Southeast Transportation Consortium

Final Report 512

STC Synthesis of Best Practices for Determining Value of Research Results

by

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Georgia Institute of Technology

Published by:

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808 | (225) 767-9131 | www.ltrc.lsu.edu

LTRC Project No. 12-3PF

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Contract with

the Southeast Transportation Consortium (STC) and the Louisiana Transportation Research Center (LTRC)

January 2014

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ACKNOWLEDGMENTS

We would like to thank everyone supporting this project by responding to our survey and providing us with valuable information. The following table provides the list of those who supported this project.

Name	Transportation Agency	Name	Transportation Agency
Rod Turochy	Alabama DOT	Cynthia J. ("Cindy") Smith	Mississippi,MS
Clint Adler	Alaska,AK	Susan C. Sillick	Montana,MT
Greg Larson	California,CA	Mrinmay Biswas	North Carolina,NC
Roberto DeDios	Colorado,CO	Vicky Fout	Ohio,OH
Darryll Dockstader Mark Greeley	Florida,FL	Michael R. Bonini	Pennsylvania,PA
David M. Jared	Georgia,GA	Michael R. Sanders	South Carolina,SC
Megan Swanson Juan D. Pava	Illinois,IL	Duncan Stewart	Texas,TX
Mark Dunn Linda Narigon Annette M. Dunn	Iowa,IA	Abdul Wakil David Stevens	Utah,UT
Mark Morvant Michael B. Boudreaux	Louisiana,LA	Jose Gomez	Virginia, VA
Dale Peabody	Maine,ME	Donald Williams	West Virginia,WV
Allison R. Hardt	Maryland,MD	David Kuehn	Federal Highway Administration
Linda Taylor Benjamin Worel Nicole Peterson	Minnesota,MN	Christopher W. Jenks	National Academy of Science
William Stone	Missouri, MO		

We would also like to thank members of Southern Transportation Center and Louisiana Transportation Research Center. Special thanks go to Mr. Mark Morvant and Mr. Kirk Zeringue for their continuous support throughout this project.

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EXECUTIVE SUMMARY

Transportation research projects are aimed at fostering innovation in different areas, such as safety, cost savings, quality, efficiency, project delivery, and policy. Transportation agencies and most notably State Departments of Transportation (State DOTs) sponsor various transportation research projects to improve transportation system features, such as safety and cost effectiveness. Determining the value of transportation research projects is one of the most important tasks towards improving various features of transportation systems, such as safety, quality, and cost effectiveness. However, for many State DOTs, the true impact of transportation research projects on the transportation systems is generally unclear. This is due to the lack of comprehensive and implementable quantitative and qualitative methods for determining the value of transportation research projects. These evaluation methods should go beyond considering the value of research projects in terms of operational costs saving and include value of the research on various impact areas, such as congestion reduction, and accident and fatalities prevention. There is a need for research that identifies the best practices in using proper methods and measures for demonstrating the true value of research projects in terms of various transportation system features, such as safety, quality, and cost effectiveness. The application of these methods and measures requires the identification and collection of relevant data on the benefits resulting from the implementation of research project findings and recommendations. Therefore, there is a need for a synthesis that identifies the best practices for determining value of research results. This synthesis presents the aggregation and summarization of what the State DOTs have done for quantifying the value of research.

Objectives

The overall objective of this project is to synthesize the best practices for determining the value of research results in order to demonstrate the impact that the research has on transportation system features, such as safety, quality, and cost effectiveness. This synthesis presents a critical review of methods used for determining the value of transportation research. Furthermore, it is intended to identify various measures and data sources used for determining the value of research.

Research Methodology

The following tasks were conducted to achieve the objectives of this research:

- Review literature on determining the value of research results
- Conduct three fact-finding surveys
    - Survey 1 was conducted to capture state of knowledge and practice in determining value of research in DOTs

    - Surveys 2 and 3 were conducted to collect best examples for determining value of transportation research
- Perform content analysis on the best examples for determining value of transportation research

Findings

Based on the literature review, it was found that the impact of transportation research projects has been studied in the following areas:

- Safety
- Environmental sustainability
- Improved Productivity and Work Efficiency
- Traffic and Congestion Reduction
- Reduced Construction, Operations, and Maintenance Costs
- Management and Policy
- Customer Satisfaction
- System Reliability
- Expedited Project Delivery
- Engineering Design Improvement
- Increased Service Life
- Reduced User Cost
- Reduced Administrative Costs
- Materials and Pavements
- Intelligent Transportation Systems

The first survey resulted in several findings:

- Several transportation agencies sponsored research projects to develop a systematic approach for assessment of value of transportation research. Several research reports related to the topic of this study (assessing the value of research) were identified from responses to the first survey. These reports were collected and analyzed. The research reports sponsored by various transportation agencies are the following:
    - Florida DOT (Two research reports)
        - Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (2003)
        - Valuing the Benefits of Transportation Research: A Matrix Approach (2002)
    - Ohio DOT (Two research reports)
        - Evaluation of ODOT Research and Development Implementation Effectiveness (1988)
        - Benefit-Cost Analysis of Transportation Research Projects (1992)
    - Kentucky DOT (One research report)

        - Research report: Value of research: SPR projects (2001)
    - Utah DOT (One research report)
        - Measuring the benefits of transportation research in Utah
    - Minnesota DOT (One research report)
        - Economic benefits from road research (2008)
    - National Cooperative Highway Research Program (NCHRP)
        - Performance Measurement Tool Box and Reporting System for Research Programs and Projects, NCHRP Project 20-63
        - RPM
        - Communication matters: a guidebook published by National Cooperative Highway Research Program (NCHRP), Report 610, Available from Transportation Research Board (TRB) (2009)
    - Transportation Research Board
        - Research Pays Off
    - American Association of State Highway and Transportation Officials (AASHTO)
        - Research Impacts: Better - Cheaper – Faster
- We found that most states have future/present plans to quantify the value of research projects.
- There is no formal guideline for assessing the benefits of research reports.
    - Although several methods are proposed for quantifying the benefits of research projects in the research reports collected in the first survey, there is no formal guideline or formal method to evaluate the quantitative and/or qualitative benefits of research projects in State DOTs.
- The evaluation methodology should not be too long or too complex.
    - It should be easy to follow.
- Collection and distribution of good evaluation examples can be extremely helpful.
- Based on the survey results, flexibility is the key for designing any guideline to assess research benefits.
    - Several classifications of areas of research projects and the corresponding benefits
    - Several methods for assessing the value of research benefits
    - Several measures for assessing the value of research benefits
- Developing a training program for researchers and DOT personnel is vital.
- Communication of research benefits is important.
- Data scarcity for evaluation of research benefits is a significant challenge.
- AASHTO high value research projects and TRB "Research pays off" documents summarize valuable examples of State DOT's attempts towards quantifying research benefits.
- There are fewer attempts for quantifying benefits that are hard to put dollar values on.
- Based on the survey results, flexibility is the key for designing any guideline to assess research benefits.
    - Several classifications of areas of research projects and the corresponding benefits
    - Several methods for assessing the value of research benefits

    - Several measures for assessing the value of research benefits

The second and third surveys resulted in several findings. These finding are:

- Identified methods to determine value of research
    - Several methods were identified for determining value of research on different areas of benefit. These methods have been used by various transportation agencies to determine value of different research projects that have impacts on various benefit areas. These methods were categorized for each area of benefit.
- Identified measures to determine value of research
    - Various measures were identified for determining value of research on different areas of benefits. These measures were categorized for each area of benefit. After analyzing the identified categories of measures, it was concluded that the measure categories can be placed in one of the following groups:
        - Measure categories specific to areas of benefits
        - "Cost Savings" measures
        - "Others" measures
- Identified data sources to determine value of research
    - Various data sources were identified for determining value of measures that have been used to research on the areas of benefits. These data sources were categorized corresponding to measures used to determine value of research in each benefit area. After analyzing the identified categories of data sources, it was concluded that the data sources can be generally placed in one of the following groups:
        - Literature (scholarly papers, databases, reports, etc.)
        - Data provided by DOTs, FHWA, TRB, AASHTO (performance records, etc.)
        - Data provided by manufacturers
        - Outcomes of surveys
        - Outcomes of lab experiments
        - Outcomes of field experiments
        - Outcomes of simulation studies
        - Assumptions (based on judgment, experience, literature, etc.)

Research Path Forward

There is a need to conduct research to develop a systematic and transparent approach to determining the value of transportation research. The proposed approach should be both scalable and flexible, and easy to understand and follow.

The proposed methods and measures should not prohibit innovative ways to objectively determine value of research. There is a need to develop a guidebook that

- Classifies types of research projects;

- Recognizes potential areas of impact;
- Recommends appropriate methods based on research types and areas of impact;
- Recommends proper measures to determine value of research;
- Describes required data for determining value of research; and
- Recommends appropriate data collection process throughout research development and implementation.

Flexibility is the key to creating such a guidebook. A proper guidebook should facilitate communicating the value of research. Current practices and research reports collected here can be a good starting point to developing such a guidebook. Last but not least, training is a key to succeed in implementing a proper guide for determining the value of research across all transportation agencies.

CHAPTER ONE
INTRODUCTION

1.1 Overview

Transportation research projects are aimed at fostering innovation in different areas, such as safety, cost savings, quality, efficiency, project delivery, and policy. Transportation agencies and, most notably state Departments of Transportation (State DOTs) sponsor various transportation research projects to improve transportation system features, such as safety and cost effectiveness. Determining the value of transportation research projects is one of the most important tasks towards improving various features of transportation systems. However, for many State DOTs, the true impact of transportation research projects on the transportation systems is generally unclear. This is due to the lack of comprehensive and implementable quantitative and qualitative methods for determining the value of transportation research projects. These evaluation methods should go beyond considering the value of research projects in terms of operational cost saving and include value of the research on various impact areas, such as congestion reduction, and accidents and fatalities prevention. There is a need for research that identifies the best practices in using proper methods and measures for demonstrating the true value of research projects in terms of various transportation system features, such as safety, quality and cost effectiveness. The application of these methods and measures requires the identification and collection of relevant data on the benefits resulting from the implementation of research project findings and recommendations. Therefore, there is a need for a synthesis that identifies the best practices for determining value of research results. This synthesis can be used as a basis for making the business case for transportation research.

1.2 Research Objectives

The overall objective of this project was to synthesize the best practices for determining the value of research results, in order to demonstrate the impact that the research has on transportation system features, such as safety, quality and cost effectiveness. This synthesis presents a critical review of methods used for determining the value of transportation research. Furthermore, it is intended to identify various measures and data sources used for determining value of research. The specific objectives of research are:

- Identify major areas of benefits, determine common methods, measures, and information required to reasonably determine benefits of implementing research results;
- Identify current research evaluation methods and (qualitative/quantitative) benefit metrics used by transportation agencies for determining the value of research results;
- Identify relevant data and information currently used by transportation agencies for calculating the value of research results;

- Identify the most exemplary research projects that clearly demonstrate the value of research results;
- Describe the process of computing research value in these exemplary cases;
- Identify the critical knowledge gaps in the evaluation of research results that require further research.

1.3 Research Methodology

The following tasks were conducted to achieve the objectives of this research:

- Review literature on determining value of research results
- Conduct three fact-finding surveys
  - Survey 1 was conducted to capture state of knowledge and practice in determining value of research in DOTs
  - Surveys 2 and 3 were conducted to collect best examples for determining value of transportation research
- Perform content analysis on the best examples for determining value of transportation research

1.3.1 Literature Review

A comprehensive literature review regarding the determination of the value of transportation research was conducted. Several research reports were identified and reviewed. Chapter 2 presents the literature review. One of the outcomes of this literature review was the identification of areas of benefit that transportation research can provide.

1.3.2 Surveys

Three surveys were conducted to achieve the objectives. The first survey was designed to capture the state of knowledge and practice in determining the value of research in DOTs. The first survey was distributed among representatives from 50 State DOTs, the District of Columbia, the Federal Highway Administration (FHWA), and the Transportation Research Board (TRB) via email. The first survey, along with its findings, is discussed in Chapter 3.

Best examples for determining the value of transportation research were collected using the second and third surveys. Results show that different methods have been utilized by transportation agencies to determine the value of research under various identified impact areas, such as safety, environmental sustainability, improved productivity and work efficiency, traffic and congestion reduction, reduced construction, and operations and maintenance costs. Several measures and data sources have been used by transportation agencies to determine the value of research. The second and third surveys, along with their findings, are provided in Chapter 4.

1.3.3 Content Analysis

The collected examples in the second and the third surveys were rigorously analyzed. The following information was extracted and organized for each example:

- Title of research project
- Research objectives
- Areas of benefit
- Methods for determining value of research
- Measures
- Data sources

The above information is provided in Appendix D. The methods, measures, and data sources used in the examples collected in the second and third surveys were classified under the impact areas. The results of the content analysis and the classification of methods, measures, and data sources used in the collected best examples for determining value of research are provided in Chapter 5.

CHAPTER TWO
RESEARCH BACKGROUND

A comprehensive literature review regarding the determination of the value of transportation research has been conducted. Several research reports have been identified and reviewed. These research reports are:

- Florida DOT (Two research reports)
  - Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (2003)
  - Valuing the Benefits of Transportation Research: A Matrix Approach (2002)
- Ohio DOT (Two research reports)
  - Evaluation of ODOT Research and Development Implementation Effectiveness (1988)
  - Benefit-Cost Analysis of Transportation Research Projects (1992)
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- Transportation Research Board
  - Research Pays Off
- American Association of State Highway and Transportation Officials (AASHTO)
  - Research Impacts: Better - Cheaper – Faster

The rest of this chapter provides detailed review of the identified research reports.

2.1 Florida Department of Transportation

Ellis, Degner, O'Brien and Peasley (2003), Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables, Prepared for Florida Department of Transportation

The objective of this research was to develop a method for the FDOT to evaluate the benefits of its research projects and measure the cumulative benefits of its total research program. The approach to achieve the objective was to:

- Develop Initial Research/Benefit Evaluation form based on the investigation of current practice and literature.
- Distribute forms and receive Feedback on Draft Evaluation form.
- Develop Final Recommended Cost/Benefit Evaluation Document.

This research proposed a research evaluation process presented in Figure 2.1.

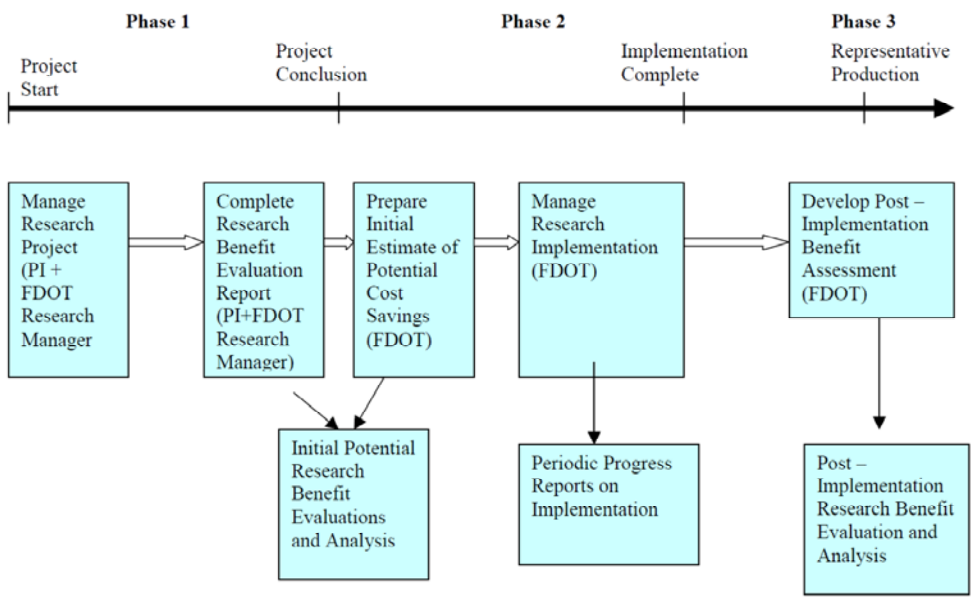

Figure 2.1: Research Evaluation Process (Copyright of Ellis, Degner, O'Brien and Peasley 2003)

The initial research/benefit evaluation form contained the following information items:

- Basic Project Information (e.g. title, PI)
- FDOT functional area that research falls under?
  - Construction
  - Environmental Management
  - Geotechnical Engineering
  - ITS
  - Maintenance Operations
  - Public Transportation

- Roadway Design
- Safety
- Materials
- Surveying and Mapping
- Structures
- Planning
- Traffic Engineering

- Two general assessment questions:
  - The results of this research can be best described as:
  - What has or will change as a result of this research?

- Subjective ranking on scale one to three (Strongly Agree=3; Agree=2; Disagree=1) was initially proposed to qualitatively assess the projects in the following areas:
  - Information Knowledge Base
    - This project expands the FDOT knowledge base.
    - This project expands the state of Florida knowledge base.
    - This project expands the national knowledge base.
    - This project lays the foundation for future research.
  - Infrastructure
    - This project improves the communications network.
    - This project assists in traffic enforcement.
    - This project will aid in planning future infrastructure.
    - This project increases facility safety.
  - Quality of Life
    - This project will produce increase the psychological comfort of users.
    - This project will produce an aesthetic improvement.
    - This project will improve transportation accessibility.
    - This project will improve the environment.
  - Management and Policy
    - This project will improve specifications or guidelines.
    - This project will improve operational processes.
    - This project will improve management practice.
    - This project will improve policy.
  - Major Incident Avoidance and Hazard Mitigation
    - This project will help to prevent rare but major life threatening accidents.
    - This project will reduce the injuries caused by major natural disasters.
    - This project will reduce the economic impact caused by major natural disasters.
    - This project will reduce the injuries caused by man-made incidents.
  - Engineering Design

        - This project will reduce the economic impact caused by man-made incidents.
        - This project will help to make the design process more efficient.
        - This project will improve our understanding of a design related issue.
        - This project will improve the factor of safety of our designs.
- Estimated Economic Benefits of the Results of Research Project include
    - Cost Savings are quantified for following sources
        - Improved Work Efficiency (for FDOT and Consultant Personnel)
        - Reduced Material Cost (for materials purchased directly by the FDOT)
        - Reduced Maintenance Cost (of FDOT facilities)
        - Reduced Construction Cost (Cost of FDOT construction contracts)
        - Reduced User Cost (Cost to road users)
        - Reduced Accident Cost
    - Improved Work Efficiency
        - What is the work activity?
        - What is the unit of production?
        - What is the estimated savings in worker hours and equipment hours per unit of production? Labor (Grade and Hours) and Equipment (Grade and Hours)
    - Reduced Material Costs
        - What is the material or product?
        - What is the Unit of Measure?
        - What is the estimated cost savings per unit?
    - Reduced User Cost
        - What is the feature that is responsible for the reduced user cost?
        - What is the estimated Average Number of Users per Year?
        - What is the estimated Annual Savings in Cost per User?
    - Reduced Maintenance Cost
        - What is the feature that is responsible for reduced maintenance cost?
        - What is the maintenance unit of measure?
        - What is the cost savings per maintenance unit?
    - Reduced Construction Cost
        - Pay Item No.
        - Unit of Measure
        - Prior Estimated Average Unit Cost
        - New Estimated Average Unit Cost
        - Estimated Cost Savings per Unit
    - Reduced Operational Cost
        - What is the Operational Unit?
        - Estimated Annual Savings per Operational Unit
- Steps Necessary for Implementation of the Results of the Research Project include:
        - Implementation Steps

- Target Dates

The initial evaluation form was reviewed by FDOT and it was concluded that the inclusion of both qualitative and economic benefits was acceptable. It was also concluded that the initial evaluation form was too long and too complex, and the respondents needed training and additional resources for calculating economic benefits. Based on the review, the initial evaluation form was revised. All qualitative benefit assessments were completed in one section, regardless of the functional area. The qualitative benefit categories were refined to a set of common benefits that are potentially applicable to any of the FDOT functional areas. An open process (Figure 2.2) was selected rather than offering a unique cost/benefit calculation structure for each functional area.

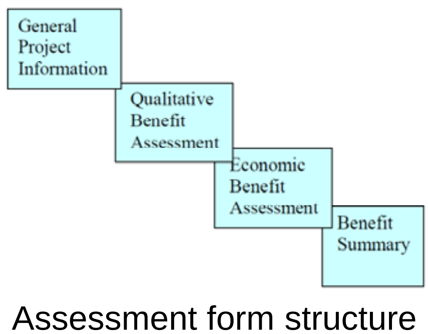

Figure 2.2: An open process for assessment of value of research (Copyright of Ellis, Degner, O'Brien and Peasley 2003)

Final recommended cost/benefit evaluation document included the following sections:

- Basic Project Information (e.g., title, PI)
- FDOT functional area that the research falls under?
    - Construction
    - Environmental Management
    - Geotechnical Engineering
    - ITS
    - Maintenance Operations
    - Public Transportation
    - Roadway Design
    - Safety
    - Materials
    - Surveying and Mapping
    - Structures
    - Planning
    - Traffic Engineering
- The objectives of the research

- The primary product of the research
- Conducting Qualitative Benefits Assessment based on the following ranking:
    - Absolutely no benefit in this category = 0
    - There is some slight benefit in this category =1
    - Project is partially successful in providing a positive benefit in this category =3
    - Project clearly provides a strong positive benefit in this category = 5
- The qualitative benefits assessment fall under the following areas:
    - Level of Knowledge
        - The results of this project, when implemented, will expand the current level of knowledge in this research area.
        - Explanation
    - Safety
        - The results of this project, when implemented, will improve the safety of the users of transportation systems and/or DOT or contractor employees.
        - Explanation
    - Quality of Life
        - The results of this project, when implemented, will improve the quality of life of visitors and residents of the state. (To include issues such as: aesthetic beauty, convenience, comfort, and security)
        - Explanation
    - Environmental
        - The results of this project, when implemented, will improve the quality of the natural environment.
        - Explanation
    - Management and Policy
        - The results of this project, when implemented, will provide for improved management and policy decisions.
        - Explanation
    - Benefits/Costs Calculation is the total savings:
        - Estimated Cost/Benefit Ratio = (Present Value of Total Savings) / (Present Value of Cost of Research)
        - Total Savings = [Estimated Savings per Unit x Estimated Number of Units] – Estimated Cost of Implementation

Based on the results of this research, FDOT was recommended to:

- Adopt, on a trial basis, the recommended research benefit assessment process
- Implement, on a trial basis, the suggested research benefit assessment process
- Implement a program-wide research benefit assessment process
- Develop a practical guide for estimating the cost of future research benefits
- Develop a training program for researchers and FDOT personnel

- Support a national initiative to implement research benefit assessment in transportation
- Develop a research implementation process

Concas, Reich, and Yelds (2002), Valuing the Benefits of Transportation Research: A Matrix Approach, Prepared for Florida Department of Transportation

The objective of this research was to develop an approach to measure the value of research projects and provide some measure of the benefit and return on research expenditures. In order to achieve these objectives, the research team categorized projects and reviewed previous work for determining value of research, surveyed selected transportation projects and finally created an approach to measure the value of research projects. Based on initial classification of the summaries of 200 research projects and testing the categorization using a survey, a research classification was proposed. This categorization is shown in Table 2.1.

Table 2.1: Research classification (Concas, Reich, and Yelds 2002)

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

Concas, Reich, and Yelds (2002) conducted a survey of PIs and PMs of 281 projects and asked the respondents to provide their perceptions of project success, knowledge of implementation, and, where possible, quantitative data on their projects. It was found that completing the surveys was quite challenging for many project managers and principal investigators. "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."

It is helpful to make the distinction between "outcome" and "output" clear. Outputs are the products, while outcomes are the impacts/effects (e.g., a report is an output, as are devices, processes, and other products, whereas the effects of their applications are the outcomes).

It was also found that there is a need to better match evaluation tools to meet the following fundamental elements of transportation R&D:

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

In order to address these fundamental elements of transportation R&D, a Real Options (RO) Approach was proposed as an alternative. Aligned with this proposal, Concas, Reich, and Yelds (2002) also made the following statements:

- It was "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 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."
- "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."
- "Investment in transportation R&D can be regarded as the option, not the obligation to take some action in the future."
- "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."

This research provided an overview of project valuation techniques in the literature. Table 2.2 shows the identified project evaluation techniques and corresponding measures, along with pros and cons of the techniques.

Table 2.2: Overview of project evaluation techniques (Concas, Reich, and Yelds 2002)

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 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 binomial 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 implementa tion 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

Concas, Reich, and Yelds (2002) recommended that “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. 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. 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.” Figure 2.3 represents an overview of the proposed approach.

