please, try to answer the following questions as thoroughly and precisely as possible.

B 1. What was the deciding factor(s) that led to the research project approval (e.g. project cost competitiveness, project's innovative approach, etc)?

B 2. What was the total cost for this project?

B 3. What was the most significant benefit or benefits of this project? *Please, specify both qualitative and quantitative benefits.*

B 4. What was the initially expected time frame to complete the project (e.g. as per scope of work)? *Please, specify length in months or years*

B 5. What was the actual time frame to complete the project? *Please, specify length in months or years*

B 6. Please define and quantify any expected annualized direct benefits or revenue potential resulting from the project implementation or recommendations.

B 7. Was this project follow-on from previous research recommendations?

B 8. Did the project result in a subsequent awarding of another project? If so, please state the name and value of the follow on project(s).

B 9. What was the initial perception of project success in terms of implementation of its recommendations? *(circle a number)*

0	1	2	3	4	5
Not successful					Successful

B 10. How would you best describe the subject of the research in terms of its risk to the sponsoring agency? *(circle a number)*

Very likely to yield useable results for the sponsor

Somewhat likely that the results would be able to be used by the sponsor

Somewhat unlikely to result in direct impact to the sponsor

Highly speculative that the research yield a result that could be implemented

SECTION B: ECONOMIC ASSESSMENT OF PROJECT

B 11. Did the project result in any of the following?

Type of impacts	Yes/No	Estimated Annualized Value ($)
Increased Productivity		
Overall Cost Savings		
Accident Cost Savings		
Increased Job Productivity		
Increased Safety		
Decreased Highway Usage		
Other (please specify)		

B 12. In your own words, what was the economic impact of this project (i.e. increase in productivity, reduction in costs, etc?

B 13. Other comments you would like to add?

Project	Classify this research project	Total annual cost	Was this project a follow-on?	Did it result in the awarding of another project?	Success	Risk	Projected time frame	Actual time frame	Subsequent implementation phase	Did you proceed to implement these findings?	Annualized costs for this phase
1	D, E	50,000/year	No	No	4	1	18 months	39 months	No		
2	C, E	55,000/year	No	No	0	2	18 months	25 months	No		
3	E	70,000/year	No	No	3	2	18 months	19 months	No		
4	A, B, E	250,000	No	No	4	2	24 months	18 months	No		
5	A	126,000	No	No	4	2	12/12 months	36/48 months	Yes		
6	B	200,000	No	YES	5	1	12 months	24 months	Yes	Yes	
7	A, C, E, F	45,000	No	No	5	1	24 months	24 months	Yes	Yes	
8	B, D	50,000	No	No	3	2	12 months	18 months	Yes		
9	E	98,584	hicles on Flo	NO	5	1	2 years	2 years	Yes	to USDOT for	none to FDOT
10	C	150,000	No	YES	5	1	18 months	24 months	Yes		
11	A	unknown	n mobile sou	NO	3	2	12 months	24 months	Yes		

Project	Classify this research project	Total annual cost	Was this project a follow-on?	Did it result in the awarding of another project?	Success	Risk	Projected time frame	Actual time frame	Subsequent implementation phase	Did you proceed to implement these	Annualized costs for this phase
12	A	200,000	No	YES	3	1	2 years	4 years	Yes		
13	D, E, F	80,000	No	NO	4	1	2 years	30 months	Yes		
14	E	39,337.00	No	NO	5	1	4 months	4 months	Yes		
15	E	58,800	No	NO	5	1	3.5 months	4 months	Yes		
16	A	299,979	No	NO	4	2	3 years	4 years	No	No	N/A
17	B, D	150,000	No	NO	4	1	2 years	4 years	Yes		
18	E	55,000	No	NO	4	1	1 year	16 months	Yes		
19	D	99,420	No	NO	4	2	1 year	18 months	Yes		
20	E	63,363	No	YES	N/A	1	16 months	18 months	Yes/Somewhat	No	
21	E		No	NO	N/A	2	1 year	1 year	Yes/Somewhat	of Internet repor	N/A
22	B	32,000	No	NO	3	2	15 months	15 months	No		
23	B, E, F	105,325	No	NO	5	1	24 months	24 months	Yes	immediately	none

Project	Classify this research project	Total annual cost	Was this project a follow-on?	Did it result in the awarding of another project?	Success	Risk	Projected time frame	Actual time frame	Subsequent implementation phase	Did you proceed to implement these	Annualized costs for this phase
24	C, F	100,000	No	NO	5	1	18 months	24 months	Yes	immediately	none
25	E	449,982	No	NO	4	1	2 years	not yet completed	Yes/Somewhat		
26	E	95,000	s and untreat	NO	5	1	2 years	3 Years	Yes/Somewhat	N/A	N/A
27	C	See Contract	es in asphalt	NO	5	1	See contract documents		Yes	spec developm	Not available
28	A	See contract	No	No	4	2	N.A.		No		
29	C	See contract	No	YES	4	2	N.A.		Yes/Somewhat		
30	C	See contract	No	YES	4	2	N.A.		No		
31	C	See contract	GTM) for so	NO	4	3	N.A.		No		
32	D	See contract	No	NO	4	1	N.A.		No		
33	E	See contract	of use of cru	NO	5	1	N.A.		Yes		
34	C	See contract	sts and specs	YES	5	1	N.A.		Yes		

Project	Classify this research project	Total annual cost	Was this project a follow-on?	Did it result in the awarding of another project?	Success	Risk	Projected time frame	Actual time frame	Subsequent implementation phase	Did you proceed to implement these	Annualized costs for this phase
35	D	See contract	No	NO	4	1	N.A.		Yes		
36	A	See contract	elerated Age	NO	5	1	N.A.		Yes/Somewhat		
37	F	270,000	is is a yearly	NO	5	4	1 year	1 year	Yes		
38	F	142,800	is is a yearly	NO	4	4	1 year	1 year	Yes		
39	A, B, F	30,000	No	NO	5	1	3 months	3 months	Yes	Two weeks	$30K
40	E	249,554	No	NO	5	1	30 months	40 months	No		
41	E	149,900	No	NO	5	1	29 months	5 years	Yes		
42	E	200,000	rrosion Prote	YES	4	1	26 months	5 years	Yes		
43	A	122,418	-Reinforced (	YES	5	1	30 months	34 months	Yes		
44	C	132,970	No	YES	4	1	27months	31 months	No		
45	A, B	178,034	No	NO	4	1	18 months	21 months	No		
46	C	39,970	No	NO	3	2	18 months	42 months	No		

Appendix B

Principal Investigator Project Survey:
Template and Results

Principal Investigator Project Survey Template

INTRODUCTION

The Center for Urban Transportation Research (CUTR), at the University of South Florida, is conducting a study on behalf of the Florida Department of Transportation Research Center. This study is indented to develop and test various methodologies to provide some measures of the benefits and returns on research expenditures.

The information collected from you will remain strictly confidential, and your name or other identifying information will not appear on any survey reports. Only aggregate data will be analyzed and reported. As a project manager or principal investigator responsible for the projects in question, you can help us by answering a few questions about the research projects you have performed or managed. Your input is very important to us, and it will help us to assess and document the benefits of transportation research in Florida. This survey will take just a few minutes to complete and your participation is completely voluntary. Thank your for your assistance.

Should you require any assistance in completing the survey, please contact Mr. Stephen L. Reich (813-974-3120, reich@cutr.usf.edu) or Mr. Sisinnio Concas (813-974 -7760, concas@cutr.usf.edu) at CUTR.

Sincerely,

Stephen L. Reich
Principal Investigator

RESEARCH PROJECT IDENTIFICATION

Research Project Title	Contract	Principal Investigator

SECTION A: GENERAL INFORMATION

A 1. Please state when and if research results of this project were first implemented.

A 2. Clients or sponsors using the research results. Please list the primary contact person for each agency or organization using the research results of this project.

SECTION B: ECONOMIC ASSESSMENT OF PROJECT

Please, try to answer the following questions as thoroughly and precisely as possible.

B 1. What was the deciding factor(s) that led to the research project approval (e.g. project cost competitiveness, project's innovative approach, etc)?

B 2. What was the total cost for this project?

B 3. What was the most significant benefit or benefits of this project? *Please, specify both qualitative and quantitative benefits.*

B 4. What was the initially expected time frame to complete the project (e.g. as per scope of work)? *Please, specify length in months or years*

B 5. What was the actual time frame to complete the project? *Please, specify length in months or years*

B 6. Please define and quantify any expected annualized direct benefits or revenue potential resulting from the project implementation or recommendations.