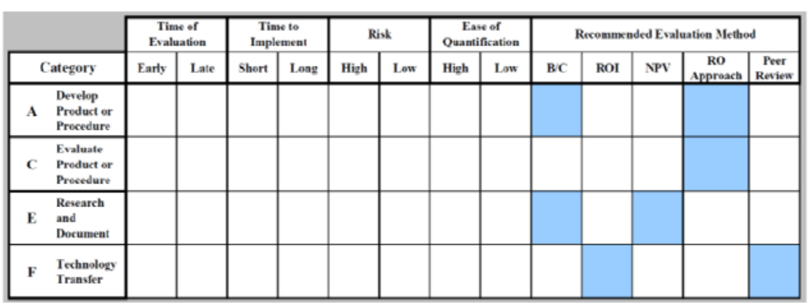

Figure 2.3: Matrix approach to project evaluation (Copyright of Concas, Reich, and Yelds 2002)

Concas, Reich, and Yelds (2002) also recommended that FDOT should utilize an extended Real Option Approach as a more sophisticated tool for measuring the potential benefits of transportation research. They recommended that a change of “mindset” is required for R&D

programs to grow. Adopting RO facilitates this change in mindset by considering research expenditure today as a "call option" on future gains for the FDOT.

They recommended FDOT to track "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." It was also recommended that FDOT should implement a formal data collection approach. For current lack of historical data, they recommended FDOT incorporate statistical simulation processes to compensate. More specifically, they recommended a Monte Carlo simulation approach as an accepted and commonly used approach to provide valid inferences of project value using a small number of data sets.

2.2 Ohio Department of Transportation

Ardis (1988), Evaluation of ODOT Research and Development Implementation Effectiveness, Prepared for Ohio DOT

The objectives of this research were to

- "Determine the effectiveness of the initiation and review process for problem statements and proposals in terms of implementation.
- Compare research results of completed ODOT research and development projects against initial ODOT research objectives.
- Determine the extent of implementation and effectiveness of research results; determine the dollar value of benefits (if possible) and compare with costs.
- Identify implementation success factors associated with ODOT research and development which can be used when implementing future research findings.
- Develop a methodology to ensure better implementation effectiveness of future projects.
- Develop a method to measure the effectiveness of future ODOT research and development."

In order to achieve these objectives, Ardis (1988) selected a sample of 30 projects completed since 1980. Ardis (1988) used a combination of exploratory research and survey as his research approach. In this exploratory research, Ardis (1988) sought information from experienced people to identify evaluation and success criteria and define survey questions. Ardis' survey included telephone interview, personal interview, and questionnaire distributed among researchers at different agencies and ODOT staff senior administrators.

He defined six variables as the following:

- Implementability: "A number between 0 and 100. This number was assigned for each project by the researcher, the liaison representatives, or by the investigator after studying the final report and the implementation forms. The number 0 was assigned to pure basic research where the results could not be directly put into everyday practice, i.e. increase in knowledge or a survey type research. Zero was also assigned to the unsuccessful applied research projects that did not have any implementable findings. Projects with fully implementable results were assigned 100."
- Implementation: "A number between 0 and 100. This parameter was assigned to each project in the same way as implementability. ODOT staff interviews were the main source of information for determining the findings that were implemented."
- Dollar Savings: "The investigator could determine the dollar savings for only four research projects. The other projects in the sample did not have an identifiable direct dollar benefit. The benefits of these projects were of a qualitative nature."
- Benefit/Cost: "Because of the lack of information concerning the dollar benefits of the projects, a formal benefit/cost study applying engineering economy techniques was not possible. However, the benefit/cost variable according to the value judgment of the people involved in the research project was determined. This variable takes a value for any given project, from very low to very high."
- Project Success: "A successful project is one that has met its objectives, has enjoyed wide user acceptance, or provided some technological information for immediate use in the field or for later use in future research projects. A number between 1 and 5 was assigned to each project, with 5 representing a very successful project. The numbers were investigator's own interpretation of ODOT staff comments recorded during the interviews and stated in the documentation."
- Implementation Effectiveness (IE): "Implementation effectiveness was defined as the result of the implementation divided by the implementability in a percentage term. The mean value of the variable IE was 80. A 90% confidence interval was computed and resulted in: $66 < \text{mean (IE)} < 94$."

Ardis (1988) found that at least 33% of the research projects were 100% implemented and 53% were at least 50% implemented. He found that ODOT research projects were successful and benefit cost ratios were from medium to high at a 90% level of confidence. However, Ardis pointed out that the R&D implementation process in ODOT was weak and recommended that the benefits associated with implementation should be determined in order to improve implementation procedures for research and development in ODOT. Adris found communication as the biggest problem.

Ardis (1988) recommended the revision of ODOT research and development communication process as the "bottom line" recommendation. For example, Ardis recommended that:

- “The Engineer of Research and Development should attend and participate in regularly scheduled meetings of the Director where the Assistant Director and three Chief Engineers are present.”
- “The successful team building and communication improvement plans developed in Xerox, Honeywell and Northern Telecom should be seriously considered by ODOT.”
- “The Engineer of Research and Development and/or members of his staff should meet with each District Deputy Director and his Staff at least twice a year.”
- “ODOT should start a monthly newsletter which highlights employee activity, employee success stories, and “Research Pays Off in Ohio” stories.”
- “Each district should start a monthly newsletter.”
- “ODOT's Deer Creek Conference should be continued.”
- “The annual transportation engineering conference should have a session added which deals with research and implementation success stories.”
- “"Quarterly Progress Reports" should continue.”
- “The Research Coordination Committee, RCC, needs to re-evaluate its purpose and the frequency of meetings. The RCC should function more like an executive steering committee concerned with the R&D program; that is, review, not details. Decisions concerning research initiation, problem statement review, priorities, and proposal approval should be made in each Division and each District.”
- “ODOT should require that researchers define in their proposal how they would like to be involved in the implementation process during; the research phase and after the final report is completed. ODOT should include guidelines for this involvement in the Manual for Research and Development.”
- “Training and development must become another strategy essential to successful implementation.”
- “The mechanism for managing implementation achievement should be revised.”
- “The R&D Manual should contain an ODOT organizational chart and a flowchart depicting people involved from research initiation through to implementation.”
- “An Executive Summary should be required of the research contractor, not optional as is the current practice.”
- “The final review session must include discussion of implementation status and plans.”
- “The Bureau of Research and Development should continue to facilitate research initiation and coordinate ODOT research activities.”
- “The Manual of Procedures for Research and Development should be rewritten to incorporate these recommendations.”

Tavakoli and Collyard (1992) Benefit-Cost Analysis of Transportation Research Projects (1992), Provided for Ohio DOT

The objective of this research was to create an evaluation tool that could be applied to completed transportation research projects. This evaluation tool resulted in realization of the true value achieved from the completed transportation research in the Ohio DOT. Tavakoli and Collyard (1992) conducted this research in four phases:

- A review of recent Ohio DOT research projects
- A review of current Ohio DOT evaluation techniques
- A literature survey and a questionnaire survey of best current practices and techniques
- Development of a research project evaluation methodology and system

As a result, the authors developed an evaluation methodology, system, and computer application program based on benefit-cost analysis and multi-objective analysis techniques. The final evaluation tool had four sections:

- The basic project information was recorded and keyed on the project number
- The project evaluation was conducted in two categories:
    - Technical
    - performance
- Within the technical evaluation two approaches were utilized:
    - quantitative benefit-cost analysis
    - qualitative multi-objective ratings
- The performance evaluation of research project was a qualitative multi-objective rating system

In order to achieve the objective, factors noted in recently completed transportation research projects were recorded. These factors were verified and augmented by reviewing evaluation techniques utilized by other DOTs. These factors were sent to all DOTs and several transportation agencies via a questionnaire for evaluation and identification of corresponding relative importance. The list of factors was revised based on the feedback from the questionnaire. The factors were weighted according to the responses. The authors believe that the "weighting allows the policies, attitudes and goals of the DOT to be incorporated into the evaluation processes."

Averages and standard deviations of the collected importance of factors are presented in Table 2.3. It is worth noting that the respondents could assign a number from "1" to "10" to factors. "10" represented the most important and "1" represented the least important.

Table 2.3: Averages and standard deviations of the collected importance of factors (Tavakoli and Collyard 1992)

Factors	Avg.	SD
Construction savings	**8.11**	**2.08**
Savings of material costs	7.59	2.08
Savings of labor costs	7.48	2.08
Savings of equipment costs	7.07	2.16
Savings of construction time	7.56	2.27
Increase in quality control	7.93	2.34
Increase lifetime of subject	**8.26**	**1.53**
Decrease lifecycle costs	**8.52**	**1.55**
Operation and Maintenance(O& M) savings	8.19	1.83
Decrease in O & M material costs	7.52	1.99
Decrease in O & M labor costs	7.85	1.82
Decrease in O & M equipment costs	7.30	2.05
Decrease in O & M time	7.81	2.00
Decrease in engineering costs(design)	**5.96**	**2.22**
Decrease in administrative costs	**4.59**	**2.73**
Increase in info. capacity/capability	**5.89**	**2.47**

Factors	Avg.	SD
Meeting mandated projects	**5.63**	**2.63**
Safety	**8.74**	**1.48**
Reduction in accident frequency	8.56	1.40
Reduction in # of damage accidents	7.89	1.69
Reduction in # of injury accidents	8.52	1.71
Reduction in # of fatal accidents	8.93	1.80
Added environmental protection	**6.56**	**2.28**
Reduction in environmental pollution	**6.81**	**2.28**
Recycling of material	**7.26**	**1.94**
Project user benefit	**7.44**	**2.63**
User time savings	6.89	2.94
User dollar savings	7.11	2.87
Development of new material	**6.85**	**2.59**
Development of new technology	**7.41**	**1.64**
Development of new design methods	**7.41**	**1.75**

Tavakoli and Collyard (1992) defined their benefit-cost format as “a traditional quantitative format with calculated dollar values for savings and added costs (dis-benefits) being determined for four key technical areas - construction, operation and maintenance, lifecycle, safety.” For the purposed benefit-cost analysis, first, they factored the dollar value for each area by the corresponding weight. Then, they divided all area weights by the area weight “which was the lowest, based on the assumption that the value of the lowest actually funded area reflects the value of the funding dollars themselves.” Then, they converted the dollar amounts to present worth for each of the five first years of implementation and an additional amount. The utilized interest rate was set by ODOT and/or the State.

Tavakoli and Collyard (1992) also created a multi-objective benefit matrix. Using this approach for evaluating a project, the project should be rated on its technical success in nine areas: construction, operation and maintenance, life cycle length, lifecycle costs, safety, engineering/administrative costs, environmental, technology, and user benefits. Each of the nine areas should be rated from 1 to 10, with 10 being the most successful. Then, the ratings should be multiplied by the corresponding weights of the areas. The factored rates should be totaled into a composite benefit index. Tavakoli and Collyard claimed that this “index can be tracked historically to provide a full understanding of the success of the project and the return on the invested funding dollars.”

Tavakoli and Collyard (1992) also created a second analytical index (benefit-cost effectiveness) that was the ratio of the composite benefit index per a cost number for the funded amount. The cost number was the total research cost. Tavakoli and Collyard (1992) claimed that this “index can also be tracked historically to provide a fuller understanding of the return on investment of funding dollars, as well as bridge the gap between the traditional (quantitative) benefit-cost ratio and the qualitative composite benefit index.”

Tavakoli and Collyard (1992) also determined the performance of the research project using a multi-objective format of rating factors on a basis of 1 to 5 with two factors given ratings of 1 to 6. The ratings determined by ODOT personnel were weighted. The factors involved the quality, timeliness, and workmanship of the research project and the principal investigator of the research project. The performance evaluation factors and corresponding weights were:

- Proposal (Initial Submission):
    - Well written & easy to understand (0.60)
    - Objectives clearly identified (0.70)
    - Responsive to ODOT needs (0.20)
    - PI consultation with ODOT (0.10)
    - Prepared in a timely manner (0.10)
    - Budget accuracy (0.10)
    - Support information for auditor review (0.20)
- Project:
    - Objectives met (6 = more than expected) (3.60)
    - Implementation findings (6 = early delivery) (1.40)
    - Liaison(s) informed of milestones (1.40)
    - Quality of review presentations (0.70)
    - Quarterly reports timely & informative (1.00)
    - PI management of project (2.10)
    - Work completed on time (1.40)
    - Work completed within budget (1.40)
    - Invoice accuracy & backup information (0.70)
    - Accuracy of equipment inventory (0.30)
- Final Report (First Draft):
    - Easy to read & well presented (0.80)
    - Documentation complete (0.80)
    - Objectives addressed (0.80)
    - Conclusions valid (0.80)
    - Implementation practical (0.40)
    - Timely revision & publication (0.20)
    - Submitted on time (0.20)

2.3 Kentucky Transportation Cabinet

Hartman (2001), Value of Research: SPR projects from 1995 to 1999, Provided for Kentuky Transportation Cabinet

The objectives of this research were:

- Provide the summary documentation of 45 State Planning and Research (SPR) research projects
- Highlight the results and benefits of eleven of these projects
- Demonstrate considerable breadth of implementation results
- Discuss briefly the research process and program areas of research at the Kentucky Transportation Center

Hartman (2001) presented a Step-by-Step Research Process shown in Figure 2.4. Hartman noted that the step-by-step research process is associated with applied research (not basic research) and not all the applied research projects go through the complete sequence specified in the step-by-step research process.

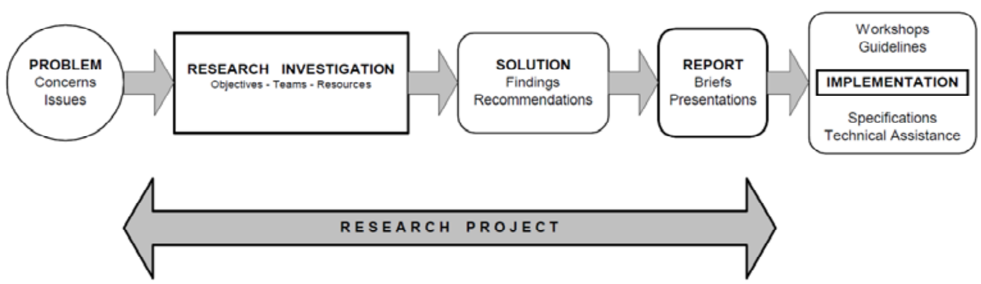

Figure 2.4: Step-by-Step Research Process (Copyright of Hartman 2001)

Hartman (2001) categorized the research project with the specified period into the following areas of research:

- Construction management
- Environmental analysis
- Geotechnology
- Intelligent transportation systems
- Pavements and materials
- Policy and systems analysis
- Structures
- Traffic and safety

Hartman (2001) found it useful to consider a three-part approach for evaluating research performance:

1) "Were the research objectives achieved?"

2) “Can we attribute benefits to the solution?
3) “Will it work in the real world?”

Table 2.4 represents the summary table of eleven selected research projects, and corresponding results and benefits.

Table 2.4: Summary table of eleven selected projects, and corresponding results and benefits (Copyright of Hartman (2001))

	Research Topic	Results	Benefits	Rpt. #
1	Critical Path Construction Scheduling	Delivered workshop and ‘specification’ for construction project scheduling tool.	Central/district staff understand use of tool to track projects and reduce delays.	KTC-97-22
2	Protective Coatings for Steel Bridges	Developed a new coating system that offers superior performance on steel bridges.	$26 million saved on painting of 100 Kentucky bridges. (based on national av.)	KTC-96-7
3	Embankment Construction Using Shale	Prepared compaction specification to avoid embankment settlement and failure.	Special specification for shale compaction is saving millions of dollars annually.	KTC-98-2
4	Rock Scour Around Bridge Piers	Determined from collected data that rock scour is not a significant problem.	Eliminated the need for $30 million analysis as suggested by FHWA.	KTC-99-57
5	Intelligent Transportation Systems Strategic Plan	Developed a set of goals/recommendations with the input of 100 stakeholders.	Planned deployment assures development that meets needs more efficiently.	KTC-98-9 KTC-00-5
6	Evaluation of Asphalt SUPERPAVE Projects	Confirmed SUPERPAVE mixtures perform better without a substantial cost.	Adopting SUPERPAVE will extend pavement life 3-4 years.	KTC-99-53
7	Pavement Performance with Edge Drains	Determined significant impact of drains on long-term performance of roadways.	Using recommended drain design, a cost savings of $240,000/mile is expected.	KTC-97-5
8	Motor Fuel Tax Evasion Reduction	Recommended steps to reduce evasion and increase Kentucky Road Fund revenues.	Changes in procedures and the special revenue analysis unit will produce results.	KTC-97-14 KTC-97-16
9	Freight Movement and Intermodal Access	Identified route/points for improvement and demonstrated use of forecasting data.	Identifies priority projects to reduce truck traffic congestion and improve safety.	KTC-99-48 KTC-99-65
10	Seismic Rating and Evaluation of Highway Structures (W. Ky.)	Conducted stability assessment of bridge approaches and retaining structures.	Retrofitting major bridges for earthquake will potentially save $10 million/bridge.	KTC-97-1 KTC-98-1/20 KTC-99-16/17
11	Heavy Truck Accidents and Countermeasures	Identified critical truck crash rate sections and suggested countermeasures.	Selected countermeasures—injury crashes avoided save $15-39,000 each.	KTC-98-5 KTC-99-20

2.4 Utah Department of Transportation

Anderson (2010), Measuring the benefits of transportation research in Utah, Provided for Utah DOT

The objectives of this research were:

- Estimate the benefits of major research projects and compare them with the costs to conduct the studies.
- Determine which types of projects produce the highest benefit-cost ratios and which projects are more often unsuccessful or marginal.
- Provide information on the management and support of research projects.
- Make recommendations concerning the research program and the types of projects undertaken in the future.

Anderson (2010) introduced two categories of benefits for research projects: Benefits as Cost Savings and Benefits as Improved Operations. Anderson captured the financial benefits as one of the following:

- “Savings to UDOT operations (reduced manpower, improved assets, lower bids, lower impacts to businesses, etc.);
- Benefits to the public (reduced congestion, improved safety, enhanced environment, etc.);
- Zero financial benefits (no savings from the deliverables); and
- Benefits are not known at this time; implementation continues; future benefits may be achieved, and are ‘to be determined’ (TBD).”

In order to collect the above data, Anderson asked project champions to provide minimum benefit values that could be supported with data and other analysis. Anderson defined project champions as a person who was involved throughout the study, and had the best knowledge of the project’s successes and failures. Anderson used a percentage of benefits for some projects where only a portion of the total benefits were attributed to the research projects. If the project champion provided a range of cost-saving benefits, he chose the lowest value of the range.

In order to evaluate benefits as improved operations, Anderson assigned a grade to each project based on the following definitions:

- A: Major impact- Enhanced operations (specification, standard, policy, method, etc.)
- B: Significant impact- Improved operations
- C: Contributed to state-of-the-practice
- D: Unclear or contradicting findings- More study needed
- E: Major tasks not completed- Objectives not met

Anderson (2010) demonstrated his work by determining the benefits and cost of 41 research projects completed in 2006, 2007, and 2008 by the UDOT research program. These 41 research projects had 46 deliverables. The total benefits of these 46 deliverables were estimated at $80.8 million. These benefits were related to internal savings of project costs, longer lasting materials, lower cost to produce the same quality, reduced manpower needs, reduction in accidents, lower impact to the environment, reduced delays to the traveling public. The total cost of the selected projects was estimated at $4.81 million. This total cost was the sum of contract related costs, cost of managing these projects, and cost of technical advisory committees. He estimated the benefit-cost ratio at 17.

Anderson (2010) categorized cost-saving benefits by project type (Table 2.5). He showed that highest benefits were related to research studies on big ticket items, such as highways, bridges, traffic control devices, and right-of-way. Safety research studies also had significant benefits.

Table 2.5: Benefits by project type (Copyright of Anderson 2010)

Type	Number of Projects	Benefit $ x 10^6	Percentage	Benefits x 10^6 Per Project
Infrastructure	18	$28.8	36%	$1.6
Operations	16	$38.5	47%	$2.4
Policy	7	$13.5	17%	$1.9
Totals or Average	41	$80.8	100%	$2.0

Anderson (2010) also evaluated the research program based on the benefits as improved operations. Table 2.6 represents the grade score summary. This information indicates that the program had a grade point average of 3.2 on a 4.0 scale.

Table 2.6: Project grade score summary (Copyright of Anderson 2010)

Grade	Description	Total
A	Major impact- Enhanced operations (spec, policy, method, etc.)	12
B	Significant impact- Improved operations	12
C	Contributed to state-of-the-art	7
D	Unclear or contradicting findings- More study needed	-0-
E	Major tasks not completed- Objectives not met	-0-

Anderson (2010) provided the following recommendations and conclusions to improve the research program:

- "Research programs should be evaluated on a regular basis to understand which types of research endeavors are the most effective."
- "The research projects with the highest potential to produce significant benefits are those conducted on the department's big ticket items. A portion of the research budget should be dedicated to studies on these transportation aspects."
- "A dedicated budget should also be allocated for safety related studies."
- "Continue to use and improve the UTRAC process."
- "The UDOT Research Division should utilize the "Exit Survey" form whenever possible to gather benefit information related to research projects. Create performance measures using the information acquired through the form."
- "Some champions interviewed indicted that the project deliverables needed additional implementation effort."
- "A formal process should be created to monitor the implementation of research findings. This process should include plans, milestones, funding and performance measures. An implementation meeting should be held quarterly to discuss the progress on the adoption of research deliverables."

- “The Media Marketing Program can be a very important tool in illustrating the benefits of research initiatives. This program has been shown to be of benefit to UDOT, as well as the public, in the form of enhanced tools, news clips, slow-motion video, and high level professional mediums.”
- “The research staff should increase the use of implementation tools such as the NCHRP Report 610, “Communicating the Value of Transportation Research Guidebook”.”

2.5 Minnesota Department of Transportation

Worel, Jensen, and Clyne (2008), Economic benefits resulting from road research performed at MnROAD, Third International Conference on Accelerated Pavement Testing, October 1-3, 2008, Madrid, Spain.

The objective of this research was to present a summary of the costs and benefits of the research and construction activities undertaken at MnROAD for its original Phase-I (1994-2006) and predict future benefits for Phase-II (2007-2017). The Minnesota Road Research Project (MnROAD) was created in the early 1990s by Minnesota Department of Transportation and resulted in positive economic benefits during its initial research phase. MnROAD is a full-scale accelerated pavement testing facility, with traffic opening in 1994.

Total MnROAD cost for Phase-I (1994-2006) was estimated at $44,304,562. This took into account money invested during the project (1994-2006) (including initial design, construction, environmental impact study, initial pilot projects, pavement sensors and data collection equipment, land along I-94, buildings, and equipment), operating costs, and annual research contracted projects.

The return on investment starts in the middle of MnROAD’s phase-I and continue for a finite period (up to 2012) for this analysis. This time frame is assumed (12 years) and disregards additional future benefits beyond 12 years. These benefits are usually cost savings, or perhaps potential cost savings, attributed to the research implemented. These benefits do not contain the benefits that are hard to assign a dollar value. Benefit calculation is specific to each pavement research project, such as “Spring Load Restrictions” project. “Neither national (rest of the states) nor local privately owned pavements were included in the cost savings even though they also gain a benefit through the research findings and updated construction specifications.” The phase-I benefits were estimated at $33 million per year for six research findings. This is equivalent to $396,000,000 over a 12-year period (2000-2012). The phase-I benefits/cost ratio was 8.9/1 if all costs (construction, staffing, research projects) are considered over the first 12 years of MnROAD.

With respect to Phase-II costs and benefits, the authors provided a couple of examples of calculated projected costs and projected benefits. The authors believe that it is too early to predict the real benefits of future research.

2.6 National Cooperative Highway Research Program NCHRP

Krugler, Walden, Hoover, Lin, and Tucker (2006), Performance Measurement Tool Box and Reporting System for Research Programs and Projects, NCHRP Project 20-63

The objectives of this research were to "gather and analyze available research performance measurement information, select a balanced and broadly applicable set of these performance measures, develop tools to assist practitioners in applying these measures to their research projects and programs, and deliver these products to the community of state research program managers."

"The initial task of this project was to determine current state-of-the-practice of research performance measurement. Three nationwide electronic surveys were distributed to gather this information. The targeted audiences included AASHTO RAC members, AASHTO agency administrators, and a group of federal and private industry research managers and executives."

"A comprehensive list of research-related performance measures (PMs) was then developed from the survey responses and from information found in literature. After analysis by the research team and discussions at a meeting with the NCHRP panel, 30 performance measures were selected as the standard performance measures for the system to be developed."

Krugler, Walden, Hoover, Lin, and Tucker (2006) defined performance management "as the act of comparing results to specific standards" and "the use of techniques and processes to set goals, identify performance measures, assess the impact of initiatives, and communicate the information internally and externally." They also define performance measures as indicators for gauging the impact of activities. These performance measures can be qualitative or quantitative metrics.