B 7. Was this project follow-on from previous research recommendations?

B 8. Did the project result in a subsequent awarding of another project? If so, please state the name and value of the follow on project(s).

B 9. What was the initial perception of project success in terms of implementation of its recommendations? *(circle a number)*

0	1	2	3	4	5
Not successful					Successful

B 10. How would you best describe the subject of the research in terms of its risk to the sponsoring agency? *(circle a number)*

Very likely to yield useable results for the sponsor

Somewhat likely that the results would be able to be used by the sponsor

Somewhat unlikely to result in direct impact to the sponsor

Highly speculative that the research yield a result that could be implemented

SECTION B: ECONOMIC ASSESSMENT OF PROJECT

B 11. Did the project result in any of the following?

Type of impacts	**Yes/No**	**Estimated Annualized Value ($)**
Increased Productivity		
Overall Cost Savings		
Accident Cost Savings		
Increased Job Productivity		
Increased Safety		
Decreased Highway Usage		
Other (please specify)		

B 12. In your own words, what was the economic impact of this project (i.e. increase in productivity, reduction in costs, etc?

B 13. Other comments you would like to add?

Project	Deciding factor(s) that led to the research project approval	Total cost for this project	Benefits of this project	Initially expected time frame (months)	Actual time frame (months)	Expected annualized direct benefits or revenue potential	Annualized predicted costs to implement the project
1	quick and inexpensive	272,000	NONE	36	48	none	none
2	importance of subject	110,000		15	21		
3	topic of state concern	75,000		15	18	better hurricane evacutation procedure, possible life saving	
4	great interest to FDOT	100,000	better understanding of the effects	18	24	better assessment of freeway capacity, better indetify improvement needs, helps for future revisions	
5	great interest to FDOT	70,000	better understanding of the effects	12	18	better assessment of intersection capacity, better indetify improvement needs, helps for future revisions	
6		191,500	product and training on the produ	24	24		
7	CUTR's expertise in ITS plannin	118,000	established single document, train	18	18	None	None
8	Working relation with PM.	60,000	revised methods for performing sy	16	16	transit agencies that use the acciden	None
9	training need for new technology	142,800	thouroughness of training material	11	11	increased implementation	

Project	Was this project a follow-on	Subsequent awarding of another project	Initial perception of project success	Risk to the sponsoring agency	Project results	Economic benefits	Other qualitative benefits	Classify this research project
1	NO	NO	0	3		none		B, D
2	YES	YES	5	1	Cost Savings			B, E, F
3	NO	NO	4	1	Accident Cost Saving, Increased Safety	savings of lives		C, E
4	YES	NO	4	2		better decisions about needed improvements		B, E
5	NO	YES	4	2	more accurate assessment	better decisions about needed improvements		B, E
6	NO	NO	3	2				A, C
7	NO	YES	4	1	incresed awareness and knowledge of application - saves millions	saved planning staffs and time	guidebook was nominated by FDOT for ITS America Annual Award of excellence	F
8	NO	NO	4	1	overall cost savings, accident cost savings, increased safety	decreased accidents at transit agencies		B, E, F
9	YES	NO	4	1	Overall cost savings, other		showcase presentation format flexibility very effective	B, E, F

Project	Deciding factor(s) that led to the research project approval	Total cost for this project	Benefits of this project	Initially expected time frame (months)	Actual time frame (months)	Expected annualized direct benefits or revenue potential	Annualized predicted costs to implement the project
10		21,000	Update incorporated recent research, methodologies, and statistical information, along with examples of how to apply the methodologies. The biggest benefit is the user-friendliness.	7.5	12.5		No added costs, but potential savings in time and labor to government, transit agency, and/or consultant.
11		87,000	Transit agencies received direct comparisons of customer satisfaction to other agency performance; at a state DOT level, the ability to simultaneously examine performance of multiple transit agencies may have been helpful	12	12	directional information - may results ultimately in revenue generation or other benefits	
12	improvement/modification of existing BCT terminals	100,000	technical modifications improve safety on highways	24	30	higher level of highway safety	
13	little research money had been invested in motorcycle safety	57,435	quantified level of helmet usage	15	15	0	0
14	FDOT needed product specification and application methodology before they could use compost along roadways	238,224	see B2; trained FDOT maintanance engineers; helped FDOT meet the legislative mandate for state agencies to utilize reczcled materials	36	38	cost savings - eliminated need for top soil, reduced need for fertilizers	purchase of the compost
15	use of innovative technologies, improvement of current business practices	72,260	significant cost savings, improvement in current business practices	12	12	estimated design savings: 4,500,000; estimated savings from current operations: 480,6000; estimated FDOT user savings:	1,261,200 p.a.
16	public safety issue	136,600	safer, more reliable break-away sign connections / new installation procedure for break-away signs	24	24		