Information gathering and analysis was conducted using literature and three national surveys. The survey included 20 different performance measures. These measures were identified through literature review. The surveys asked information about perceived values of the research performance measures. The respondents were asked to assign a rating in scale of one to five to measures. Rating a five indicated that the measure was extremely valuable and rating a one indicted that the measure was of little value. The respondents were also asked to identify other performance measures where needed. As a result of this research, it was found that four top performance measures were the same for transportation agency administrators and the RAC members. The top three performance measures were lives saved, reduction in crashes, and construction, maintenance, and operations cost savings. Results of the surveys are represented in Table 2.7.

Table 2.7: Results of surveys about perceived value of performance measures (Copyright of Krugler, Walden, Hoover, Lin, and Tucker 2006)

Performance Measure	Survey Group and Ranking			Mean Ranking
	RAC Members	Agency Administrators	Federal & Private	
Lives saved	3	1	1	1.7
Reduction in crashes	2	3	3	2.7
Return on investment or cost-benefit ratio	5	2	2	3.0
Construction, maintenance, & operations cost savings	1	4	4	3.0
Safety enhancement	8	5	5	6.0
Percent of satisfied customers	4	8	8	6.7
Reduction in systems delays	9	6	6	7.0
Technical practices/standards upgraded	10	7	7	8.0
Contribution to the overall mission of the department	6	10	10	8.7
Positive environmental impact	12	9	9	10.0
Percent of projects/products implemented	7	12	12	10.3
Management tool or policy improvement	11	11	11	11.0
Level of knowledge increased	14	13	13	13.3
Leadership	13	14	14	13.7
Public image enhancement	15	15	15	15.0
Quality of life enhancement	19	16	16	17.0
Percent of projects completed on time	16	18	18	17.3
Percent of projects completed within budget	18	17	17	17.3
Number of contractor partnerships	17	19	19	18.3
Number of contractors	20	20	20	20.0

Krugler, Walden, Hoover, Lin, and Tucker (2006) also provided several tools for Research Performance Measurement. These tools were:

- PM 101
- PM Selection Wizard
- Resource Collection
- Performance Measurement Reports
- Benefit Estimation Work Sheets
- Catalog of Benefit Estimation Examples
- Automated Present Value Calculation

Krugler, Walden, Hoover, Lin, and Tucker (2006) concluded that:

- "The research performance measures perceived to be of most value among state transportation agency administrators and research program managers are the number of

lives saved, the number of crashes avoided, and the amount of dollar cost savings realized from the implementation of research products."
- "Wide variability currently exists among state transportation agencies regarding the monitoring of research program and project performance."
- "Consensus use of the three outcome measures defined in the RPM System – number of lives saved, number of crashes avoided, and dollar cost savings to the agency – will likely require both coordination and encouragement from AASHTO RAC leadership and the strong support of AASHTO SCOR."

They finally recommended the following:

- "The three outcome measures (number of lives saved, number of crashes avoided, and dollar cost savings) are recommended for use by every state transportation agency."
- "It is recommended that every state transportation agency seriously consider tracking research project and program performance, even if only on several highly successful research projects each year. While determining research benefits in this manner will provide, at a minimum, strong anecdotal evidence of justification for the program's budget, a compendium of similar entries from a broad number of state transportation agencies will result in meaningful information being derived from the national summary report. Nationwide summary information should prove valuable at the time of the next federal transportation budget re-authorization."
- "Wise and limited selection of performance measures followed by thorough tracking are believed to compose the formula for success in research performance measurement."
- "Credible determination of estimated research benefits requires three rules to be strictly followed."
- "Consider requiring that contract researchers provide an estimate of expected benefits for the sponsoring agency if products from the research project are fully implemented by the research sponsor. This would be the final deliverable of the researcher's project."

PM 101 is a narrated tutorial that is an introduction to performance measurement and the application of measurement to research program activities. RPM (Research Performance Measures) is a performance tracking system developed for state transportation agencies to assess the performance of their projects. Currently, RPM is provided via a single web service.

Performance Measurement 101 introduces five types of measures:

- Outcome Measures
- Output Measures
- Resource Allocation Measures
- Efficiency Measures
- Stakeholder Measures

The 30 most common performance measures are included in RPM. RPM can be customized by adding performance measures. The PM 101 document provides detailed information about each of 30 common research performance measures including:

- Definition
- Type of Measure
- Inputs
- Calculation
- Strengths
- Challenges
- Target Audience

The common Research Performance Measures are:

- Outcome Measures
    - Agency Costs Saved
    - Lives Saved
    - Reduction in Crashes
- Output Measures
    - Technical Products
    - Management Products
    - Knowledge Products
    - Environmental Products
    - Congestion Mitigating Products
    - Traveler Comfort Products
    - Quality of Life Products
    - Safety Products
    - Agency Cost-Saving Products
    - Research Reports Published
    - Graduate Students Involved
- Resource Allocation Measures
    - Agency Cost-Saving Projects
    - Safety Projects
    - Quality of Life Projects
    - Total Active Contractors
    - % Minority Contract Funding
    - % In-House Research Funded
- Efficiency Measures
    - Benefit-Cost Ratio
    - % Administrative Costs
    - % Requests Funded

    - % Projects Implemented
    - % Projects On Time
    - % Projects within Budget
    - % Project with Reports
- Stakeholder Measures
    - Customer Satisfaction level
    - Agency Participation Level
    - Project Needs Statements

Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer (2009), Communication matters: a guidebook published by National Cooperative Highway Research Program (NCHRP), Report 610, Available from Transportation Research Board (TRB)

The Objectives of this research were to provide transportation researchers, planners, and managers with detailed information on how to communicate value of transportation research projects effectively. Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer (2009) provided elements of good communication practices, the communication process, the evaluation and feedback, and targeting specific audiences. They provided quick tips, detailed how-to descriptions, and useful resources and templates.

This guidebook listed seven signs of good communication practices:

- Involve communication professionals
- Understand the audience
- Demonstrate a tangible benefit
- Recognize that timing is relevant
- Build coalitions
- Build two-way relationships
- Tailor packaging

Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer (2009) depicted a process for communicating the value of research that is shown in Figure 2.5. The elements of the process for communicating the value of research are:

- Context: Understand the context of the problem or research issue
- Strategy: Develop a logical, appropriate, and feasible communication strategy
- Content: Prepare content that respects the context
- Channels: Select the best channels for communication
- Style: Use accessible styles that match both your needs and abilities and those of your audience.

Figure 2.5: Communication process (Copyright of Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer 2009)

Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer (2009) provided information, detailed guidance and tips on the five steps of the communication process with real-world case studies. They also provided information on how the five steps can be used effectively. They stressed the fact that communication is more than providing quantifiable statistics and dollars. They expressed that the communication should also involve the translation of the benefits into understandable terms. The importance of adopting principle of continual communications throughout the research process was also highlighted. Table 2.8 summarizes the Communication Objectives of the NCHRP 20-78 Case Studies.

Table 2.8: Communication Objectives of the NCHRP 20-78 Case Studies (Copyright of Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer 2009)

Case Study	Research Value to Sell	Communication Objective
Adaptive Control Software Lite	Public–private partnerships that advance signal software development.	Build public–private partnerships to develop new signal software.
Northwestern University New Bridge Steel	Beneficial properties of a new steel.	Convince decision makers to use new steel for bridge design.
California Seismic Bridge Retrofit Program	The life safety benefits from incremental research on seismic retrofit methods.	Divert funds from existing capital projects to retrofit bridges.
Virginia Fiber-Reinforced Polymer Bridge Deck	The cost and performance advantages of the application of fiber-reinforced polymer bridge materials.	Deploy fiber-reinforced polymer and other materials where appropriate in bridge repairs across the state.
Missouri Statewide Installation of Median Cable Barriers	A statewide solution to prevent a specific crash type.	Install median cable barriers statewide.
Oregon Mileage Fee Concept and Road User Fee Pilot Program	A more equitable and efficient way to collect road user fees to maintain, preserve, and improve Oregon's highways that is acceptable to the public.	Implement a substantial field test of the mileage fee system in Oregon.
National Cooperative Freight Research Program	The productivity and safety benefits derived from a national freight research program.	Establish a national freight research program funded under SAFETEA-LU.

Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer (2009) provided details on how to create effective communication with specific audiences. These details are summarized in Table 2.9.

Table 2.9: Effective communication with specific audiences (Zmud, Paasche, Zmud, Lomax, Schofer, and Meyer 2009)

Audience	Potential Communication Objectives	Benefits of Communication
Research Program Managers	- Ensure continued funding and support - Communicate technical aspects of research - Form partnerships for collaboration or coalitions	- Increases acceptance of the research program across the field - Increases the ability to leverage existing resources
Congress, Legislators, and Staff	- Explain the significance of research - Demonstrate benefits to constituency - Link spending to research outcomes	- Introduces legislation that benefits the field - Increases the potential to gain governmental funding for research
Policy Makers	- Document a real need for research - Explain the benefits of the research or program - Demonstrate the success of the program	- Implements action recommended by the research - Adopts new products and processes
Media	- Publicize the need for research - Publicize the benefits through success stories - Reach a broad audience	- Increases exposure for the program. - Puts research on public's "radar." - Highlights a need for change or benefits of a practice or product.
Public	- Explain research findings in non-technical terms - Show the importance of research to daily life	- Creates a better informed public. - Creates community-level support for initiatives.

2.7 Transportation Research Board

Research Pays Off

These TRB documents are prepared to address the need to continually demonstrate the benefits of research in order to enable decision makers to understand the potential for long-term rewards and properly assess the value of research. These documents usually include the following information items:

- Problem
- Solution
- Applications
- Benefits

2.8 American Association of State Highway and Transportation Officials (AASHTO)

Research Impacts: Better - Cheaper – Faster

The Value of Research Task Force of the AASHTO Research Advisory Committee (RAC) compiles high value research projects from across the nation. The annual compilations of high value research projects, titled "Research Impacts: Better - Cheaper – Faster," are available from 2009 to present (http://research.transportation.org/Pages/HighValueResearchProjects.aspx).

These highlights briefly showcase projects that are providing “Transportation Excellence through Research.” The information about each highlighted project is categorized into the following groups:

- Project title, ID, cost, and duration
- Submitter information (Agency, contact, and email)
- Research program (Sponsoring agency or organization, sponsoring agency contact, and sponsoring agency contact’s E-mail)
- Research and results (Brief summary of the research project, impact, or potential impact of implementing research results, and web links)

CHAPTER THREE
SURVEY 1: CAPTURING STATE OF KNOWLEDGE AND PRACTICE IN DETERMINING THE VALUE OF RESEARCH IN DEPARTMENTS OF TRANSPORTATION

Survey 1 was designed to capture the state of knowledge and practice in determining the value of transportation research. The survey was distributed among representatives from 50 state Departments of Transportation (State DOTs), the District of Columbia, the Federal Highway Administration (FHWA), and the Transportation Research Board (TRB). The survey was distributed among the transportation agencies via email. Appendix A presents the email draft sent to the transportation agencies. The following questions were asked in the survey:

1. Have you ever tried to determine the quantitative and/or qualitative benefits and values of your research projects?
Yes No
If the results of your findings were documented, would you please provide the link or attach the document?

2. Do you have any guideline or method to evaluate the quantitative and/or qualitative benefits of your research projects?
Yes No
If yes, would you please provide the link or attached the related documents?

3. Have you ever used RPM (Research Performance Measures) website for evaluating and documenting the benefits of your research projects?
Yes No
If yes, do you consider it as a valuable tool?
Yes No

4. What quantitative and/or qualitative benefit metrics are used by your transportation agency for determining the value of research projects?
(e.g., overall cost savings, reduced congestion, increased safety)

5. Do you have any present/future plans to quantify research benefits?
Yes No
If yes, would you please inform us about your overall plan in 1-2 sentences?

6. Have you ever conducted any study to determine the value of research projects?
Yes No
If yes, would you please provide the link or attached the related documents?

7. Are you interested to participate in a follow-up survey?
Yes No

Twenty-five individuals replied to the first survey. These individuals represent 20 State DOTs, as well as FHWA and TRB. Table 3.1 presents the list of transportation agencies that replied to Survey 1. Two individuals from the Iowa DOT and three individuals from the Minnesota DOT replied to this survey. Sections 3.1 to 3.7 provide summaries of the responses to the questions on the first survey. Section 3.8 summarizes the findings of the first survey.

Table 3.1: List of transportation agencies replied to the first survey

Alaska DOT	**California DOT**	**Colorado DOT**	**Florida DOT**
Georgia DOT	**Illinois DOT**	**Iowa DOT (2)**	**Louisiana DOTD**
Maine DOT	**Maryland DOT**	**Minnesota DOT (3)**	**Mississippi DOT**
Montana DOT	**North Carolina DOT**	**Ohio DOT**	**Pennsylvania DOT**
South Carolina DOT	**Texas DOT**	**Utah DOT**	**West Virginia DOT**
FHWA	**TRB**		

3.1 Question 1, Survey 1

Question 1: Have you ever tried to determine the quantitative and/or qualitative benefits and values of your research projects?

Yes No

If the results of your findings were documented, would you please provide the link or attach the document?

Figure 3.1 shows the distribution of responses to the first question in the survey. Out of 25 respondents to the first survey, 17 respondents expressed that they have tried to determine the quantitative and/or qualitative benefits and values of their research projects.

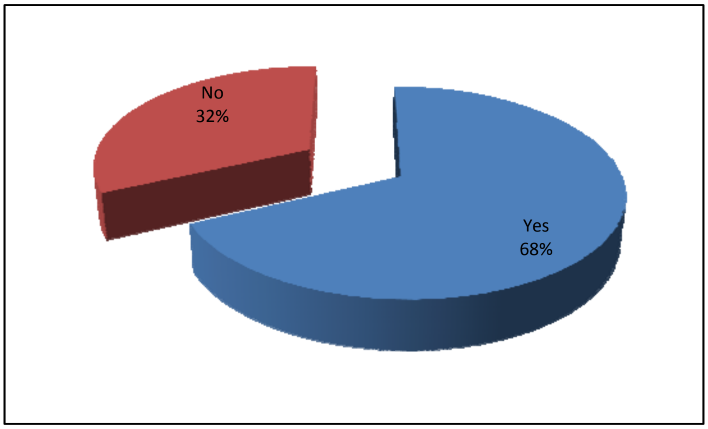

Figure 3.1: Distribution of responses to Question 1, Survey 1

3.2 Question 2, Survey 1

Question 2: Do you have any guideline or method to evaluate the quantitative and/or qualitative benefits of your research projects?
Yes No
If yes, would you please provide the link or attach the related documents?

Figure 3.2 shows the distribution of responses to the second question in the survey. Out of 25 respondents to the first survey, only three individuals expressed that they have guidelines or method to evaluate the quantitative and/or qualitative benefits of their research projects. After following up with these three individuals and further clarification of the question, it was found that these individuals considered implementation guidelines as the guideline for evaluating the quantitative and qualitative benefits of their research and they do not have any guideline other than implementation guidelines.

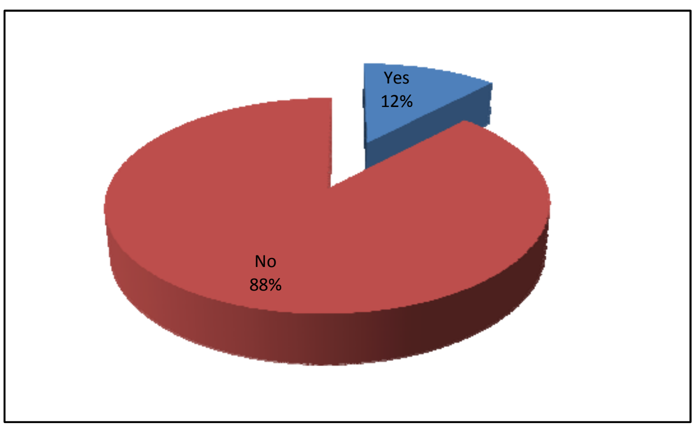

Figure 3.2: Distribution of responses to Question 2, Survey 1

3.3 Question 3, Survey 1

Question 3: Have you ever used RPM (Research Performance Measures) website for evaluating and documenting the benefits of your research projects?

Yes No

If yes, do you consider it as a valuable tool?

Yes No

Figure 3.3 shows the distribution of responses to the third question in the survey. Out of 25 respondents to the first survey, only four individuals expressed that they have used the RPM (Research Performance Measures) website for evaluating and documenting the benefits of their research projects. Out of four individuals that have used the RPM website, three believed that it was a valuable tool and one believed that it was not a valuable tool.

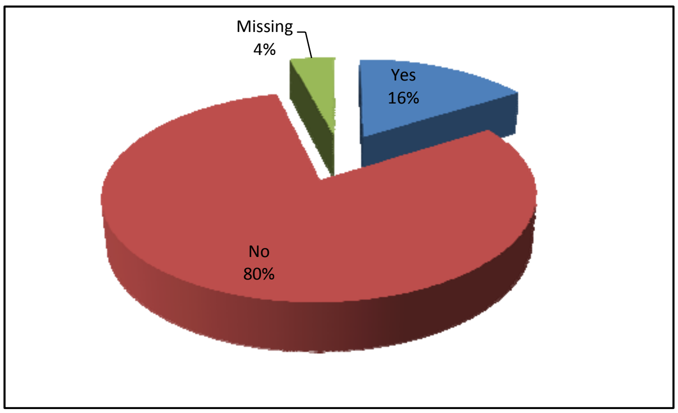

Figure 3.3: Distribution of responses to Question 3, Survey 1

3.4 Question 4, Survey 1

Question 4: What quantitative and/or qualitative benefit metrics are used by your transportation agency for determining the value of research projects?
(e.g., overall cost savings, reduced congestion, increased safety)

Out of 25 responses to the first survey, 19 responses indicated the utilization of metrics, five responses indicated the lack of utilization of metrics, and one of the participants did not respond to this question. Table 3.2 summarizes the responses to this question classified for each State DOT.

Table 3.2: Responses to Question 4, Survey 1

State DOTs	Responses
Alaska DOT	"Overall cost savings, Number of people or organizational units implementing the results."
California DOT	"We have just completed an internal survey using the recommended metrics from the RPM, and decided to adopt the top seven measures for our initial cut at measures our research program."
Colorado DOT	"Implemented (Yes/No), Implementation product, total cost and benefits in dollar"
FHWA	"There is no specific Agency-wide measure. As a program, we have reported on the task up of research results by other organizations and other units within the Agency."
Florida DOT	"Safety Improvements, Infrastructure Condition, Congestion Reduction (TT, Gas), System Reliability Improvement, Freight/Economic Benefit, Environmental Benefit, Project Time Reduced, Materials Saved, Man Hours Saved, Variation Reduced (Process, Material), Liability to FDOT Reduced"
Georgia DOT	"Overall project cost savings, lives saved, man-hours saved"
Illinois DOT	"Quantitative metrics such as overall cost savings or reduced manpower/time are viewed as the gold standard. Since it can be difficult to quantitatively measure the value of research projects, qualitative metrics such as reduced congestion, increased safety, greater use of recycled materials, etc. are often used to illustrate the value of a project."
Iowa DOT	"Project Dependent. Determined by the TAC (which includes the researcher)"
Louisiana DOTD	"Not all projects go through a quantitative analysis. Certain high value projects are chosen to quantify overall cost savings. Implementation products are tracked and documented."
Maryland DOT	"We currently only use a customer satisfaction rating to evaluate the performance/value of the research program to our agency. This is determined through a survey to our internal customers every two years."
Minnesota DOT	"We've talked about trying to measure a return on investment, so whichever metric would be appropriate."
Minnesota DOT	"We have used both quantitative and qualitative benefits since each research project provides unique benefits. We use our state wide planning numbers "STIP" for mile estimates, Statewide Unit costs for average construction "pavement" costs, and pavement management data to come up with overall cost savings selecting one design/material over another. I believe simple calculations and using rational/reasonable examples of cost savings are the best and can be defended. Using reduced congestion and increased safety we have not used because it is more subjective calculation."
N. Carolina DOT	"Meet the expected utilization objective of the NCDOT Customers"
Ohio DOT	"A benefit metric does not currently exist. Based on feedback from our current administration, emphasis will be placed on cost savings, time savings, knowledge increase, and leverage."
Penn. DOT	"We plan to use the Research Performance Measurement website developed under the TRB NCHRP."
S. Carolina DOT	"Varies on a project by project basis according to subject matter – cost savings used whenever possible."
Texas	"A new set of metrics is being prepared at this time. In the past we have focused upon

DOT	research tied to the Department's goals and mission statement. The new set of metrics will use the goals and missions as a base to set particular value based targets."
Utah DOT	"We have used overall cost savings, savings to State DOT operations, and benefits to the public (less congestion, improved safety)."
W. Virginia DOT	"None other than specifications incorporated."

3.5 Question 5, Survey 1

> Question 5: Do you have any present/future plans to quantify research benefits?
> Yes No
> If yes, would you please inform us about your overall plan in 1-2 sentences?

Figure 3.4 shows the distribution of responses to the fifth question in the survey. Out of 25 respondents to the first survey, 21 individuals expressed that they have present/future plans to quantify research benefits. Six states showed interest in using RPM as the future plan. This was the most common reply to this question across State DOTs. Table 3.3 presents the responses to this question classified for each State DOT.

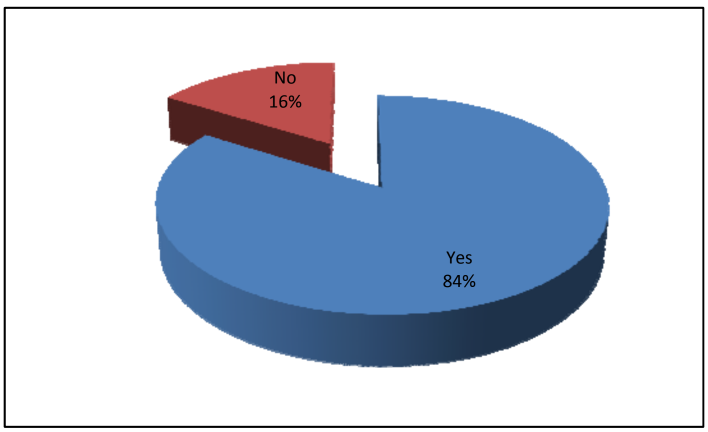

Figure 3.4: Distribution of responses to Question 5, Survey 1

Table 3.3: Responses to Question 5, Survey 1

State DOTs	Responses
Alaska DOT	"Implement RPM. (NCHRP 20-63)"
California DOT	"Only for a small number of projects, ones that we think have had significant impact to our business practices. We have identified a draft list of completed research projects, but have not yet started the analysis. However, based on anecdotal evidence, we believe that just a few wildly successful research projects can justify the investment in the entire program, and its easier to promote a smaller number than each and every one."
Colorado DOT	We will coordinate with our newly created Performance Measure Branch on how to measure the values of our research projects. We plan to use the RPM website for a start.
FHWA	"We plan to refine the measure of take up by other agency programs and by external organizations. Right now the measure if qualitative but, we want to make it a meaningful quantitative measure to track changes over time."
Florida DOT	"In addition to the current process of project evaluation described above (question #2) FDOT plans to investigate development of a system for analyzing the financial achievability provided by select implemented research projects. This analysis will be more involved than the two-step analysis described for question #2 above, and will be done using accepted accounting practices."
Georgia DOT	"Office of Research prepares an annual implementation report for executive management, and this report includes, to extent possible, quantification of research benefits."
Illinois DOT	"IDOT plans to require a benefit quantification statement on all project statement submittals, as well as require a benefit analysis as part of all contract research projects. This will be integrated throughout the process, from problem statement to work plan to implementation plan to ongoing implementation monitoring."
Louisiana DOTD	"We track the implementation status of every project from the start of the project until 5 yrs after the end date of the project. Percent of projects implemented is one of our performance measures."
Minnesota DOT	"We currently have a consultant interviewing our clients to determine the benefit they need to utilize our research. This will result in a Marketing and Communication plan that outline the best method(s) to reach a specific audience. We plan to hire a consultant to do synthesis of how other DOT state quantify benefits of research and summary state of practice. They will also be charged with putting together a procedure guide to help staff, PI, and others quantify benefits related to research program." "Currently is working on documentation of MnROAD second phase research efforts from 2007 – 2017 that is expected out in the next two months. I will look over the research performance measures for some ideas."
Montana DOT	"I would like to familiarize myself with RPM and use that tool to quantify research benefits. I plan to pick and choose for which projects we quantify research benefits. Also, I plan to add this task to research contracts."
N. Carolina DOT	"We have a rating scale. Fully meeting customers' utilization expectation rates 10"
Ohio DOT	"A staff member in the research program has been dedicated to establishing and tracking program-level performance measures and ROI on projects. The initial focus is on: (1) establishing a historical perspective on the benefits research has brought to the department and (2) identifying current projects that are providing useful and measurable results. As a result we have funded a couple of "implementation" projects that are assisting the technical offices in transiting the research findings into real-world applications."
Penn.	"We plan to use the Research Performance Measurement website developed under the

DOT	TRB NCHRP.”
Utah DOT	“We plan to conduct another review/study of our research projects from the past few years, similar to the 2010 report, to show value/benefits of the research.”

3.6 Question 6, Survey 1

Question 6: Have you ever conducted any study to determine the value of research projects?

Yes No

If yes, would you please provide the link or attached the related documents?

Figure 3.5 shows the distribution of responses to the sixth question in the survey. Out of 25 respondents to the first survey, five individuals expressed that they have conducted studies to determine the value of research projects and 20 replied that they have not.

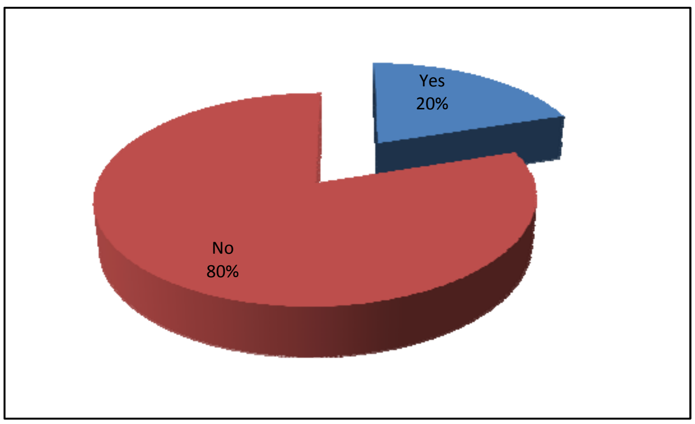

Figure 3.5: Distribution of responses to Question 6, Survey 1

3.7 Question 7, Survey 1

Question 7: Are you interested to participate in a follow-up survey?

Yes No

Figure 3.6 shows the distribution of responses to the seventh question in the survey. Out of 25 respondents to the first survey, 22 individuals expressed their interest to participate in the follow-up survey, two individuals expressed their lack of interest, and one individual did not respond.

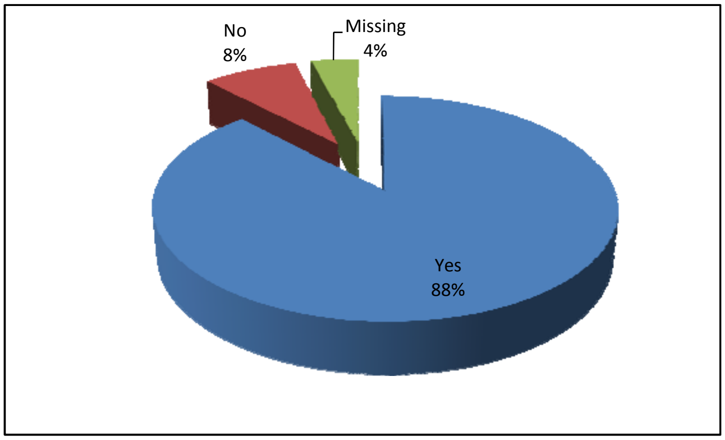

Figure 3.6: Distribution of responses to Question 7, Survey 1

3.8 Summary of Findings of Survey 1

- Several research reports were identified from responses to the first survey. These reports were collected and analyzed. The research reports sponsored by various transportation agencies are the following:
  - Florida DOT (Two research reports)
    - Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (2003)
    - Valuing the Benefits of Transportation Research: A Matrix Approach (2002)
  - Ohio DOT (Two research reports)
    - Evaluation of ODOT Research and Development Implementation Effectiveness (1988)
    - Benefit-Cost Analysis of Transportation Research Projects (1992)
  - Kentucky DOT (One research report)
    - Research report: Value of research: SPR projects (2001)
  - Utah DOT (One research report)
    - Measuring the benefits of transportation research in Utah
  - Minnesota DOT (One research report)
    - Economic benefits from road research (2008)
  - National Cooperative Highway Research Program (NCHRP)
    - Performance Measurement Tool Box and Reporting System for Research Programs and Projects, NCHRP Project 20-63
    - RPM
    - Communication matters: a guidebook published by National Cooperative Highway Research Program (NCHRP), Report 610, Available from Transportation Research Board (TRB) (2009)

    - Transportation Research Board
        - Research Pays Off
    - American Association of State Highway and Transportation Officials (AASHTO)
        - Research Impacts: Better - Cheaper – Faster
- We found that most states have future/present plans to quantify the value of research projects.
- There is not a formal guideline for assessing the benefits of research reports.
    - Although several methods are proposed for quantifying the benefits of research projects in the research reports collected in the first survey, there is not any formal guideline or formal method to evaluate the quantitative and/or qualitative benefits of research projects in State DOTs.
- The evaluation methodology should not be too long and too complex.
    - It should be easy to follow.
- Collection and distribution of good evaluation examples can be extremely helpful.
- Based on the survey results, flexibility is the key for designing any guideline to assess research benefits.
    - Several classifications of areas of research projects and the corresponding benefits
    - Several methods for assessing the value of research benefits
    - Several measures for assessing the value of research benefits
- Developing a training program for researchers and DOT personnel is vital. This training program introduces common methods and measures of quantifying value of research.
- Communication of research benefits is important.
- Data scarcity for evaluation of research benefits is a significant challenge.
- AASHTO high value research projects and TRB "Research pays off" documents summarize valuable examples of State DOT's attempts towards quantifying research benefits.
- There are fewer attempts for quantifying benefits that are hard to put dollar values on than those that are easy to put dollar values on.
- Based on the survey results, flexibility is the key for designing any guideline to assess research benefits.
    - Several classifications of areas of research projects and the corresponding benefits
    - Several methods for assessing the value of research benefits
    - Several measures for assessing the value of research benefits

CHAPTER FOUR
SURVEY 2 AND SURVEY 3: CAPTURING BEST EXAMPLES FOR DETERMINING VALUE OF RESEARCH

The best examples for determining value of transportation research were collected using two surveys:

- Survey 2: Following up the first survey to collect best examples for determining value of research
- Survey 3: Requesting further details on background calculations of selected high value research projects

Surveys 2 and 3 are discussed in sections 4.1 and 4.2, respectively. The list of collected examples in these surveys is provided in Section 4.3.

4.1 Survey 2: Following Up the First Survey to Collect Best Examples for Determining Value of Research

Survey 2 was a follow-up survey to ask respondents of the first survey to provide the research team with examples of quantifying research benefits. A copy of survey 2 was also distributed among contacts from the American Association of State Highway and Transportation Officials (AASHTO) Research Advisory Committee (RAC) via email. These contacts were retrieved from the RAC roster provided in the AASHTO webpage: http://research.transportation.org/Pages/RACRoster.aspx. Survey 2 asked individuals to provide examples of quantifying research benefits in the following areas:

- Safety
- Environmental Sustainability
- Management and Policy
- Infrastructure Condition
- Traffic and Congestion Reduction
- Quality of life
- Freight movement and Economic Vitality
- Customer Satisfaction
- System Reliability
- Expedited Project Delivery
- Engineering Design Improvement
- Increased service life
- Improved productivity and work efficiency
- Reduced User Cost
- Reduced administrative costs
- Reduced Construction, Operations and Maintenance Cost

- Materials and Pavements

These areas represent various areas where a transportation research project can have impact. These impact areas were selected based on the research background reviewed in Chapter 2. More specifically, impact areas proposed in the following sources were considered in the selection of the above impact areas:

- Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (Ellis, Degner, O'Brien and Peasley, 2003), Prepared for Florida DOT
- Benefit-Cost Analysis of Transportation Research Projects (Tavakoli and Collyard, 1992), Prepared for Ohio DOT
- MAP-21 (AASHTO MAP-21 Analysis, 2012)
- Transportation Research Board Research Pays Off website

It is worth highlighting that the selected impact areas are not mutually exclusive. The research team attempted to include as many research areas as possible to facilitate the collection of examples.

Survey 2 was distributed via email. The subject of the email was "Follow up - Survey about Best Practices for Determining Value of Research Results." Appendix B presents the email draft that was distributed. Out of 22 agencies that replied to the first survey and contacted in the second survey for collecting examples, 16 agencies replied. Figure 4.1 represents the response rate to Survey 2.

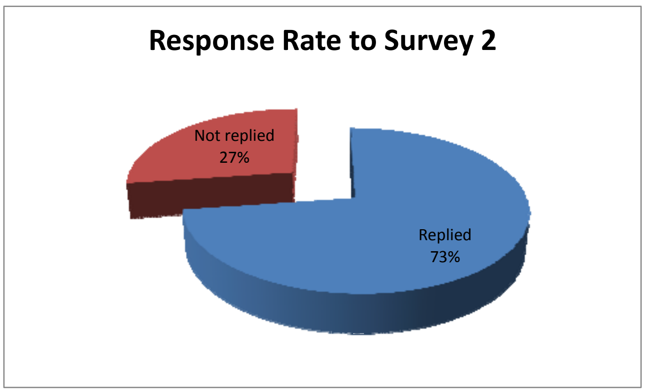

Figure 4.1 Response rate to Survey 2

Out of 16 transportation agencies that replied to Survey 2, nine transportation agencies expressed that they have not yet quantified the value of research. These nine transportation agencies represent 56% of all the transportation agencies that replied to Survey 2 (Figure 4.2). This result shows that more than half of the Survey 2 respondents have not ever quantified the value of research. Out of 16 transportation agencies that replied to Survey 2, seven transportation agencies replied that they have examples for quantifying the value of research. These examples are listed in Section 4.3 along with the examples collected in Survey 3.

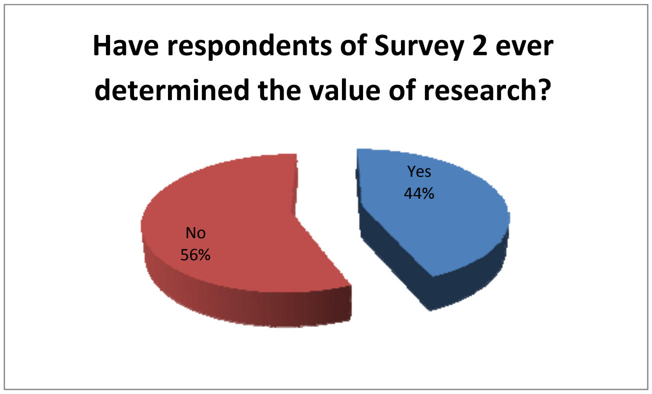

Figure 4.2 Responses to Survey 2

4.2 Survey 3: Requesting Further Details on Background Calculations of Selected High Value Research Projects

The Value of Research Task Force of the AASHTO Research Advisory Committee (RAC) compiles high value research projects from across the nation. The annual compilations of high value research projects, titled "Research Impacts: Better - Cheaper – Faster," are available from 2009 to present (http://research.transportation.org/Pages/HighValueResearchProjects.aspx). These highlights briefly showcase projects that are providing "Transportation Excellence Through Research." The information about each highlighted project is categorized into the following groups:

- Project title, ID, cost, and duration
- Submitter information (Agency, contact, and email)
- Research program (Sponsoring agency or organization, sponsoring agency contact, and sponsoring agency contact's E-mail)
- Research and results (Brief summary of the research project, impact, or potential impact of implementing research results, and web links)

We reviewed these documents representing high value research projects from across the nation and preliminarily selected 69 projects for further content analysis. The selection of these projects was based on an objective assessment. We only selected projects that explicitly highlighted benefits of research in an objective manner. Figure 4.3 presents the distribution of the selected 69 projects based on the year of publication in the AASHTO Research Impacts documents. These 69 projects were sponsored by 27 transportation agencies. Corresponding agencies of the selected 69 projects were contacted via email. The email draft is presented in Appendix C. The corresponding agencies were asked to provide further details on the background calculations for determining the benefits of the research projects.

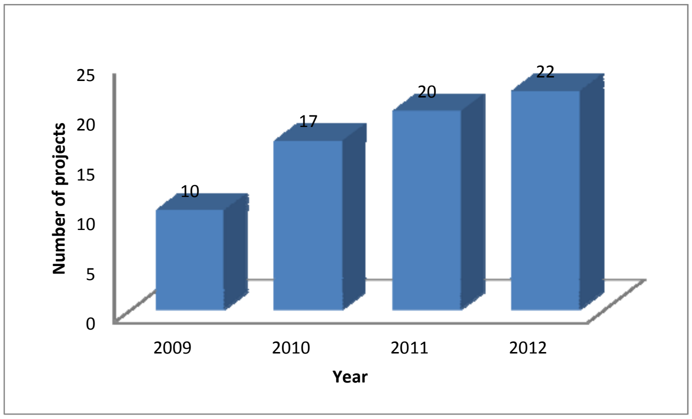

Figure 4.3 Distribution of the selected 69 projects based on year of publication in AASHTO Research Impacts documents

Out of 27 agencies that were contacted, nine replied and provided further details on the background calculations for determining the benefits of the research projects. The authors used further details provided by these nine agencies for content analysis and identification of best practices to determine value of research. In case the corresponding agency did not respond to the survey, the authors tried to find the actual full research reports published on the website of the transportation agency to understand the process used for determining the value of research projects. Survey 3 resulted in collection of several examples that are listed in Section 4.3 along with the examples collected in Survey 2.

4.3 List of Examples

Several examples were collected using Survey 2 and 3. The collected examples were usually in the form of research reports. These examples were reviewed and their contents analyzed rigorously. Appendix D summarizes the findings about these examples. The summaries in Appendix D include the following sections for each example:

- Title of research project
- Research objectives
- Areas of benefit
- Methods for determining value of research
- Measures
- Data sources

The list of the collected examples organized based on the areas of benefits are presented here:

4.3.1 Safety

1) Improving Safety in High-Speed Work Zones: A Super 70 Study, Sponsored by Indiana DOT
2) An Evaluation of the Benefits of the Alabama Service and Assistance Patrol, Sponsored by Alabama DOT
3) Rural Road Low Cost Safety Improvements, Sponsored by FHWA
4) Mobile Work Zone Barrier, Sponsored by California DOT
5) Placement of Detection Loops on High Speed Approaches to Traffic Signals, Sponsored by North Carolina DOT
6) Operational and Safety Impacts of Restriping Inside Lanes of Urban Multilane Curbed Roadways to 11 Feet or Less to Create Wider Outside, Sponsored by Florida DOT
7) Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II), Sponsored by Georgia DOT
8) Winter Operations GPS/AVL, Sponsored by Iowa DOT
9) Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Sponsored by Missouri DOT
10) Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document, Sponsored by Missouri DOT
11) Freeway Ramp Management Strategies, Sponsored by Pennsylvania DOT
12) Development and Application of Safety Performance Functions for Illinois, Sponsored by Illinois DOT

4.3.2 Environmental Sustainability

1) An Evaluation of the Benefits of the Alabama Service and Assistance Patrol, Sponsored by Alabama DOT
2) Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions, Sponsored by Florida DOT
3) Evaluation of Ternary Cementitous Combinations, Sponsored by Louisiana DOTD
4) Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri, Sponsored by Missouri DOT
5) Retrofitting Culverts and Fish Passage-Phase II, Sponsored by Utah DOT
6) Recycling of Salt-Contaminated Stormwater Runoff for Brine Production, Sponsored by Virginia DOT
7) An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options, Sponsored by Virginia DOT
8) Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule, Sponsored by Missouri DOT
9) A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit, Sponsored by Connecticut DOT

4.3.3 Improved Productivity and Work Efficiency

1) Mobile Work Zone Barrier, Sponsored by California DOT
2) Winter Operations GPS/AVL, Sponsored by Iowa DOT
3) Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction, Sponsored by Louisiana DOTD
4) Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance, Sponsored by Louisiana DOTD
5) MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery, Sponsored by Mississippi DOT
6) Geotechnical Data Management at the Virginia Department of Transportation, Sponsored by Virginia DOT

7) Implementation of Rolling Wheel Deflectometer (RWD) in PMS and Pavement Preservation, Sponsored by Louisiana DOTD

4.3.4 Traffic and Congestion Reduction

1) An Evaluation of the Benefits of the Alabama Service and Assistance Patrol, Sponsored by Alabama DOT
2) Mobile Work Zone Barrier, Sponsored by California DOT
3) Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri, Sponsored by Missouri DOT
4) Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document, Sponsored by Missouri DOT
5) Placement of Detection Loops on High Speed Approaches to Traffic Signals, Sponsored by North Carolina DOT
6) Freeway Ramp Management Strategies, Sponsored by Pennsylvania DOT
7) Bituminous Surface Treatment Protocol, Sponsored by Washington State DOT

4.3.5 Reduced Construction, Operations, and Maintenance Costs

1) Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions, Sponsored by Florida DOT
2) Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule, Sponsored by Missouri DOT
3) Winter Operations GPS/AVL, Sponsored by Iowa DOT
4) Evaluation of Ternary Cementitous Combinations, Sponsored by Louisiana DOTD
5) Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction, Sponsored by Louisiana DOTD
6) Mechanistic Flexible Pavement Overlay Design Program, Sponsored by Louisiana DOTD
7) A Sensor Network System for the Health Monitoring of the Parkview Bridge Deck, Sponsored by Michigan DOT
8) MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery, Sponsored by Mississippi DOT
9) Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document, Sponsored by Missouri DOT
10) Freeway Ramp Management Strategies, Sponsored by Pennsylvania DOT
11) Use of Fine Graded Asphalt Mixes Project 0-6615, Sponsored by Texas DOT
12) Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements, Sponsored by Texas DOT
13) Analysis of Full-Depth Reclamation Trial Sections in Virginia, Sponsored by Virginia DOT
14) Investigation of the use of tear-off shingles in asphalt concrete, Sponsored by Virginia DOT
15) Recycling of Salt-Contaminated Stormwater Runoff for Brine Production, Sponsored by Virginia DOT
16) An assessment of the Virginia Department of Transportation’s Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options, Sponsored by Virginia DOT
17) Geotechnical Data Management at the Virginia Department of Transportation, Sponsored by Virginia DOT
18) Performance of Virginia’s Warm-Mix Asphalt Trials, Sponsored by Virginia DOT
19) Field Comparison of the Installation and Cost of Placement of Epoxy-Coated and MMFX 2 Steel Deck Reinforcement: Establishing a Baseline for Future Deck Monitoring, Sponsored by Virginia DOT
20) Accelerated Loading Evaluation of Subbase Layers in Pavement Performance, Sponsored by Louisiana DOTD

21) Development of Procedures for Determining the Axial Capacity of Drilled Shafts Founded in Illinois Shale, Sponsored by Illinois DOT

4.3.6 Management and Policy

1) Assessment of the Impact of Future External Factors on Road Revenues, Sponsored by Georgia DOT

4.3.7 Customer Satisfaction

1) An Evaluation of the Benefits of the Alabama Service and Assistance Patrol, Sponsored by Alabama DOT
2) Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document, Sponsored by Missouri DOT

4.3.8 System Reliability

1) A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit, Sponsored by Connecticut DOT

4.3.9 Expedited Project Delivery

No project

4.3.10 Engineering Design Improvement

2) Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II), Sponsored by Georgia DOT
3) Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts, Sponsored by Louisiana DOTD
4) Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements, Sponsored by Texas DOT

4.3.11 Increased Service Life

1) Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule, Sponsored by Missouri DOT
2) Cost Effective Prevention of Reflective Cracking of Composite Pavement, Sponsored by Louisiana DOTD
3) Accelerated Loading Evaluation of Subbase Layers in Pavement Performance, Sponsored by Louisiana DOTD
4) Examination of an implemented asphalt permeability specification, Sponsored by Virginia DOT
5) Analysis of Full-Depth Reclamation Trial Sections in Virginia, Sponsored by Virginia DOT

4.3.12 Reduced User Cost

1) An Evaluation of the Benefits of the Alabama Service and Assistance Patrol, Sponsored by Alabama DOT
2) Mobile Work Zone Barrier, Sponsored by California DOT
3) Rural Road Low Cost Safety Improvements, Sponsored by Federal Highway Administration (FHWA)
4) Winter Operations Geographic Positioning Systems and Automatic Vehicle Location, Sponsored by Iowa DOT

5) Placement of Detection Loops on High Speed Approaches to Traffic Signals, Sponsored by North Carolina DOT
6) Freeway Ramp Management Strategies, Sponsored by Pennsylvania DOT

4.3.13 Reduced Administrative Costs

1) Winter Operations Geographic Positioning Systems and Automatic Vehicle Location, Sponsored by Iowa DOT

4.3.14 Materials and Pavements

1) Evaluation of Ternary Cementitous Combinations, Sponsored by Louisiana DOTD
2) Accelerated Loading Evaluation of Subbase Layers in Pavement Performance, Sponsored by Louisiana DOTD
3) Mechanistic Flexible Pavement Overlay Design Program, Sponsored by Louisiana DOTD
4) Cost Effective Prevention of Reflective Cracking of Composite Pavement, Sponsored by Louisiana DOTD
5) Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements, Sponsored by Texas DOT
6) Investigation of the use of tear-off shingles in asphalt concrete, Sponsored by Virginia DOT
7) Performance of Virginia's Warm-Mix Asphalt Trials, Sponsored by Virginia DOT
8) Examination of an implemented asphalt permeability specification, Sponsored by Virginia DOT

4.3.15 Intelligent Transportation Systems

1) Systems Engineering Guidebook, Sponsored by Caltrans and FHWA

CHAPTER FIVE
SUMMARY OF BEST PRACTICES

Best practices to determine the value of transportation research are summarized for several impact areas, as the following:

1) **Safety**
2) **Environmental sustainability**
3) **Improved Productivity and Work Efficiency**
4) **Traffic and Congestion Reduction**
5) **Reduced Construction, Operations and Maintenance Costs**
6) **Management and Policy**
7) **Customer Satisfaction**
8) **System Reliability**
9) **Expedited Project Delivery**
10) **Engineering Design Improvement**
11) **Increased Service Life**
12) **Reduced User Cost**
13) **Reduced Administrative Costs**
14) **Materials and Pavements**
15) **Intelligent Transportation Systems**

Different methods that have been utilized by transportation agencies to determine the value of research under each impact area are presented in this report. Several measures have been used by transportation agencies to characterize the value of research. These measures are classified under each impact area. The data sources that have been used by transportation agencies to quantify the value of the identified measures are summarized under each impact area.

1. Safety

1.1 Methods for Determining the Value of Research in Transportation Safety

Methods used for determining the value of safety research can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and benefit (dollar)/cost (dollar) analysis. These methods were identified from the detailed analysis of several research projects in transportation safety. Figure 5.1 shows the classification of methods used for determining value of safety research in conjunction with research projects that have utilized these methods.

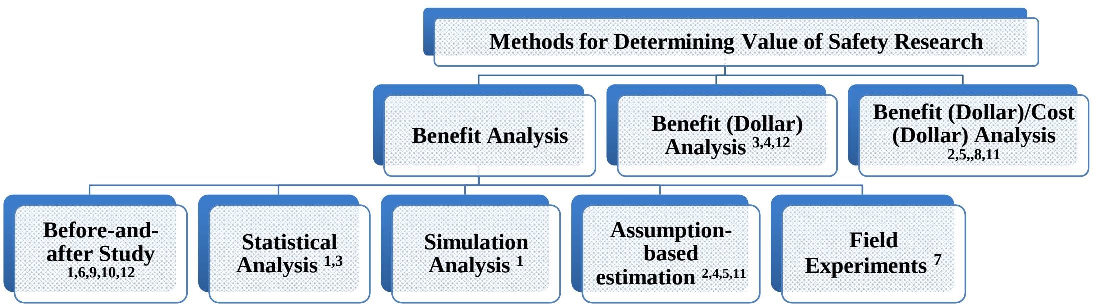

Figure 5.1 Classification of methods used for determining value of safety research

Notes:

[1]“Improving Safety in High-Speed Work Zones: A Super 70 Study” Sponsored by Indiana DOT
[2]“An Evaluation of the Benefits of the Alabama Service and Assistance Patrol” Sponsored by Alabama DOT
[3]“Rural Road Low Cost Safety Improvements” Sponsored by FHWA
[4]“Mobile Work Zone Barrier” Sponsored by California DOT
[5]“Placement of Detection Loops on High Speed Approaches to Traffic Signals” Sponsored by North Carolina DOT
[6]Operational and Safety Impacts of Restriping Inside Lanes of Urban Multilane Curbed Roadways to 11 Feet or Less to Create Wider Outside
[7]Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)
[8]Winter Operations GPS/AVL by Iowa DOT
[9]Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri DOT
[10]Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document
[11]Freeway Ramp Management Strategies by Pennsylvania DOT
[12]Development and Application of Safety Performance Functions for Illinois sponsored by Illinois DOT

1.1.1 Benefit Analysis for Determining the Value of Safety Research

Benefit analysis is a systematic approach for calculating the value of safety research projects. Safety research projects aim to improve safety-related features of transportation systems. Benefit analysis determines the improvement in one or several safety-related features and uses this improvement as the basis to determine the value of safety research in transportation. Benefit analysis can be conducted using one of the following five approaches as shown in Figure 5.1: before-and-after study, statistical analysis, simulation analysis, assumption-based estimation, and field experiments. These methods for benefit analysis were used by different transportation agencies to estimate the safety impact of high value research projects identified in our surveys:

Before-and-after study: has been used to compare safety conditions before-and-after a project is implemented to present the benefits of the research project sponsored by the transportation agency. For instance, the research project sponsored by Indiana DOT, entitled "Improving Safety in High-Speed Work Zones: A Super 70 Study," determined safety benefits using before-and-after study. Super 70 was a high-speed six-mile construction project in 2007 on a heavily traveled interstate I-70 in the central area of Indianapolis. Indiana DOT applied several innovative and traditional solutions, including traffic management and enforcement countermeasures, during the nine-month of construction to improve safety. Indiana DOT sponsored this research project to determine the value of safety improvement in Super 70. A before-and-after study was conducted to estimate the overall change in safety in the work zone impact area. The before-and-after study was conducted to estimate the safety change in terms of *Number of Crashes* on other roads in the I-70 work zone area before-and-after the work zone onset on February 22, 2007. Another example of determining safety benefits using a before-and-after study is the research project sponsored by Missouri DOT, entitled "Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document." In this study, before-and-after analysis was conducted to compare pre-construction and post-construction crash conditions to evaluate the safety performance of the first Diverging Diamond Interchange installed in the United States.