Project	Was this project a follow-on	Subsequent awarding of another project	Initial perception of project success	Risk to the sponsoring agency	Project results	Economic benefits	Other qualitative benefits	Classify this research project
10	NO	NO	5	1	Increased Productivity, Overall Cost Savings, Increased Job Productivity			A, B, C, D, E
11	NO	NO	3	1	Increased Productivity, Overall Cost Savings, Increased Job Productivity, Increased Safety	better understanding of customer needs for the agency, better understanding of relative agency performance for FDOT		C
12	NO	NO	5	1	Accident Cost Savings, Increased Safety	increased highway safety		A, C, E
13	YES	YES		1		none today	none	E
14	NO	YES	5	1	all (except job productivity)	less money and time is necessary for vegetation along those roadsides	can help erosion to road shoulders	B, C, D, F
15	unknown	unknown	5	1	increased productivity, overall cost savings, increased job productivity, increased safety	see pp 15-20 in report		C, D
16	NO	NO	1	2				A, B

Project	Deciding factor(s) that led to the research project approval	Total cost for this project	Benefits of this project	Initially expected time frame (months)	Actual time frame (months)	Expected annualized direct benefits or revenue potential	Annualized predicted costs to implement the project
17	increase overall realism	45,150	framework for cr	24	not completed	none	N/A
18	continued utility of USF	30,000	recommended sp	12	12	unknown	unknown
19	innovative approach and	29,531	we identified two	17	17	unknown	unknown
20	innovative approach and	137,707	we learned much	24	24	unknown	unknown
21	use of visualization tech	79,913	provided decisio	13	13	critical information and ability to understand implications of decisions	
22	project's innovative appr	87,500	I provided FDOT	11	11	direct benefits - reduced the li	costs - changing of
23	poor access managemen	63,363	Tough to say	16	18	Impossible to quantify	$14,000 – pilot int
24	My guess would be inno	135,000	1) Development	18	29	The application of the model	Really weren't rec

Project	Was this project a follow-on	Subsequent awarding of another project	Initial perception of project success	Risk to the sponsoring agency	Project results	Economic benefits	Other qualitative benefits	Classify this research project
17	NO	YES	2	2			This project h	B, F
18	NO	unknown	4	1		independent assessment and research		A, C
19	YES	NO	3	2		turfgrass should reduce need	Replacement c	B, E
20	YES	NO	2 (FDOT) / 5 (otl	2		groundwater shoud reduce need for	Replacement c	B, E, F
21	NO	NO	2	2	Increased produ	saved time and money	decreased frus	A, F
22	NO	NO	4	1	Increased produ	upfront planning. Reduced law	Recs provided	B, D
23	NO	NO	4	1	all	Extended useful life of the facility - reduced	Improve produ	E
24	NO	YES	5	2	Increased Produ	fact that the results could not be	See B-3	A, B, E, F