Statistical analysis: refers to methods, such as regression analysis, that enables objective analysis of safety based on historical data. For example, in the Indiana Super 70 research project, the research aimed to estimate the safety effect of traffic management and enforcement countermeasures applied during the nine months of construction. In this project, logistic regression is used to estimate the impacts of individual safety countermeasures and other safety variables on number of crashes.

Simulation: is used to replicate the operation of a transportation network or a transportation system over time in order to calculate safety benefits. Safety simulation requires developing proper models that represent key characteristics and behavior, including safety characteristics, of a transportation system. For instance, in the Indiana Super 70 research project, statistical models were used to predict the number of crashes expected in prolonged periods and under certain traffic, weather, and geometry conditions. A sample of 156,646 30-minute intervals with 132 crashes reflecting the historical geometric, traffic, and weather conditions during the Super 70 period, and it was used to simulate selected safety effects.

Assumption-based estimation: refers to the calculation of benefits through assumption-based estimations for key safety improvement features, such as the percentage of crash avoidance with a specific project. The sources of assumptions can be experience, engineering judgment, and/or the literature. For example, in a project sponsored by Alabama DOT, entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol," crash reduction rates (after the project is implemented) was drawn from the literature and used to estimate safety benefits.

Field experiments: refers to experiments that examine the impact of safety research in the real world. For example in the project sponsored by Georgia DOT, entitled "Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)," field experiments were used to evaluate the behavioral responses of captive white-tailed deer to visual and physical barriers designed to minimize deer-vehicle collisions. In this research, the effects of exclusion fencing on movements of free-ranging deer were also determined.

1.1.2 Benefit (Dollar) Analysis for Determining the Value of Safety Research

Benefit (Dollar) analysis goes beyond benefit analysis by transferring the value of safety research in dollar values. Reduction of fatalities, crashes, and injuries are three measures of safety improvement that have been calculated in dollar terms. For instance, Crash Reduction Factor (CRF) was applied in the research project sponsored by the Federal Highway Administration (FHWA) entitled "Rural Road Low Cost Safety Improvements." The CRF is a crash reduction percentage which is expected after implementing a given countermeasure. Also a Crash or Accident Modification Factor[1] (CMF or AMF, respectively) is a multiplier to adjust the number of expected crashes based on the estimated safety benefit for a particular countermeasure into planning, design, operations, and project maintenance. The CMF represents the expected percent change in target crashes compared with a configuration with 3.05-m (10-ft) lanes for given total paved widths (the most safety-effective configuration for a given paved width is indicated by the lowest CMF). Results of CMFs calculation yield a reduction of 6 crashes per year. Estimated crash costs are then applied to the expected change in crashes to estimate the annual dollar savings. Crash costs typically vary by states but can be estimated from the recent FHWA crash cost guide when State-specific crash cost data are not available (Council, F. et al. 2005).

1.1.3 Benefit (Dollar)/Cost (Dollar) Analysis for Determining Value of Safety Research

Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates and compares safety benefits and costs in terms of dollar values. For example, in the North Carolina research project entitled "Placement of Detection Loops on High Speed Approaches to Traffic Signals" and published in 2010, benefit (Dollar)/cost (Dollar) analysis is

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[1] $\text{CMF or AMF} = 1 - \frac{CRF}{100}$

used to assess cost effectiveness of alternatives to evaluate various systems. An estimated percent reduction (a marginal 10 percent reduction) of crashes is assumed due to installation of technologies. Crash data for years 2006, 2007 and 2008 were collected from the North Carolina Department of Transportation and the average number of crashes is used for calculating benefits. The equivalent unit crash cost is extracted for each county from the North Carolina Department of Transportation Traffic Engineering and Safety Systems branch website. This cost was considered as the project benefit in terms of dollars and compared with the cost of installation of various systems, such as Detector-Control System (D-CS) and NQ4 system, which make this safety improvement possible.

1.2 Measures for Determining Value of Safety Research

Various measures have been used by different transportation agencies for determining the value of safety research. These measures can be classified into three major categories that address different aspects of transportation safety: "crashes and injuries", "cost saving" and "others" as shown in Figure 5.2. "Crashes or injuries" measures are used to present the value of safety research in terms of reduction in crashes and/or injuries. Some of these measures consider a group of crash types. For example, "Rural Road Low Cost Safety Improvements" research project considers injury crashes, rear-end crashes and angle crashes. The other "crashes or injuries" measures focus on one specific type of crashes. For instance, "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" research project focuses on secondary crashes. Secondary crashes can occur in the congestion upstream of an incident that has already occurred. "Cost savings" measures refer to costs avoided by the reduction in crashes and injuries. There are several safety measures that are categorized as "others." These measures, such as "motor vehicle shift to the outside through lane," characterize the value of safety research in specific conditions. Reduction in the value of the "others" measures, such as "reduction in time for set-up and breakdown of a lane closure" provides safety value by decreasing the chance of crashes or injuries.

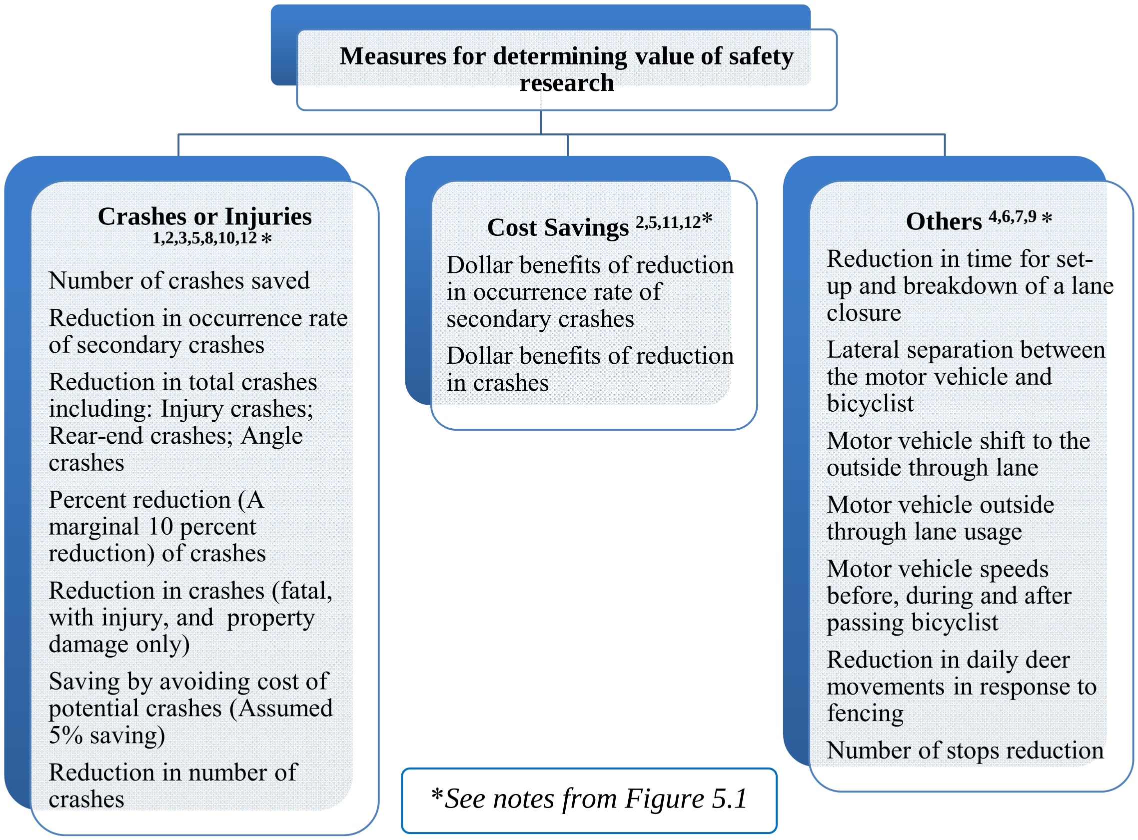

Figure 5.2 Measures for determining value of safety research

1.3 Data Sources for Determining Value of Safety Research

Various data sources have been used to evaluate safety in different research projects. The identified data sources for determining the value of safety research are presented in Figure 5.3. “Crashes and injuries” data sources were used to present the value of safety research in terms of reduction in crashes and/or injuries. “Cost savings” data sources were used to calculate dollar of avoided crashes and injuries. The last category of data sources, called “Others,” include all the other sources of data that were used in the methods for determining value of safety research.

Data Sources for determining value of safety research

Crashes or Injuries [1,2,3,4,5,6,7,9,10,11,12]*

Crash dataset: Indiana State Police Crash Data Records

Secondary crash rates from a study of the service patrol in the Los Angeles area (Moore et al., 2004)

Secondary crash reduction rates from a study of the Hoosier Helper program in northwestern Indiana and a comprehensive study of the benefits of the service patrol in the Hudson Valley region of New York State

Geometric, traffic, and crash data provided for the entire population of rural, two-lane, undivided road segments in Pennsylvania (1997–2001 and 2003–2006) and Washington (1993–1996 and 2002–2003)

Crash data for year's 2006, 2007 and 2008 collected from North Carolina Department of Transportation4

PennDOT iTMS data and PennDOT ATR counts, and number of crashes within the limits of the ramp metering from the data given by PennDOT

Crash data archived by Florida DOT

Field data

Output of simulation models

Cost Savings [2,5,8,11]*

Economic value of reduction in secondary crashes from NHTSA report entitled, "The Economic Impact of Motor Vehicle crashes 2000" (Blincoe et al., 2002)

Equivalent unit crash cost is extracted for each county from North Carolina

Cost of crashes provided by agency

AASHTO User Benefit Analysis for Highways Handbook

Others [1,11]*

Traffic dataset: Detectors set up by INDOT

Geometry dataset: Google Earth and Super 70 work zone drawing

Weather dataset: National Climatic Data Center

Maintenance dataset: Super 70 work zone drawing

Enforcement dataset: Super 70 work zone activity log

http://www.inflationdata.com/, Census (2005-2009 Average) data, "Intelligent Transportation Systems Benefit: 2001

**See notes from Figure 5.1*

Figure 5.3 Data Sources for determining the value of safety research

2. Environmental Sustainability

2.1 Methods for Determining the Value of Research on Environmental Sustainability

The identified methods for determining the value of research about environmental sustainability can be classified into two major categories: benefit analysis and benefit (dollar) analysis. These methods were identified from the detailed analysis of several research projects in environmental sustainability. Figure 5.4 shows the classification of methods used for determining value of environmental sustainability in conjunction with research projects that have utilized these methods.

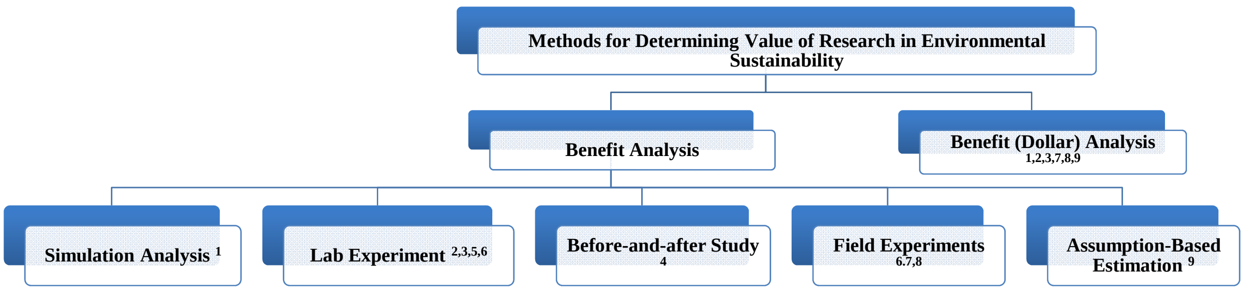

Figure 5.4 Classification of the methods for determining the value of research on Environmental Sustainability

Notes:

[1]"An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" Sponsored by Alabama DOT

[2]"Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions" Sponsored by Florida DOT

[3]" Evaluation of Ternary Cementitous Combinations" Sponsored by Louisiana DOTD

[4]" Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri" Sponsored by Missouri DOT

[5]" Retrofitting Culverts and Fish Passage-Phase II" Sponsored by Utah DOT

[6]"Recycling of Salt-Contaminated Stormwater Runoff for Brine Production" by Virginia DOT

[7]"An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options" by Virginia DOT

[8]"Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule" Sponsored by Missouri DOT

[9]"A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit"

2.1.1 Benefit Analysis for Determining Value of Research on Environmental Sustainability

Benefit analysis is a systematic approach for calculating the value of research in environmental sustainability. Environmental sustainability research projects aim to improve environmental aspect of transportation systems. Benefit analysis determines the improvement in one or several environmental features and uses this improvement as the basis to determine the value of environmental sustainability research in transportation. Benefit analysis can be conducted using one of the following five approaches as shown in Figure 5.3: simulation analysis, lab experiment, before-and-after study, field study, and assumption-based estimation. These methods for benefit analysis were used by different transportation agencies to estimate the environmental impact of high value research projects identified in our survey.

***Simulation*:** is used to replicate the operation of a transportation network or a transportation system over time in order to calculate environmental sustainability benefits. Environmental sustainability simulation requires developing proper models that represent key characteristics and behavior, including environmental sustainability characteristics, of a transportation system. For instance, simulation software is used for calculating mobility measures and emission outputs in the research project entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" sponsored by the Alabama DOT.

Lab experiment: is used to test environmental sustainability impacts of transportation research project under controlled conditions. For example, in the research project sponsored by the Florida DOT, entitled "Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions," 46 tests were conducted at the University of Central Florida to examine how the amount of phosphorus (which is undesirable adjacent to bodies of water) can be reduced.

Before-and-after study: is used to evaluate environmental impact of proposed systems by comparing the field data collected before-and-after deployment of the system. For example, in the research project entitled "Evaluation of an Adaptive Traffic Signal System" sponsored by the Missouri DOT, changes in vehicle emissions (estimated by the amount of released HC, CO, and NO_x) were determined using a before-and-after study approach on Route 291 in Lee's Summit DOT. Results showed a decrease of 50 percent in vehicle emissions through using traffic signal system.

Field experiments: refers to experiments that examine the impact of research in environmental sustainability in the real world. For example in the project sponsored by the Missouri DOT, entitled "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule," field experiments were used to evaluate LEDs in terms of energy savings. Field experiments were also used to evaluate the impact of the manufacturer, indicator type, color and directional view on the degradation of LED traffic signals, and to develop a comprehensive replacement plan for the LEDs based on the data collected.

Assumption-based estimation: refers to the calculation of benefits through assumption-based estimations for key improvement in environmental sustainability features. The sources of assumptions can be experience, engineering judgment, and/or the literature. For example, in a project sponsored by Connecticut DOT, entitled "A Study of Bus Propulsion Technologies

Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit", emission rates were drawn from the literature and used to estimate environmental sustainability benefits.

2.1.2 Benefit (Dollar) Analysis for Determining the Value of Research on Environmental Sustainability

Benefit (dollar) analysis goes beyond benefit analysis by presenting the value of research on environmental sustainability in dollar values. For example, the research project entitled "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule" and sponsored by the Missouri DOT, found out an annual energy saving of $120.75 for installing one unit of LED can be achieved. A 10-year life span and an average electric cost $0.1/kWh (MoDOT Electricity Bill, 3rd quarter 2010) are applied in this analysis.

2.2 Measures for Determining the Value of Research on Environmental Sustainability

Various measures have been used by different transportation agencies for determining the value of research in environmental sustainability. These measures can be classified into four major categories that address different aspects of transportation research in environmental sustainability: "Emissions," "Energy Consumption," "Cost Savings," and "others" as shown in Figure 5.5. "Emissions" measures are used to present the value of research in terms of reduction in emission outputs, such as HC, CO, NO_x. "Energy Consumption" measures are used to present the value of research in terms of reduction in energy consumption. "Cost savings" measures refer to costs avoided by the reduction in emissions and energy consumption. There are several measures categorized under "others." These measures, such as "Fish passages," characterize the value of research on environmental sustainability in specific conditions.

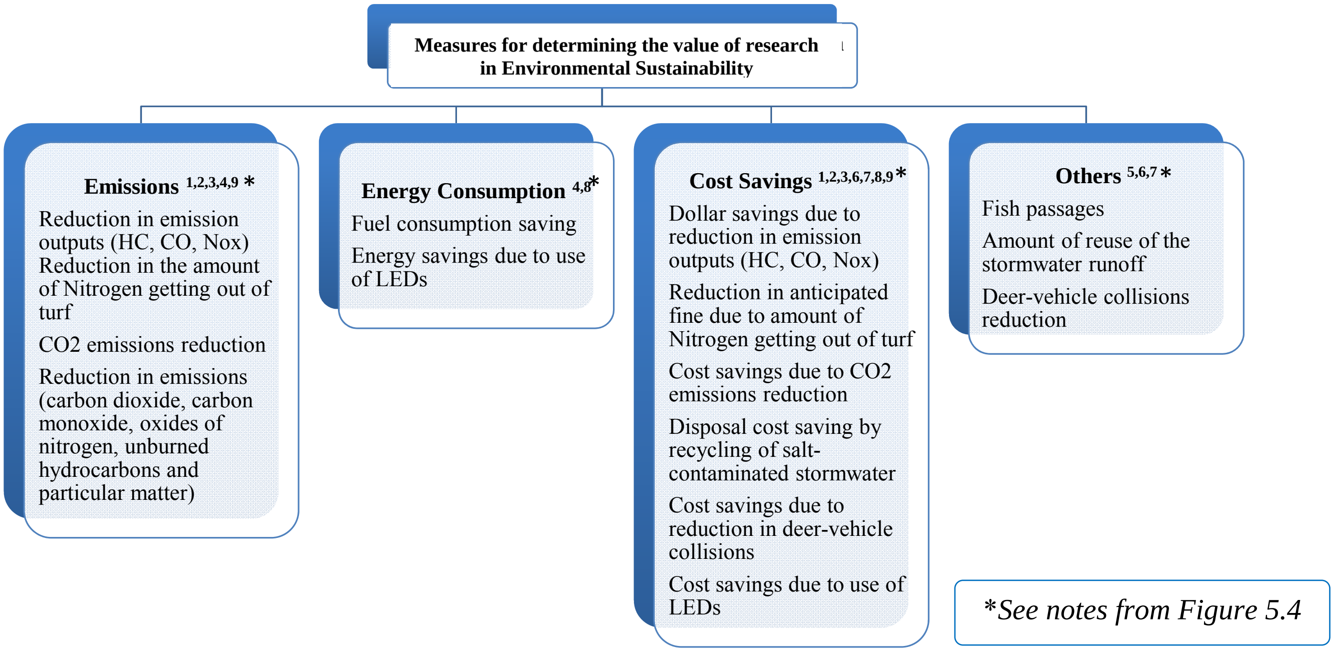

Figure 5.5 Measures for determining the value of research in environmental sustainability

2.3 Data Sources for Determining the Value of Research on Environmental Sustainability

Various data sources have been used to evaluate environmental sustainability in different research projects. The identified data sources for determining the value of environmental sustainability research are presented in Figure 5.6. “Emissions” data sources were used to present the value of research in terms of reduction in emission outputs, such as HC, CO, NOx. “Energy Consumption” data sources were used to present the value of research in terms of reduction in energy consumption. “Cost savings” data sources were used to calculate dollars equivalence of avoided emissions.

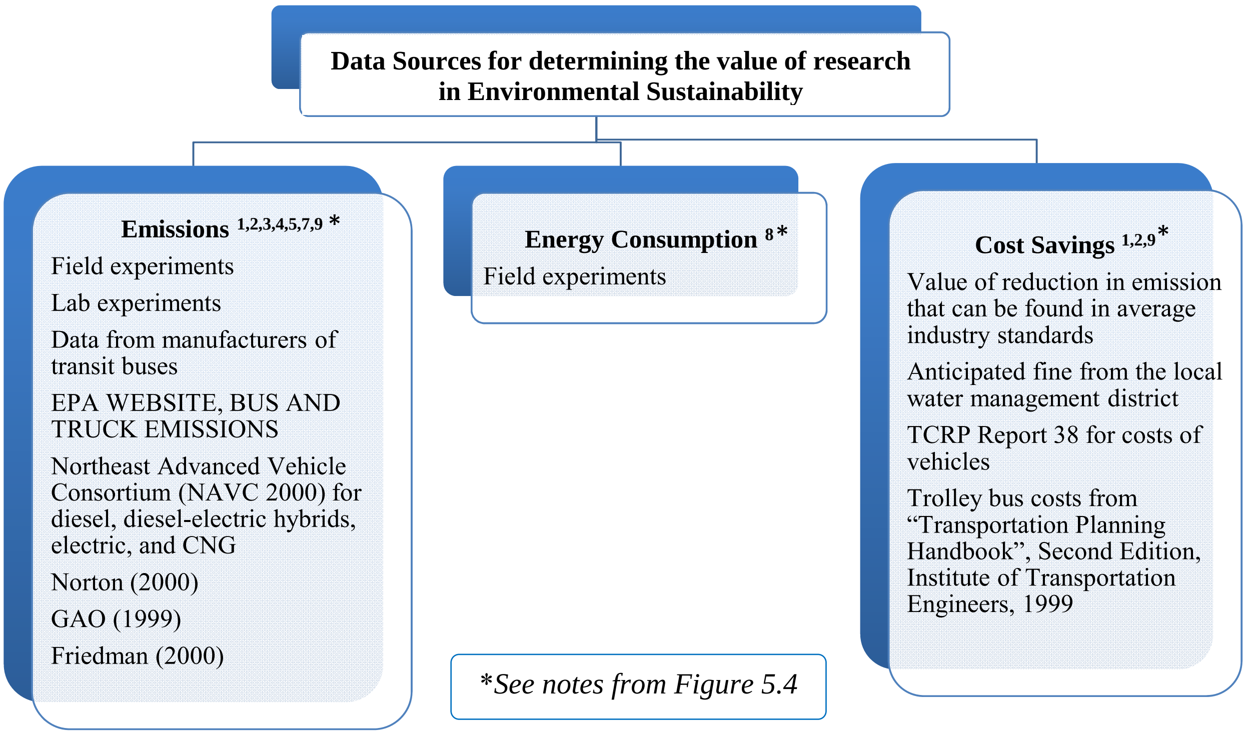

Figure 5.6 Data Sources for determining the value of research in environmental sustainability

3. Improved Productivity and Work Efficiency

3.1 Methods for Determining the Value of Research on Improved Productivity and Work Efficiency

The identified methods for determining the value of research about improved productivity and work efficiency can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and benefit (dollar)/cost (dollar) analysis. These methods were identified from the detailed analysis of several research projects in improved productivity and work efficiency. Figure 5.7 shows the classification of methods used for determining value of improved productivity and work efficiency in conjunction with research projects that have utilized these methods.

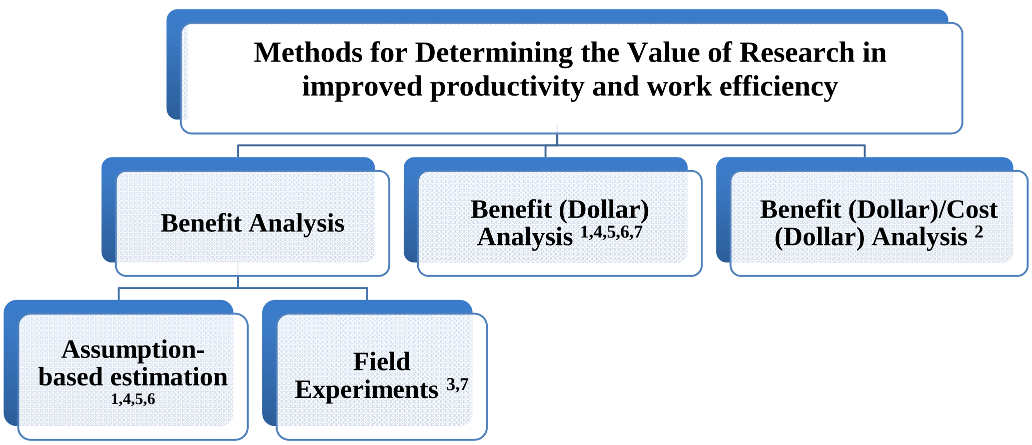

Figure 5.7 Classification of the methods for determining the value of improved productivity and work efficiency research

Notes:

[1]"Mobile Work Zone Barrier" Sponsored by California DOT

[2]"Winter Operations GPS/AVL" Sponsored by Iowa DOT

[3]"Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction" Sponsored by Louisiana DOTD

[4]"Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance" Sponsored by Louisiana DOTD

[5]"MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery" Sponsored by Mississippi DOT

[6]"Geotechnical Data Management at the Virginia Department of Transportation" Sponsored by Virginia DOT

[7]"Implementation of Rolling Wheel Deflectometer (RWD) in PMS and Pavement Preservation" sponsored by Louisiana DOTD

3.1.1 Benefit Analysis for Determining the Value of Research on Improved Productivity and Work Efficiency

Benefit analysis is a systematic approach for calculating the value of improved productivity and work efficiency. Research projects focusing on improved productivity and work efficiency aim to improve the productivity and the efficiency of activities involved in transportation projects. Benefit analysis determines the improvement in one or several productivity and efficiency features and uses this improvement as the basis to determine the value of research in productivity improvement and work efficiency. Benefit analysis can be conducted using one of the following two approaches as shown in Figure 5.7: Assumption-based estimation and field experiments. These methods for benefit analysis were used by different transportation agencies to estimate the productivity and the efficiency impact of high value research projects identified in our survey.

Assumption-based estimation: refers to the calculation of benefits through assumption-based estimations for key improvement features attributed to improved productivity and work efficiency. The sources of assumptions can be experience, engineering judgment, and/or the literature. For example, in the project sponsored by the Virginia DOT, entitled "Geotechnical Data Management at the Virginia Department of Transportation," it was estimated that on average, the use of this technology would cut in half the time required to gather and process borehole data, resulting in approximately 16 person-hours of savings.

Field experiments: refers to experiments that examine the impact of research regarding improved productivity and work efficiency in the real world. For example in the project sponsored by the Louisiana DOTD, entitled "Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction," field experiments demonstrated that Fiber Reinforced Polymers (FRP) can accelerate the deck installation in half a day, which is faster than current practice.

3.1.2 Benefit (Dollar) Analysis for Determining Value of Research on Improved Productivity and Work Efficiency

Benefit (dollar) analysis goes beyond benefit analysis by presenting the value of research on productivity improvement and work efficiency in dollar values. For example, in the research project entitled "Geotechnical Data Management at the Virginia Department of Transportation," it is conservatively estimated that the labor-cost savings would be approximately $600 for each average small- to mid-size bridge project. For the past 15 years, the Virginia DOT has been approving an average of 102 bridges per year for construction. Therefore, the potential cost savings are estimated to be in the order of $160,000 per year.

3.1.3 Benefit (Dollar)/Cost (Dollar) Analysis for Determining Value of Research on Improved Productivity and Work Efficiency

Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates the benefits and the costs of productivity and efficiency benefits in terms of dollar values. For example, the research project entitled "Winter Operations GPS/AVL" assesses the expected benefits and costs of an integrated GPS/AVL system. The benefits of the Winter Operations GPS/AVL system were calculated in terms of reducing paperwork costs and operating costs. Both initial and annual operating and maintenance costs were also calculated in dollar values. The ratio of benefits to costs was used as an indicator for determining the value of this research project.

3.2 Measures for Determining the Value of Research on Improved Productivity and Work Efficiency

Various measures have been used by different transportation agencies for determining the value of research related to improved productivity and work efficiency. These measures can be classified into two major categories that address different aspects of the impact that transportation research can have on improved productivity and work efficiency: "Productivity Improvement and Work Efficiency Metrics" and "Cost Savings" as shown in Figure 5.8. "Productivity Improvement and Work Efficiency Metrics" are used to present the value of research in terms of improvement in productivity and work efficiency. "Cost saving" measures refer to costs avoided by improving productivity and work efficiency.

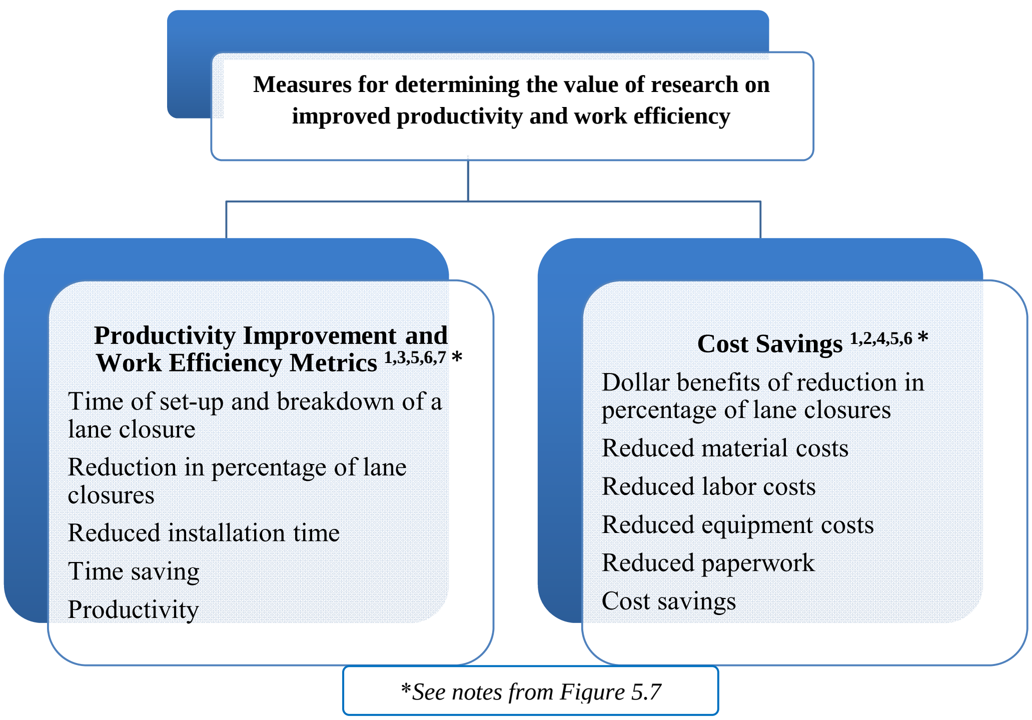

Figure 5.8 Measures for determining the value of research on improved productivity and work efficiency

3.3 Data Sources for Determining the Value of Research on Improved Productivity and Work Efficiency

Various data sources have been used by various transportation agencies to evaluate different measures related to improved productivity and work efficiency. The identified data sources for determining the value of research on improved productivity and work efficiency are presented in Figure 5.9. “Productivity improvement and work efficiency metrics” data sources were used to measure improvements in productivity and efficiency following the implementation of research results. For example, the research project entitled “Mobile Work Zone Barrier” uses field data as the data source to measure productivity in terms of reduction in time of a setup and breakdown of a lane closure. Analysis of field data in the “Mobile Work Zone Barrier” research showed that the current set-up and breakdown of a lane closure requires approximately three hours with current safety measures. In contrast, the mobile work zone barrier requires only 10-20 minutes each for set-up and break-down representing improvement in productivity. “Cost saving” data sources were used to calculate dollar values of avoided costs by improving productivity and work efficiency.

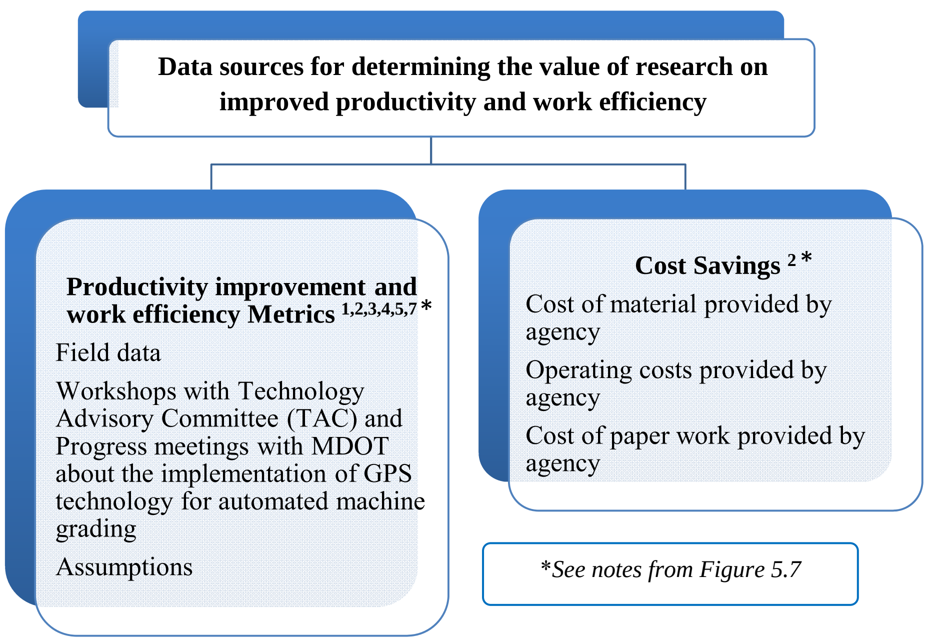

Figure 5.9 Data Sources for determining the value of research on improved productivity and work efficiency

4. Traffic and Congestion Reduction

4.1 Methods for Determining the Value of Research on Traffic and Congestion Reduction

The identified methods for determining the value of research on traffic and congestion reduction can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and benefit (dollar)/cost (dollar) analysis. These methods were identified from the detailed analysis of several research projects on traffic and congestion reduction. Figure 5.10 shows the classification of methods used for determining value of traffic and congestion reduction in conjunction with research projects that have utilized these methods.

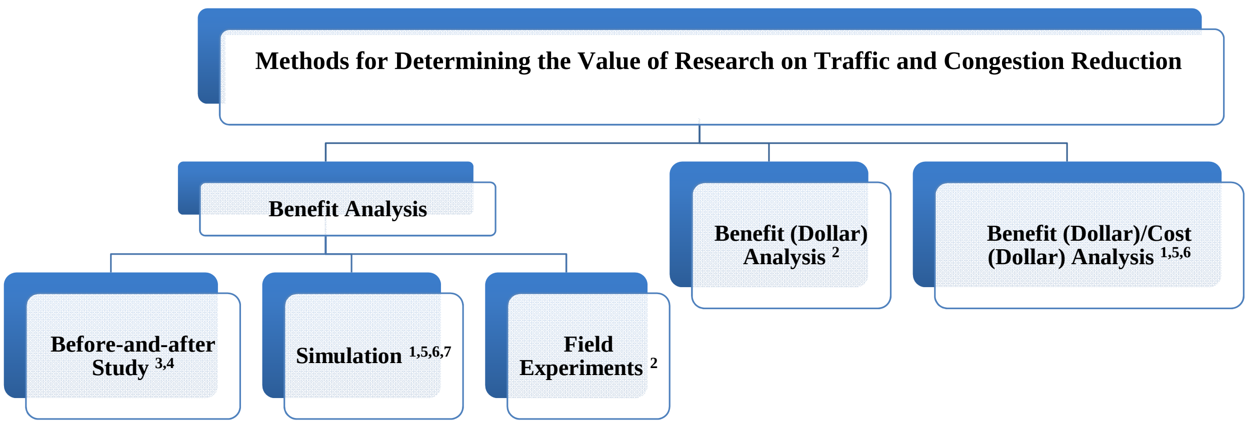

Figure 5.10 Classification of the methods for determining the value of traffic and congestion reduction research

[1]"An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" Sponsored by Alabama DOT
[2]"Mobile Work Zone Barrier" Sponsored by California DOT
[3]"Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri" Sponsored by Missouri DOT
[4]"Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document" Sponsored by Missouri DOT
[5]"Placement of Detection Loops on High Speed Approaches to Traffic Signals" Sponsored by North Carolina DOT
[6]"Freeway Ramp Management Strategies" by Pennsylvania DOT
[7]"Bituminous Surface Treatment Protocol" by Washington State DOT

4.1.1 Benefit Analysis for Determining the Value of Research on Traffic and Congestion Reduction

Benefit analysis is a systematic approach for calculating the value of research on traffic and congestion reduction. Research projects focusing on traffic and congestion reduction aim to improve traffic and reduce congestion in transportation projects. Benefit analysis determines the improvement in one or several traffic and congestion features and uses this improvement as the basis to determine the value of research in traffic and congestion reduction. Benefit analysis can be conducted using one of the following three approaches as shown in Figure 5.10: before-and-after study, simulation, and assumption-based estimation. These methods for benefit analysis were used by different transportation agencies to estimate the traffic and congestion impact of high value research projects identified in our surveys.

Before-and-after study: has been used to compare traffic and congestion conditions before-and-after a project is implemented to present the benefits of the research project sponsored by the transportation agency. For instance, the research project sponsored by the Missouri DOT, entitled "Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri", before-and-after study was used to compare operational measures, such as travel time in morning off-peak and noon-peak period and change in average speed, taken before the implementation of the system to the same measures taken one month and five months after the implementation.

Simulation: is used to replicate the operation of a transportation network or a transportation system over time, in order to calculate traffic and congestion reduction benefits. Traffic simulation requires developing proper models that represent key characteristics and behavior, including traffic characteristics, of a transportation system. For example, the research project sponsored by the Alabama DOT, entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" used traffic simulation to estimate the overall delay in vehicle-hours. This research demonstrated that the reduction in delay to the traveling public is one of the major benefits of the Alabama Service and Assistance Patrol in the area of traffic and congestion reduction.

Field experiments: refers to experiments that examine the impact of a research project on traffic and congestion reduction in the real world. For instance, the research project sponsored by the California DOT, entitled "Mobile Work Zone Barrier," used field experiments to determine the impact of this research project on traffic and congestion reduction. The maintenance crew currently using the barrier found that it has eliminated approximately 15% of the lane closures previously required to perform necessary maintenance.

4.1.2 Benefit (Dollar) Analysis for the Determining the Value of Research on Traffic and Congestion Reduction

Benefit (Dollar) analysis goes beyond benefit analysis by presenting the value of research on traffic and work efficiency in dollar values. For example, in the research project entitled "Mobile Work Zone Barrier," it is estimated that the number of avoided lane closures equates to a potential annual savings of $115,464,000 in public user road costs, due to reduced travel delay.

4.1.3 Benefit (Dollar)/Cost (Dollar) Analysis for Determining the Value of Research on Traffic and Congestion Reduction

Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates the benefits and the costs of traffic and congestion reduction in terms of dollar values. For instance, the research project entitled "Placement of Detection Loops on High Speed Approaches to Traffic Signals," sponsored by the North Carolina DOT, found that well-placed detectors and a carefully chosen signal timing strategy reduces the likelihood that vehicles would be caught in dilemma zones at the onset of yellow. The research project calculates dollar values of both benefits (reduction in delay) and system costs. It was found that the Detector-Control System (D-CS) system produced benefit-cost ratios significantly greater than 1.0.

4.2 Measures for Determining the Value of Research on Traffic and Congestion Reduction

Various measures have been used by different transportation agencies for determining the value of research on traffic and congestion reduction. These measures can be classified into two major categories that address different aspects of transportation research on traffic and congestion reduction: "Traffic and Congestion Metrics" and "Cost Savings" as shown in Figure 5.11. "Traffic and Congestion Metrics" are used to present the value of research in terms of congestion reduction and improved traffic management. "Cost saving" measures refer to dollar benefits resulting from congestion reduction and improved traffic management.

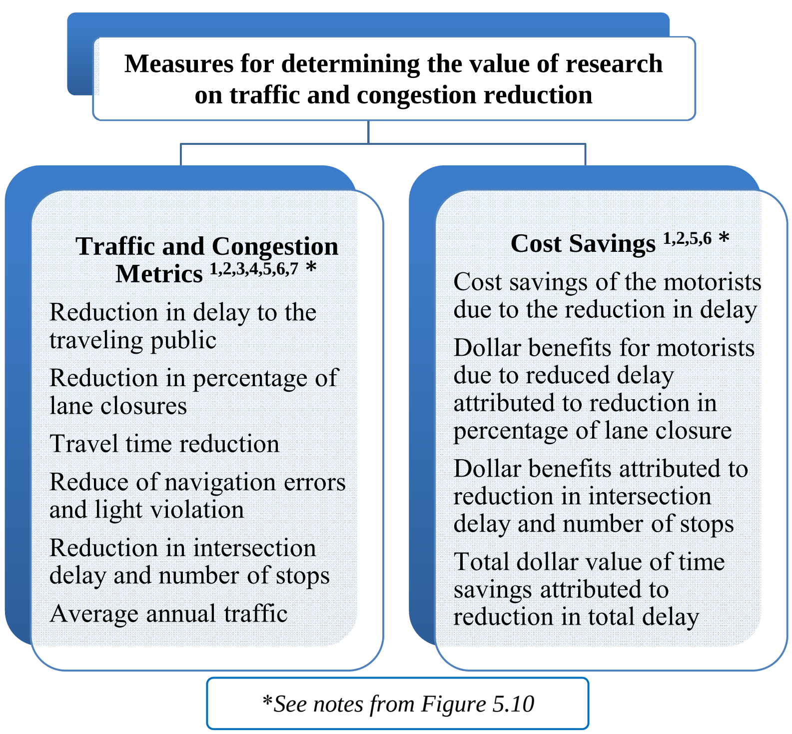

Figure 5.11 Measures for determining the value of research on traffic and congestion reduction

4.3 Data Sources for Determining the Value of Research on Traffic and Congestion Reduction

Various data sources have been used to evaluate traffic and congestion reduction in different research projects. The identified data sources for determining the value of research on traffic and congestion reduction are presented in Figure 5.12. “Traffic and Congestion Reduction Metrics” data sources were used to present the value of research in terms of reduction in congestion and improved traffic management. “Cost Saving” data sources were used to calculate dollar values of avoided costs by reducing congestion and improving traffic management. The last category of data sources, called “Others,” include all the other sources of data (i.e., not “Cost savings” and “Traffic and Congestion” data sources) that were used in the methods for determining the value of research on traffic and congestion reduction. Data sources in this category provide supporting information that is necessary to calculate the benefits of research related to traffic management and congestion control. These data sources provide fundamental information, such as the census information and average vehicle occupancy, which is required for quantifying the value of research on traffic and congestion reduction in a specific corridor.

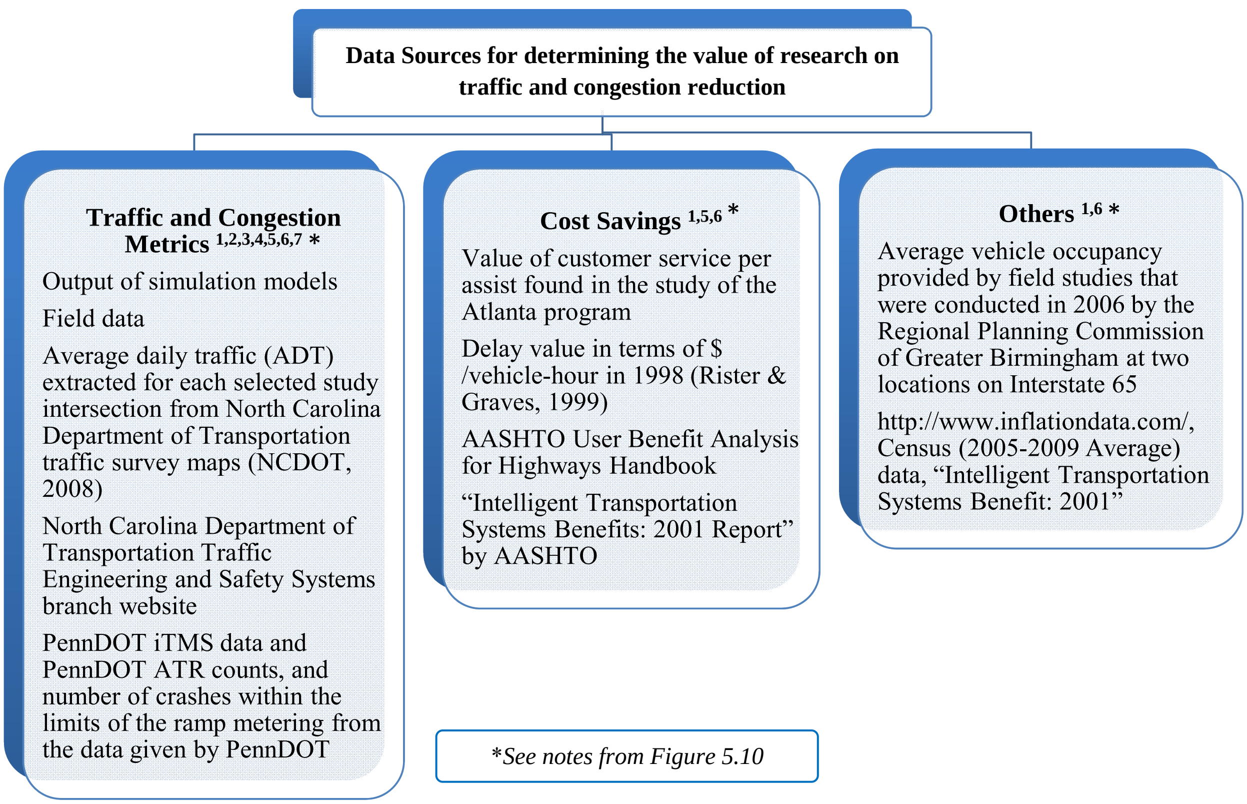

Figure 5.12 Data Sources for determining the value of research on traffic and congestion reduction

5. Reduced Construction, Operations and Maintenance Costs

5.1 Methods for Determining the Value of Research on Reduced Construction, Operations and Maintenance Costs

The identified methods for determining the value of research on reduced construction, operations and maintenance costs can be classified into three major categories: benefit (dollar) analysis, benefit (dollar)/cost (dollar) analysis, and Life Cycle Cost Analysis (LCCA). These methods were identified from the detailed analysis of several research projects on reduced construction, operations and maintenance costs. Figure 5.13 shows the classification of methods used for determining the value of research on reduced construction, operations and maintenance costs in conjunction with research projects that have utilized these methods.

5.1.1 Benefit (Dollar) Analysis for Determining the Value of Research on Reduced Construction, Operations, and Maintenance Costs

Benefit (Dollar) analysis presents the value of research on reduced construction, operations and maintenance costs in dollar values. For example, in the research project sponsored by the Louisiana DOTD entitled "Evaluation of Ternary Cementitous Combinations", it was shown that cement mixtures containing up to 70 percent fly ash and slag exhibit concrete test results that are comparable (or better) than those obtained from control mixtures containing no supplemental cementitious materials. This research indicated potential material cost savings around $25,000 per lane-mile when replacing 70 percent Portland cement with fly ash and slag.

5.1.2 Benefit (Dollar)/Cost (Dollar) Analysis for Determining the Value of Research on Reduced Construction, Operations and Maintenance Costs

Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates the benefits and the costs of to reduced construction, operations and maintenance costs in terms of dollar values. For instance, the research project entitled "Winter Operations Geographic Positioning Systems and Automatic Vehicle Location," sponsored by the Iowa DOT, studied the benefits and expected costs of an integrated Geographic Positioning Systems and Automatic Vehicle Location (GPS/AVL) system. The research project calculates dollar values of both benefits (reduced material costs, reduced labor costs, reduced equipment costs, reduced paperwork) and system costs. It was found that the system produced benefit-cost ratio of 17.3.