Appendix C

Survey of other DOT research centers

DOT	Contact	Response		Articles/Reports		
		Y/N	Detail	Author	Title	Lit. Review
Alabama	Jeffery Brown 334-206-2288					
Alaska	Simon_howell@dot.state.ak.us	Y	No specific work undertaken to date			
Arizona	Dale Steele – dsteele@dot.state.az.us	Y	Previous Efforts	Arizona DOT	Cost Benefit Analysis of the ARTC research program	
	Steve Owens - stowen@dot.state.az.us	Y	Not aware of prior work			
Arkansas	Alan.meadors@ahtd.state.ar.ua					
California	Kazem_Attaran@dot.ca.gov	Y	Previous Efforts	Fielding, Gordon; Cohn, Linda	New Technology Research: Cost and Benefits	YES
Colorado	Joan.pidamont@dot.state.co.us	Y	Previous Efforts	Colorado DOT		
Connecticut	James.sime@po.state.ct.us					
Delaware	Larry Klepner lklepner@mail.dot.state.de.us	Y	No specific work undertaken to date			
Georgia	Adfo Amekudzi – adjo.amekudzi@ce.gatech.edu	Y	No specific work undertaken to date			
Hawaii	Julia Tsumoto dotstp@exec.state.hi.us	Y	Not aware of prior work			
Idaho	Doug Benzon – dbenzon@itd.state.id.us	Y	No specific work undertaken to date			
Illinois	T2LRSDOT@nt.dot.state.il.us	Y	Referenced Kansas DOT			
Indiana	Barry Partridge bpartridge@indot.state.in.us	Y	Referenced Joint Transportation Research Program (JTRP)	Joint Transportation Research Program (JTRP)	Research Pays Off	
Iowa	Sandra Larson – P.E. Sandra.larson@dot.state.ia.us	Y	Previous Efforts			
Kansas	Lon Ingram – lingram@ksdot.org	Y	Current Efforts	Dr. Robert Stokes	Guidelines for Estimating the Triennial Benefits of Kansas Transportation Research and New Developments	
Kentucky	Paul Toussaint – toussain@engr.uky.edu					
Louisiana	Joe T. Baker, P.E. jbaker@dotd.state.la.us					

DOT	Contact	Response		Articles/Reports		
		Y/N	Detail	Author	Title	Literature Review
Maine	Dale Peabody – dale.Peabody@state.me.us	Y	Referenced NCHRP (Sabol)	National Cooperative Highway Research Program – Scott Sabol	Performance Measures for Research, Development, and Technology Programs	
Maryland	mdta@mdot.state.md.us					
Massachusetts	Thomas Broderick – thomas.broderik@MHD.state.ma.us	Y	Not aware of prior work			
Michigan	John Reincke – reinkej@michigan.gov	Y	Not aware of prior work			
Minnesota	Abigail Mckenzie – abby.mckenzie@dot.state.mn.us	Y	No specific work undertaken to date			
Mississippi	James H. Kopf – jkopf@mdot.state.ms.us					
Missouri	Ray Purvis (573) 751-3002 – purvir@mail.modot.state.mo.us	Y	No specific work undertaken to date			
Montana	Susan Sillik – ssillick@state.mt.us	Y	No specific work undertaken to date			
Nebraska	Leona Kolbet – lkolbet@dot.state.ne.us					
Nevada	Alan Hilton – ahilton@dot.state.nv.us	Y	No specific work undertaken to date			
New Hampshire						
New Jersey	Nick Vitillo – nick.vitillo@dot.state.nj.us					
New Mexico	David Albright – Albright@unm.edu	Y	Previous Efforts; details yet to come			
New York	Sreevinas Alamapalli salampalli@gw.dot.state.ny.us	Y	Previous Efforts; details yet to come			
North Carolina	Douglas Cox dcox@dot.state.nc.us	Y	No specific work undertaken to date			
North Dakota	Grant Levi glevi@state.nd.us	Y	No specific work undertaken to date			
Ohio	Monique.Evans@dot.state.oh.us	Y	Previous Efforts	University of Toledo	Evaluation of ODOT Research and Implementation Effectiveness	
				Transportation Research Board	Research Pays Off- same as Indiana	