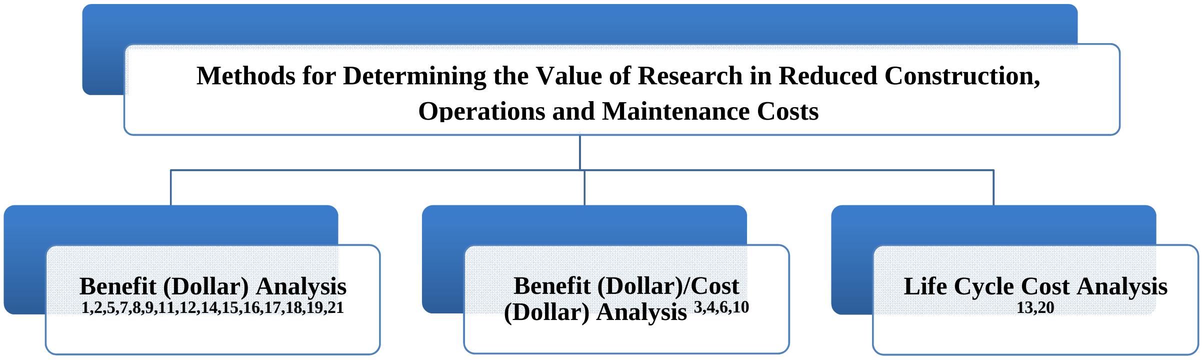

Figure 5.13 Classification of the methods for determining the value of Reduced Construction, Operations and Maintenance Costs

[1]"Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions" Sponsored by Florida DOT
[2]"Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule" Sponsored by Missouri DOT
[3]"Winter Operations GPS/AVL" Sponsored by Iowa DOT
[4]"Evaluation of Ternary Cementitous Combinations" Sponsored by Louisiana DOTD
[5]"Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction" Sponsored by Louisiana DOTD
[6]"Mechanistic Flexible Pavement Overlay Design Program" Sponsored by Louisiana DOTD
[7]"A Sensor Network System for the Health Monitoring of the Parkview Bridge Deck" Sponsored by Michigan DOT
[8]"MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery" Sponsored by Mississippi DOT
[9]"Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document" Sponsored by Missouri DOT
[10]"Freeway Ramp Management Strategies" Sponsored by Pennsylvania DOT
[11]"Use of Fine Graded Asphalt Mixes Project 0-6615" Sponsored by Texas DOT
[12]"Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements" Sponsored by Texas DOT
[13]"Analysis of Full-Depth Reclamation Trial Sections in Virginia" Sponsored by Virginia DOT
[14]"Investigation of the use of tear-off shingles in asphalt concrete" Sponsored by Virginia DOT
[15]"Recycling of Salt-Contaminated Stormwater Runoff for Brine Production" Sponsored by Virginia DOT
[16]"An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options" Sponsored by Virginia DOT
[17]"Geotechnical Data Management at the Virginia Department of Transportation" Sponsored by Virginia DOT
[18]"Performance of Virginia's Warm-Mix Asphalt Trials" Sponsored by Virginia DOT
[19]"Field Comparison of the Installation and Cost of Placement of Epoxy-Coated and MMFX 2 Steel Deck Reinforcement: Establishing a Baseline for Future Deck Monitoring" Sponsored by Virginia DOT
[20]"Accelerated Loading Evaluation of Subbase Layers in Pavement Performance" Sponsored by Louisiana DOTD
[21]"Development of Procedures for Determining the Axial Capacity of Drilled Shafts Founded in Illinois Shale" by Illinois DOT

5.1.3 Life Cycle Cost Analysis (LCCA) for Determining the Value of Research on Reduced Construction, Operations and Maintenance Costs

Life Cycle Cost Analysis evaluates reduced construction, operations, and maintenance cost associated with all the stages of a transportation system's life. For example, the project sponsored by the Virginia DOT entitled "Analysis of Full-Depth Reclamation Trial Sections in Virginia," compared a traditional pavement rehabilitation program (based on partial- and full-depth mill and replacement) with one that incorporated full-depth reclamation (FDR) using a LCCA approach. If the present costs of the traditional pavement rehabilitation approach are multiplied by the total area of the potential FDR sites, the cost over a 50-year life cycle is calculated as \$60.95 million (\$42.80/yd^2). If the present costs of the pavement rehabilitation approach incorporating FDR are multiplied by the total area of the potential FDR sites, the cost over a 50-year life cycle is calculated as \$51.00 million (\$35.81/yd^2). It is feasible that VDOT could save approximately \$10 million (approximately \$40,000/lane-mile) over a 50-year period by implementing an FDR program for those flexible pavements identified on the primary network. If these savings are annualized, the potential savings are approximately \$463,000/year (approximately \$1,850/lane-mile/year).

5.2 Measures for Determining the Value of Research in Reduced Construction, Operations and Maintenance Costs

Various measures have been used by different transportation agencies for determining the value of research on reduced construction, operations and maintenance costs. These measures can be classified into three major categories that address different aspects of transportation research on reduced construction, operations, and maintenance costs: "Construction Costs," "Operations Costs," and "Maintenance Costs" as shown in Figure 5.14.

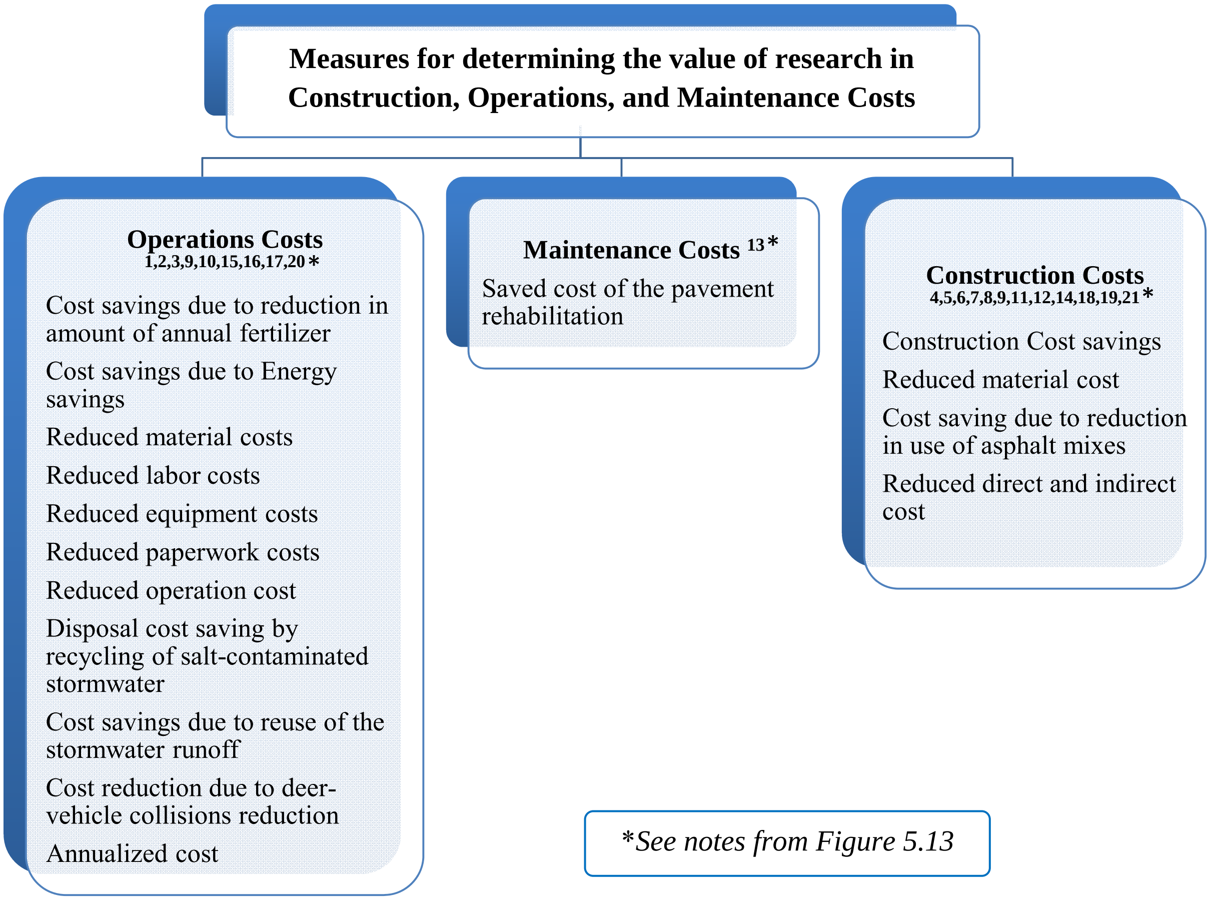

Figure 5.14 Measures for determining the value of research on reduced construction, operations, and maintenance costs

5.3 Data Sources for Determining the Value of Research on Reduced Construction, Operations and Maintenance Costs

Various data sources have been used to evaluate reduced construction, operations and maintenance costs in different research projects. The identified data sources for determining the value of research on reduced construction, operations and maintenance costs are presented in Figure 5.15. These data sources can be classified into three major categories help quantify the benefits of research in different aspects of transportation research on reduced construction, operations, and maintenance costs: "Construction Costs," "Operations Costs," and "Maintenance Costs."

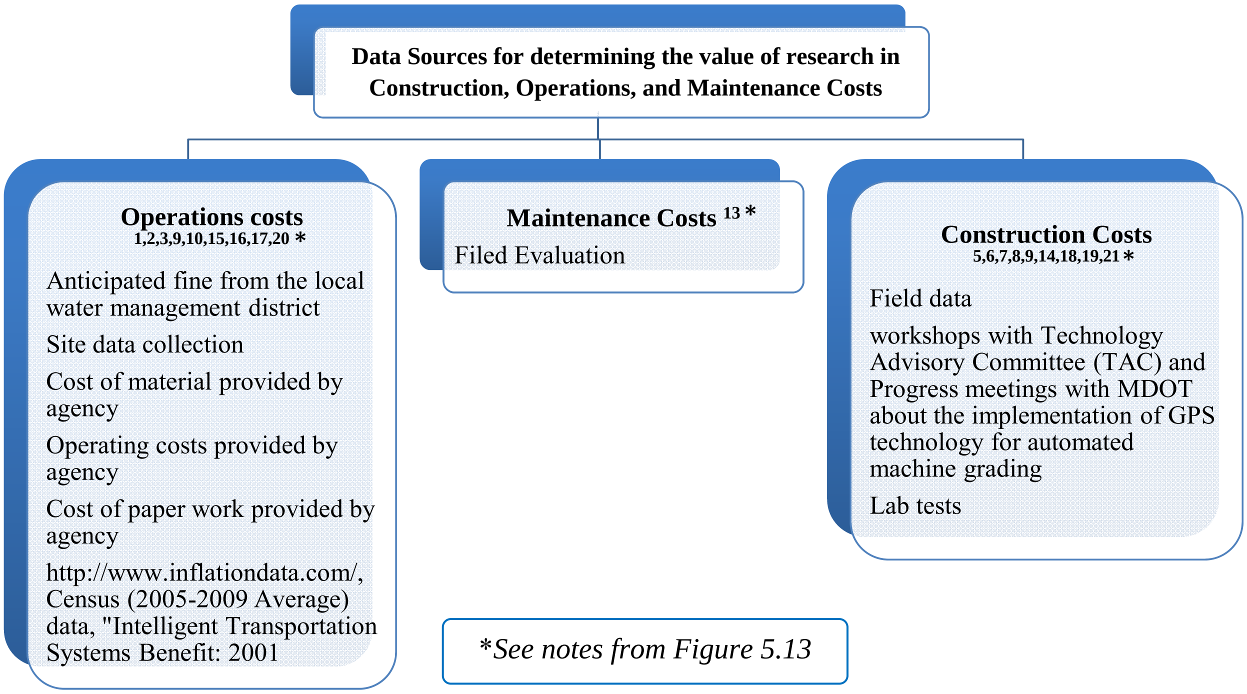

Figure 5.15 Data Sources for determining the value of research on reduced construction, operations, and maintenance costs

6. Management and Policy

6.1 Methods for Determining the Value of Research on Management and Policy

Only one project was found that determined the value of research on Management and Policy. This research used benefit analysis for determining the value of research. Figure 5.16 shows the method used for determining the value of research on Management and Policy in conjunction with the research project that has utilized this method.

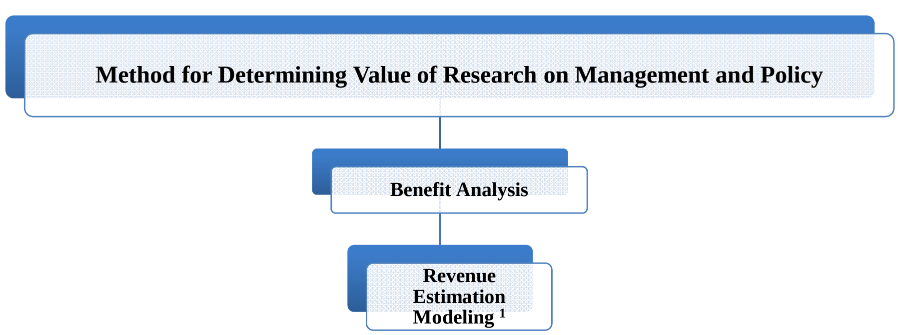

Figure 5.16 Method used for determining the value of research on Management and Policy

[1]"Assessment of the Impact of Future External Factors on Road Revenues" sponsored by Georgia DOT

6.1.1 Benefit Analysis for Determining the Value of Research on Management and Policy

Benefit analysis is a systematic approach for calculating the value of research on Management and Policy. Benefit analysis determines the improvement in the areas related to Management and Policy. Benefit analysis can be conducted using the approach shown in Figure 5.16: Revenue Estimation Modeling. This method for benefit analysis was used by one transportation agency to estimate the Management and Policy impact of a high value research project identified in our survey.

Revenue Estimation Modeling: refers to modeling that enables objective analysis of Management and Policy based on historical data. For example, in the research project, entitled "Assessment of the Impact of Future External Factors on Road Revenues," a revenue forecasting model was developed to evaluate the implications of changes in several factors that have been shown to impact overall levels of transportation revenue. The model was developed as a "revenue estimation toolbox" to quickly evaluate how different scenarios could influence future fuel tax revenue in Georgia. For example, this model was used to evaluate the reduction in the Department revenues from electric and hybrid vehicles entering the fleet. The analysis showed that the reduced motor fuel tax revenues due to electric and hybrid vehicles entering the fleet would be in tens of millions of dollars annually in the future.

6.2 Measures for Determining the Value of Research on Management and Policy

Revenue Levels was the measure used by the identified project for determining the value of research on management and policy. The revenue refers to total fuel tax revenue. Total fuel tax revenue is the total of the excise tax revenue and the sales tax revenue.

6.3 Data Sources for Determining the Value of Research on Management and Policy

Historical and forecasted values for about oil productions, fuel efficiency, clean energy, public transit, and taxes were the data sources used by the identified project for determining the value of research on management and policy.

7. Customer Satisfaction

7.1 Methods for Determining the Value of Research on Costumer Satisfaction

The identified methods for determining the value of research on Customer Satisfaction can be classified into two major categories: benefit analysis and benefit (dollar)/Cost (Dollar) analysis. These methods were identified from the detailed analysis of several research projects on Customer Satisfaction. Figure 5.17 shows the classification of methods used for determining the value of research on customer satisfaction in conjunction with research projects that have utilized these methods.

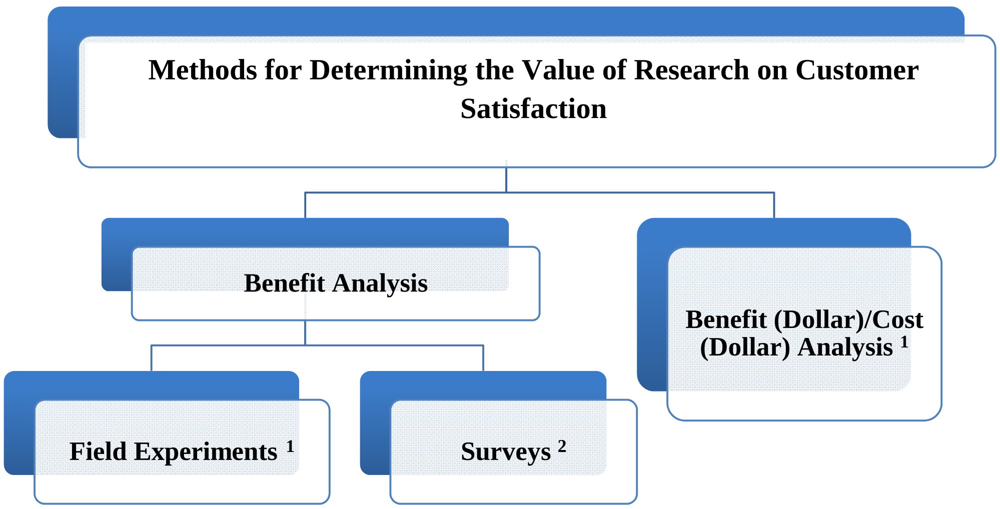

Figure 5.17 Classification of the methods for determining the value of research on Customer Satisfaction

[1]"An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" sponsored by Alabama DOT
[2]"Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document" sponsored by Missouri Department of Transportation

7.1.1 Benefit Analysis for Determining the Value of Research on Customer Satisfaction

Benefit analysis is a systematic approach for calculating improvements in customer satisfaction. Benefit analysis can be conducted using one of the following two approaches as shown in Figure 5.17: field experiments and surveys. These methods for benefit analysis were used by different transportation agencies to estimate the improvement in customer satisfaction in high value research projects identified in our surveys.

Field experiments: refers to experiments that examine the impact of a research project on customer satisfaction in the real world. For instance, the research project sponsored by the Alabama DOT, entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol," used field data to evaluate services provided for customers. The program provided 17,090 assists from July 1, 2004 through June 30, 2005. This amount is equivalent to an average of approximately 66 assists per weekday.

Surveys: Methods that are used to collect information from a random sample of a certain population. For example, in the research project entitled "Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document" sponsored by the Missouri DOT, survey was used to collect public perception about the project. The public perceptions were collected from general public, pedestrians, bikers, and drivers of larger vehicles, such as truck drivers. The survey results showed that more than 80% of respondents expressed that traffic flow had improved and traffic delay had decreased. 87% of respondents expressed that a crash was more likely to occur within a standard diamond when compared to a DDI. About 80% of respondents expressed that larger vehicles and pedestrian/bike movements through the DDI were better or similar to a standard diamond interchange. More than 90% of respondents expressed good understanding on how the interchange operated with the current design of islands, signing, signals, and pavement markings.

7.1.2 Benefit (Dollar)/Cost (Dollar) Analysis for Determining the Value of Research on Customer Satisfaction

Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates the benefits and the costs of customer satisfaction in terms of dollar values. For instance, the research project, entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" sponsored by the Alabama DOT studied the benefits and expected costs of the Alabama Service and Assistance Patrol. Estimation from the literature (GDOT 2006; Hawkins 1993) was used for the value of customer service per assist. Based on these studies, a range of values from $30 to $60 per assist was used, with the midpoint of $45 assumed to be the most likely value. When applied to 17,090 assists recorded by the Alabama Service and Assistance Patrol (A.S.A.P.) during the study year, the low-end estimate for the economic value of customer service benefits became $512,700, the high-end estimate was $1,025,400, and the most likely value was $769,050. Assistance rendered and program costs were provided by "Third Division office of the Alabama Department of Transportation." The recorded cost of providing these services was $592,243 from July 1, 2004 through June 30, 2005. The cost information, provided by the Third Division office of ALDOT, includes (a) capital costs, such as new equipment; and (b) operations and maintenance costs, such as personnel salaries and associated benefits.

7.2 Measures for Determining the Value of Research on Customer Satisfaction

Various measures have been used by different transportation agencies for determining the value of research on customer satisfaction. These measures can be classified into two major categories: "Customer Satisfaction Metrics" and "Cost Savings" as shown in Figure 5.18. Two metrics to measure the value of research on customer satisfaction were identified: number of services provide to motorists and enhanced public perceptions. Enhanced public perception can be represented by the increase in the percentage of population expressed that they are satisfied with the provided transportation system.

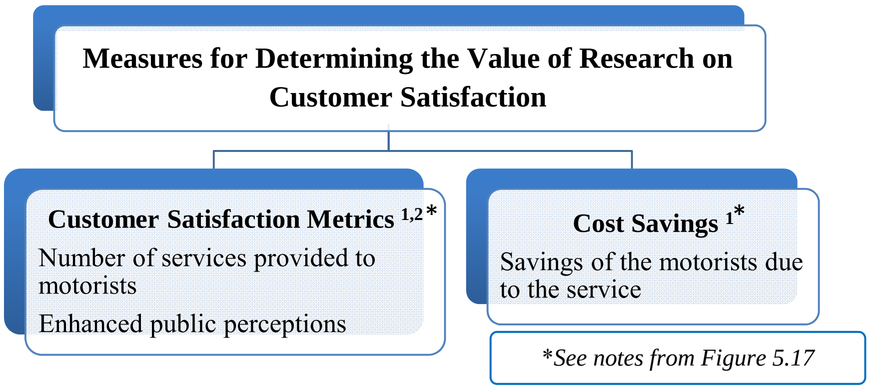

Figure 5.18 Measures for determining the value of research on Customer Satisfaction

7.3 Data Sources for Determining the Value of Research on Customer Satisfaction

Various data sources have been used to evaluate the benefits of customer satisfaction in different research projects. The identified data sources for determining the value of research on customer satisfaction are presented in Figure 5.19. These data sources can be classified into two major categories: "Customer Satisfaction Metrics" and "Cost Savings."

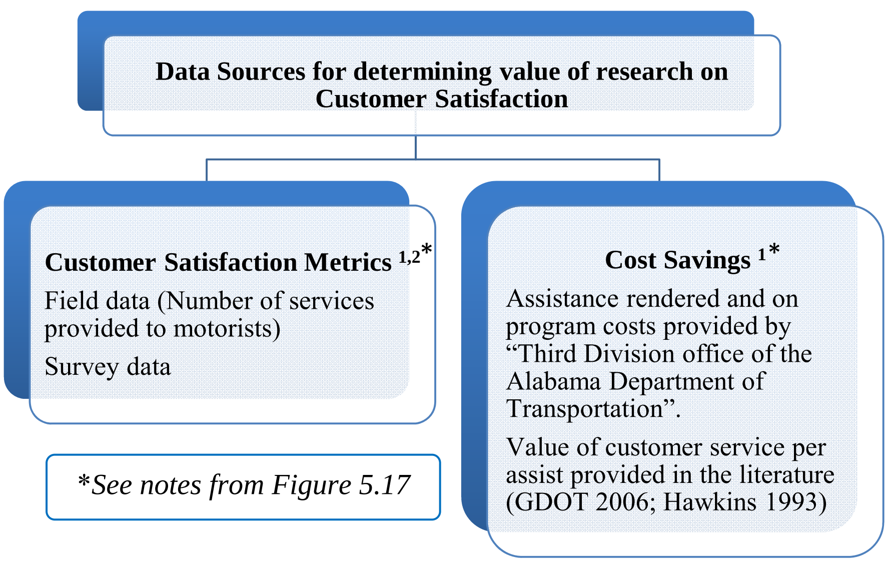

Figure 5.19 Data Sources for determining the value of research on Customer Satisfaction

8. System Reliability

8.1 Methods for Determining the Value of Research on System Reliability

Only one project was found that determined the value of research on System Reliability. This research used benefit analysis for determining the value of research. Figure 5.20 shows the assumption-based estimation method used for determining the value of research on System Reliability in conjunction with the research project that has utilized this method.

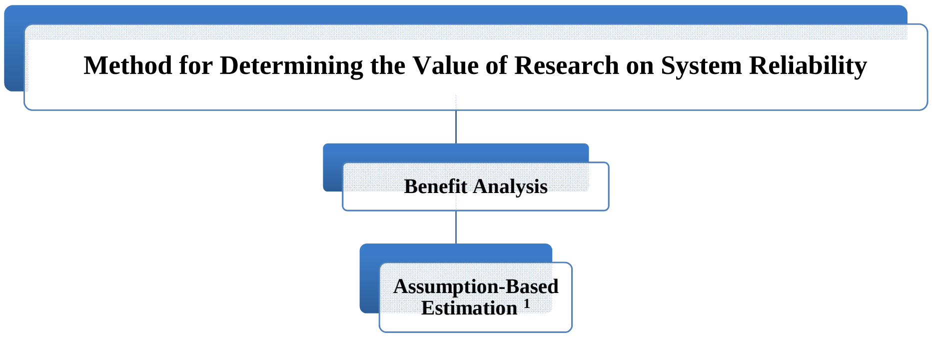

Figure 5.20 Method Used for determining the value of research on System Reliability

[1]"A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit" sponsored by Connecticut Department of Transportation

8.1.1 Benefit Analysis for Determining the Value of Research on System Reliability

Benefit analysis is a systematic approach for calculating the value of research on System Reliability. Benefit analysis determines the improvement in the reliability of transportation systems. Benefit analysis can be conducted using the approach as shown in Figure 5.20: assumption-based estimation. This method for benefit analysis was used by one transportation agency to estimate the system reliability impact of a high value research project identified in our survey.

Assumption-based estimation: refers to the calculation of benefits through assumption-based estimations for key reliability improvement features. The sources of assumptions can be experience, engineering judgment, and/or the literature. For example, in a project sponsored by the Connecticut Department of Transportation, entitled "A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit," reliability of buses (after the project is implemented) was drawn from the literature and used to estimate reliability benefits. In this project, the authors used the report by Lowell (2000B) expressing that Compressed Natural Gas (CNG) buses are about 50 to 75% as reliable as comparable diesel buses in revenue service. This report also indicates that an average mean distance between failures (MDBF) of about 1,500 miles as compared with 2,000 miles for diesel buses.