DOT	Contact	Response		Articles/Reports		
		Y/N	Detail	Author	Title	Lit. Review
Oklahoma	David Ooten – dooten@	Y	No specific work undertaken to date			
Oregon	Barnie P.Jones@odot.state.ok.us	Y	No specific work undertaken to date			
Pennsylvania	Jodi Sivak –jsivak@dot.state.pa.ua	Y	Directs Penn State University LTAP	Rossi, Freeman, Lipsey	Evaluation: A Systematic Approach	
	John A. Anderson jaa5@psu.edu		No specific work undertaken to date		Transportation Technology Transfer: A Primer on the State of the Practice	
Rhode Island	K. Wayne Lee leew@egr.ure.edu	Y	No specific work undertaken to date			
South Carolina	Mide Sanders sandersmr@dot.state.sc.us					
South Dakota	Dave Huft@state.sd.us					
Tennessee	J Bruce Saltsman, Sr. TDOT.commissioner@state.tn.us	Y	No specific work undertaken to date			
Texas	Tom Yarbrough					
Utah	Stan Burns sburns@dot.state.ut.us					
Vermont	Scott Sabol ssabol@vtc.edu	Y	Current Efforts	Scott Sabol	Performance Measures for Research, Development, and Technology Programs	
Virginia	Carolyn Goodman goodmanCD@vdot.state.va.us	Y	No specific work undertaken to date-on NCHRP Pane	Scott Sabol	Performance Measures for Research, Development, and Technology Programs	
Washington	Martin Piets pietz@wsdot.wa.gov	Y	Current Efforts	Scott Sabol	Performance Measures for Research, Development, and Technology Programs	
West Virginia	John Lancaster jlancaster@dot.state.wv.us	Y	No specific work undertaken to date			
Wisconsin	Nina.mclawhorn@dot.state.wi.us	Y	Current Efforts	Scott Sabol	Performance Measures for Research, Development, and Technology Programs	
Wyoming	Delber McOmie dmcomi@dot.sate.wy.us	Y	Previous Efforts			

Appendix D

Data Collection for Model Validation:

Survey Template

Project Number: **Project Title:**

Please rate each of the benefit/savings types listed using a scale of 1 to 10 as detailed below.
Rating Guide:
NA = factor does not apply to this project;
0 = no benefit at all;
1 = a perceived feeling that the project has some benefit;
5 = some evidence and strong subjective feeling that the project has positive benefit;
10 = clear evidence the project has excellent, positive benefit.

Next, please ***circle or shade*** **the appropriate $ ranges** of estimated benefits/costs.

SECTION I - Economic Benefits Assessment

Most likely time frame over which overall savings will occur ***Circle or shade whichever appropriate***	1-3 years	3-5 years	5-10 years	10-15 years	15-20 years	20 -25 years	30 + years

Construction Savings	**Rating**
Materials	
Labor	
Equipment	
Time	

OVERALL Construction Savings Range - Circle or shade whichever appropriate						
Lowest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Most likely	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Highest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Actual Savings if known:	$			**Time period of savings if known**		

Maintenance Savings	**Rating**
Materials	
Labor	
Equipment	
Time	

OVERALL Maintenance Savings Range - Circle or shade whichever appropriate						
Lowest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Most likely	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Highest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Actual Savings if known:	$			**Time period of savings if known**		

Project Number: 0 **Project Title:**

SECTION I - Economic Benefits Assessment *(Continued)*

Administrative Savings	**Rating**
Planning/Design	
Increased Productivity	

OVERALL Administrative Savings Range - Circle or shade whichever appropriate						
Lowest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Most likely	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Highest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Actual Savings if known:	$			**Time period of savings if known**		

Technology	**Rating**
Tech. Transfer	
New Methods	
New Procedures	

OVERALL Technology Savings Range - Circle or shade whichever appropriate						
Lowest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Most likely	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Highest	$0 - $0.5 M	$0.6 - $1 M	$1 M - $5 M	$6 M -$ 10 M	$11 M-$20 M	$20 M +
Actual Savings if known:	$			**Time period of savings if known**		

Appendix E

Black-Scholes Differential Equation

for Option Valuation

Black-Scholes Option Pricing Model

In the Black-Scholes model, a fair value for an option is the present value of the option payoff at expiration under a risk-neutral random walk for the underlying asset prices. The equation computes the value of a European option; that is, an option that can only be exercised at the expiration date. The expected present value of the payoff is:

$$E\,[e^{-rT}\,(K-S^{T})^{+}]$$

Where:

r = risk neutral interest rate;

T = Time to expiration;

K = strike price;

S = price of the underlying asset

In order to compute this expectation, Black and Scholes (1973) modeled the stochastic process generating the price of a non-dividend-paying stock as a geometric Brownian motion. The Black-Scholes price for a European Call option on a non-dividend-paying stock is:

$$C_t(S_t, T-t) = S_t N(d_1) - Ke^{-r(T-t)} N(d_2),$$

Where:

$$d_1 = \frac{\log(S_t/K) + (r + 1/2\sigma^2)(T-t)}{\sigma\sqrt{T-t}},$$

$$d_2 = \frac{\log(S/K) + (r - 1/2\sigma^2)(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t},$$

Note: N (d_i) is the cumulative distribution value for a standard normal variable with value.