8.2 Measures for Determining the Value of Research on System Reliability

Two measures have been used by the identified project for determining the value of research on System Reliability as shown in Figure 5.21: (1) comparative reliability in percentage; and (2) average mean distance between failures. For example, Lowell (2000B) uses the first measure and expresses that Compressed Natural Gas (CNG) buses are about 50 to 75% as reliable as comparable diesel buses in revenue service. This report also uses the second measure and indicates that an average mean distance between failures (MDBF) of about 1,500 miles as compared with 2,000 miles for diesel buses.

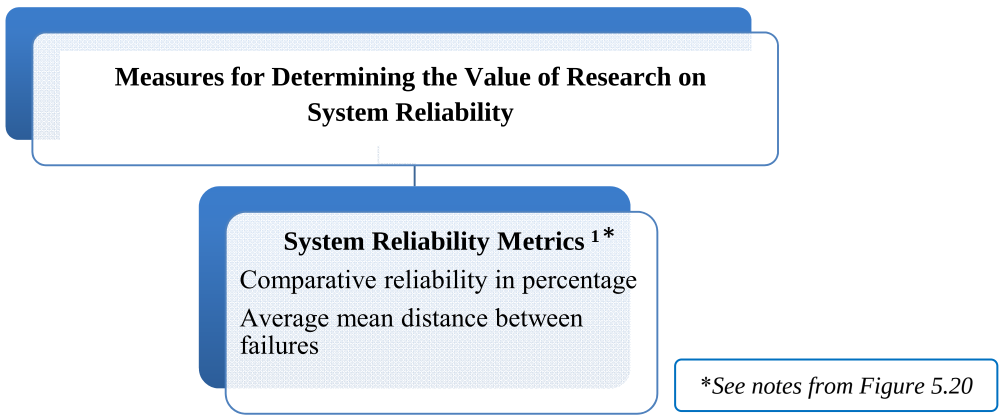

Figure 5.21 Measures for determining the value of research on System Reliability

8.3 Data Sources for Determining the Value of Research on System Reliability

Data taken from the reliability literature have been used to evaluate system reliability in the research project. The identified data sources for determining the value of research on system reliability are presented in Figure 5.22.

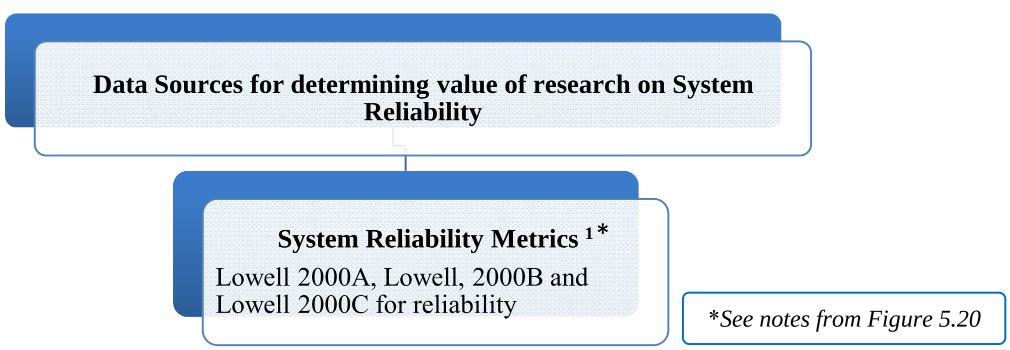

Figure 5.22 Data Sources for determining the value of research on System Reliability

9. Expedited Project Delivery

No high value transportation project that determined the value of research on Expedited Project Delivery was found in this survey. There is a pressing need to develop proper methods for determining the value of research in this area. Most recently several State DOTs have sponsored several research projects in this area considering the emphasis by the Federal Highway Administration on expedited project delivery as clearly outlined in the Moving Ahead for Progress in the 21st Century (MAP-21) .

10. Engineering Design Improvement

10.1 Methods for Determining the Value of Research on Engineering Design Improvement

The identified methods for determining the value of research on Engineering Design Improvement can be classified into two major categories: benefit analysis and benefit (dollar) analysis. These methods were identified from the detailed analysis of several research projects on engineering design improvement. Figure 5.23 shows the classification of methods used for determining the value of research on engineering design improvement in conjunction with research projects that have utilized these methods.

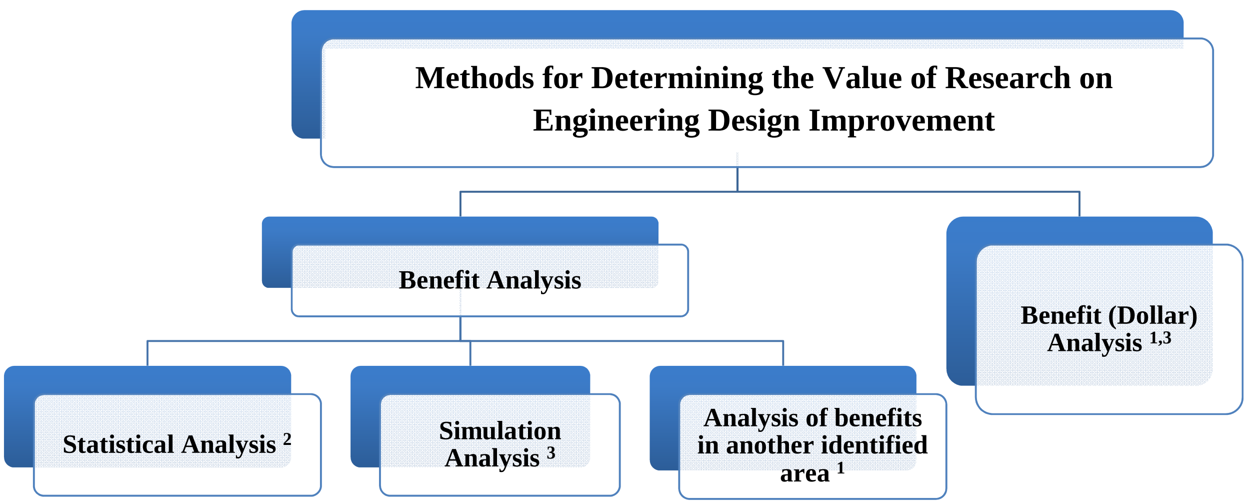

Figure 5.23 Classification of the methods for determining the value of research on Engineering Design Improvement

Notes:

[1]"Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)" by Georgia DOT

[2]"Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts" sponsored by Louisiana DOTD

[3]"Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements" sponsored by Texas DOT

10.1.1 Benefit Analysis for Determining the Value of Research on Engineering Design Improvement

Benefit analysis is a systematic approach for calculating the value of research on engineering design improvement. Research projects regarding engineering design improvement aim to improve design-related features of transportation systems. Benefit analysis determines the improvement in one or several design-related features and uses this improvement as the basis to determine the value of research on engineering design improvement. Benefit analysis can be conducted using one of the following three approaches, as shown in Figure 5.23: statistical analysis, simulation analysis, and analysis of benefits in another identified area. These methods for benefit analysis were used by different transportation agencies to estimate the engineering design improvement impact of high value research projects identified in our surveys:

Statistical analysis: refers to methods, such as regression analysis, that enables objective analysis of increased life cycle based on historical data. For example, the research project entitled "Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts" used statistical reliability analyses to calibrate the resistance factors for different design methods of axially loaded driven piles and drilled shafts needed in the LRFD design methodology. Researchers collected and evaluated drift shaft tests and used the statistical reliability analyses to calibrate the resistance factors of the different design methods. The results of this research showed that that local resistance factors were about 10 percent higher than those recommended by AASHTO.

Simulation analysis: is used to replicate the operation of a transportation network or a transportation system over time, in order to calculate benefits of engineering design improvement. Simulation requires developing proper models that represent key characteristics and behavior, including design characteristics, of a transportation system. For example, the research project entitled "Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements" developed a process that integrated the upgraded overlay tester into TxDOT's current mixture design system and developed a Hot Mix Asphalt (HMA) overlay thickness design methodology. This research project used simulation to test high-performance mixes, optimal thicknesses, particularly in the area of jointed flexible concrete pavements where joints must be repaired prior to placing any overlay. Results showed that it is possible to produce as minimum 5 percent reduction on the use of asphalt mixes per year due to the improved performance of the overlays.

Analysis of benefits in another identified area: Examining the identified examples in the area of engineering design improvement shows that the value of research on this area can be represented in the other areas, such as safety. For example, the research project entitled "Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)" provided safety benefit by reducing daily deer movements in response to fencing. The team evaluated the efficacy of several fencing designs for restricting movements of captive deer. The researchers found that woven-wire fences being taller than 2.1-m and 1.2-m woven-wire fences with a top-mounted outrigger were most effective. They also found that daily deer movements in response to fencing were reduced by 98% and 90% for the 2.4-m and outrigger designs, respectively.

10.1.2 Benefit (Dollar) Analysis for Determining the Value of Research on Engineering Design Improvement

Benefit (Dollar) analysis goes beyond benefit analysis by transferring the value of research on engineering design improvement in dollar values. For example, the research project entitled "[Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)]" found that the overall cost of the outrigger design installation was 20% less than the standard 2.4 woven-wire design installation ($3,200/mile).

10.2 Measures for Determining the Value of Research on Engineering Design Improvement

Various measures have been used by different transportation agencies for determining the value of research on engineering design improvement. These measures can be classified into two major categories: "Design-Specific Metrics" and "Cost Savings" as shown in Figure 5.24. Design-specific metrics refer to measures that are used to represented improvement in one of the design parameters. For example, resistance factor (side, tip, and total resistance factors) under a target reliability index is a design-specific metric.

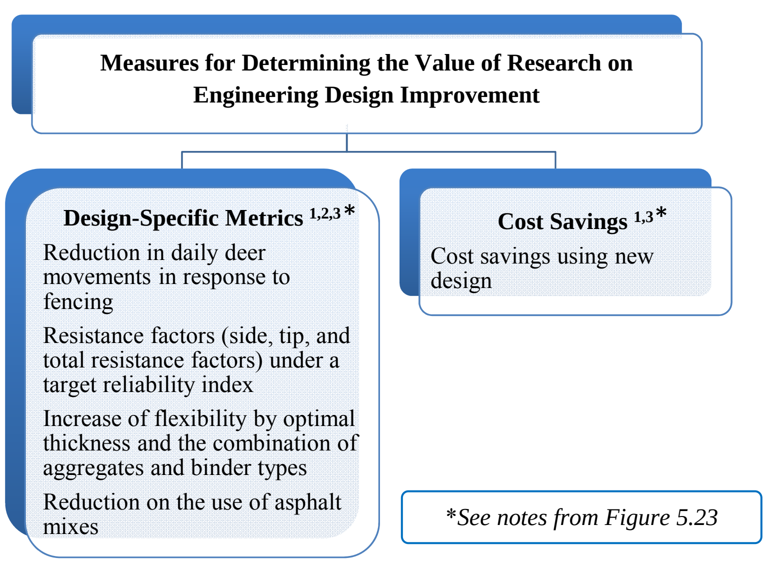

Figure 5.24 Measures for determining the value of research on Engineering Design Improvement

10.3 Data Sources for Determining the Value of Research on Engineering Design Improvement

Various data sources have been used to evaluate benefits of engineering design improvement in different research projects. The identified data sources for determining the value of research on engineering design improvement are presented in Figure 5.25. These data sources can be classified into two major categories: "Design-Specific Metrics" and "Cost Savings."

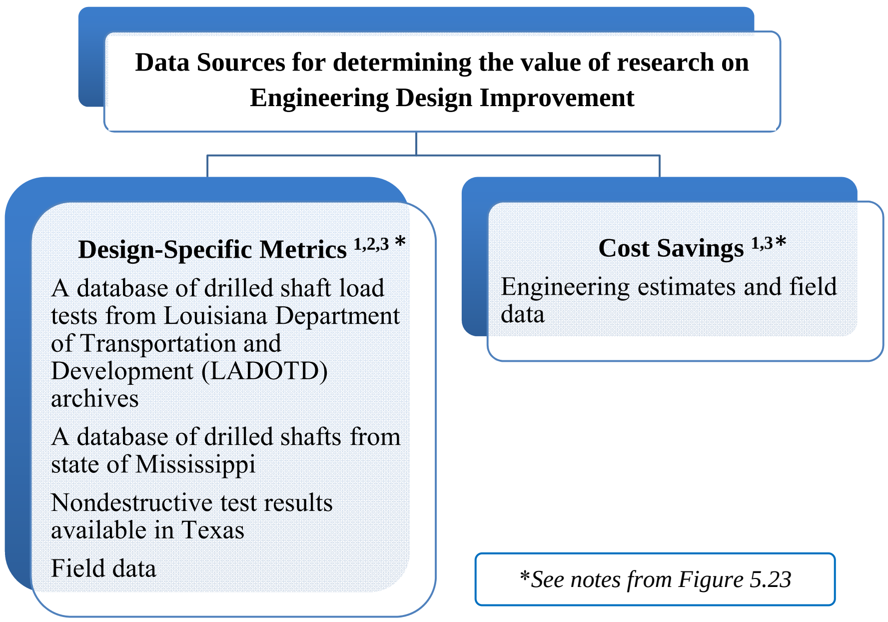

Figure 5.25 Data Sources for determining the value of research on Engineering Design Improvement

11. Increased Service Life

11.1 Methods for Determining the Value of Research on Increased Service Life

The identified methods for determining the value of research on Increased Service Life can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and Life Cycle Cost Analysis (LCCA). These methods were identified from the detailed analysis of several research projects on increased service life. Figure 5.26 shows the classification of methods used for determining the value of research on increased service life in conjunction with research projects that have utilized these methods.

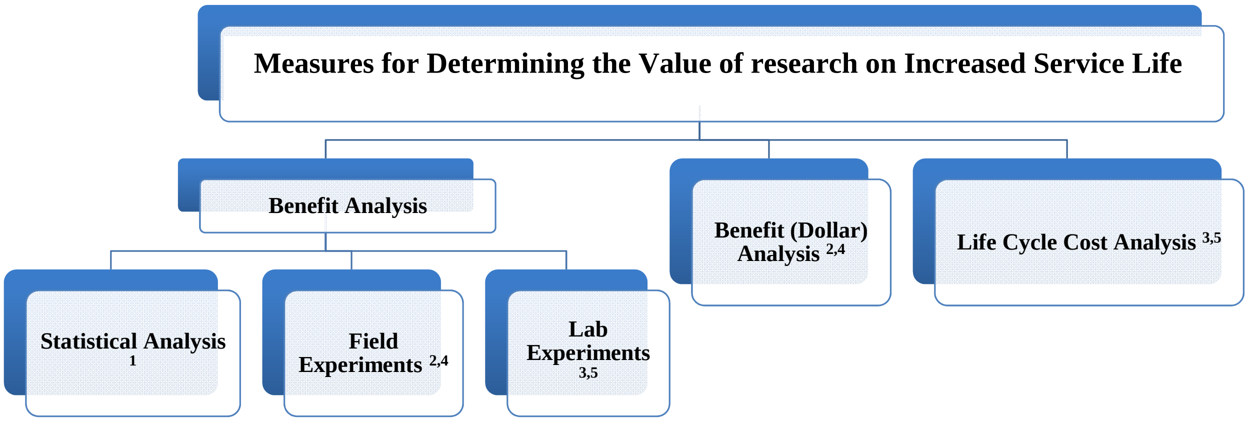

Figure 5.26 Classification of the methods for determining the value of research on Increased Service Life

Notes:

[1]"Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule" sponsored by Missouri Department of Transportation
[2]"Cost Effective Prevention of Reflective Cracking of Composite Pavement" sponsored by Louisiana DOTD
[3]"Accelerated Loading Evaluation of Subbase Layers in Pavement Performance" sponsored by Louisiana DOTD
[4]"Examination of an implemented asphalt permeability specification" sponsored by Virginia DOT
[5]"Analysis of Full-Depth Reclamation Trial Sections in Virginia" sponsored by Virginia Department of Transportation

11.1.1 Benefit Analysis for Determining the Value of Research on Increased Service Life

Benefit analysis is a systematic approach for calculating increase in service life. Benefit analysis can be conducted using one of the following three approaches as shown in Figure 5.26: statistical analysis, field experiments and lab experiments. These methods for benefit analysis were used by different transportation agencies to estimate the increase in service life in high value research projects identified in our surveys.

Statistical analysis: refers to methods, such as regression analysis, that enables objective analysis of increased life cycle based on historical data. For example, in the research project entitled "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule," rates of degradation were statistically analyzed using Analysis of Variance (ANOVA). Results of this analysis showed that LEDs have longer life expectancies.

Field experiments: refers to experiments that examine the impact of research on increased service life in the real world. For example in the project sponsored by Louisiana DOTD, entitled "Cost Effective Prevention of Reflective Cracking of Composite Pavement," field experiments were used to evaluate and compare different reflective cracking control treatments by evaluating the performance, constructability, and cost-effectiveness of pavements built with these treatments across the state. In this study, the performance of 50 different sites that were constructed with various treatments evaluated for a period ranging from 4 to 18 years. The results of this study indicated that among various treatments that were analyzed, saw and seal, and chip seal as a crack relief interlayer showed the most promising results in terms of performance and economic worthiness. The result of this study was based on the direct comparisons of the predicted service lives of treated sections with those of untreated sections. The majority of the sites showed a positive improvement due to the use of saw and seal (40 percent of the sections showed an improvement from one to three years and 47 percent of the evaluated sections showed an improvement from 4 to 12 years). The average level of improvement to the pavement service life due to the use of saw and seal was four years. The majority of the sites showed a positive improvement due to the use of chip seal (25 percent of the sections showed an improvement from one to three years and 33 percent of the evaluated sections showed an improvement from 4 to 10 years. The average level of improvement to the pavement service life was due to the use of chip seal was two years).

Lab experiments: is used to test service life impacts of transportation research project under controlled conditions. For example, in the research project sponsored by the Louisiana DOTD entitled "Accelerated Loading Evaluation of Subbase Layers in Pavement Performance," lab experiments were used to evaluate service life of subbase layers. The research results showed that clays with lime and silts with cement would create stronger foundations for pavement structure as compared to the raw natural soil. The stronger foundations eliminate the need for reconstruction of bases and pavement and result in longer service life.

11.1.2 Benefit (Dollar) Analysis for Determining the Value of Research on Increase Service Life

Benefit (Dollar) analysis goes beyond benefit analysis by transferring the value of research on increased service life in dollar values. For example, in the research project entitled "Cost Effective Prevention of Reflective Cracking of Composite Pavement", benefit (Dollar) analysis revealed that saw and seal was cost-effective in comparison with regular HMA overlays in 80 percent of sections under study. This analysis also showed that chip seal was cost-effective in comparison with regular HMA overlays in 75 percent of sections under study. Cost data for the high strain reflective crack relief interlayer and HMA overlays were obtained from actual bid items for each project.

11.1.3 Life Cycle Cost Analysis (LCCA) for Determining the Value of Research on Increased Service Life

Life Cycle Cost Analysis evaluates economic impact of increased service life on life cycle of a transportation system. For example, the project sponsored by the Louisiana DOTD entitled "Accelerated Loading Evaluation of Subbase Layers in Pavement Performance," used LCCA to determine the value of research. The research objective of this project was to explore and develop a methodology to build reliable subgrade layers stabilized with cementitious agents at various field moisture contents. The research results showed that clays with lime and silts with cement would create stronger foundations for pavement structure as compared to the raw natural soil. LCCA analysis showed that subbase in lieu of a lime-treated working table layer would create 37 percent annualized cost savings for low-volume and 31 percent cost savings for high volume pavement structures in Louisiana using a 12-in. cement stabilized soil.

11.2 Measures for Determining the Value of Research on Increased Service Life

Various measures have been used by different transportation agencies for determining the value of research on increased service life. These measures can be classified into two major categories: "Service Life" and "Cost Savings" as shown in Figure 5.27. "Service Life" measures refer to the expected life of a transportation system before it is out of service or before major maintenance is required. "Cost Savings" measures express the dollar value of the increase in "Service Life."

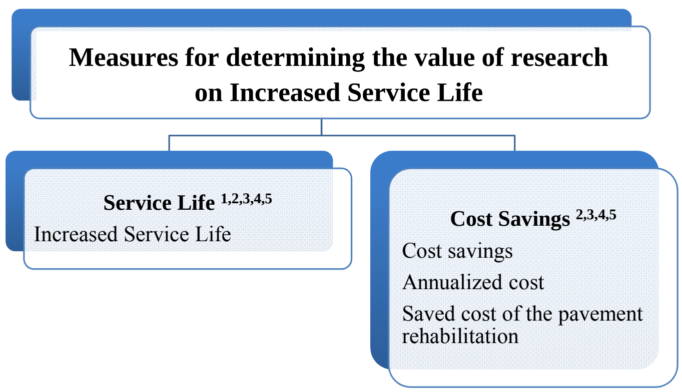

Figure 5.27 Measures for determining the value of research on Increased Service Life

11.3 Data Sources for Determining the Value of Research on Increased Service Life

Various data sources have been used to evaluate benefits of increased service life in different research projects. The identified data sources for determining the value of research on increased service life are presented in Figure 5.28. These data sources can be classified into two major categories: "Service Life" and "Cost Savings."

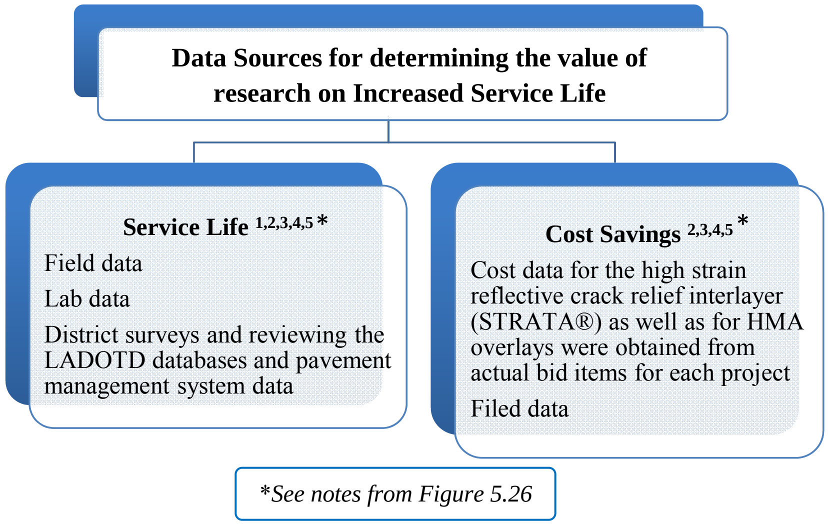

Figure 5.28 Data Sources for determining the value of research on Increased Service Life

12. Reduced User Cost

Examining all the identified examples in the area of Reduced User Cost shows that the value of research on Reduced User Cost is represented in the other areas, such as Safety. Figure 5.29 shows how various transportation agencies demonstrated the value of their research on Reduced User Cost through identifying the impact of research in the other areas. Figure 5.29 shows benefit areas used for determining the value of research on reduced user cost in conjunction with research projects that have utilized various methods in these benefit areas.

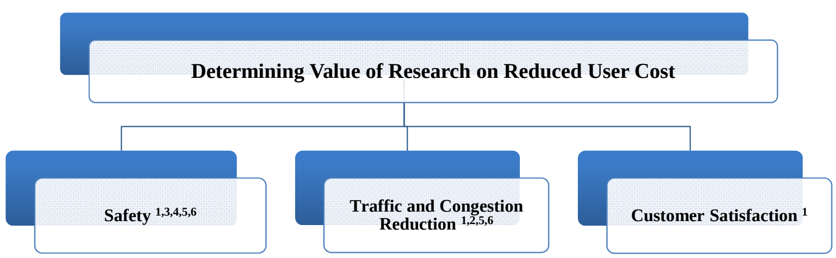

Figure 5.29 Benefit Areas related to the value of research on Reduced User Cost

Notes:
[1]"An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" sponsored by Alabama DOT
[2]"Mobile Work Zone Barrier" sponsored by California DOT
[3]"Rural Road Low Cost Safety Improvements" sponsored by Federal Highway Administration (FHWA)
[4]"Winter Operations Geographic Positioning Systems and Automatic Vehicle Location" sponsored by Iowa DOT
[5]"Placement of Detection Loops on High Speed Approaches to Traffic Signals" sponsored by North Carolina DOT
[6]"Freeway Ramp Management Strategies" sponsored by Pennsylvania DOT

In previous sections, we extensively described how transportation agencies demonstrated the value of these research projects. For example, in the research project entitled "Mobile Work Zone Barrier," it is estimated that the number of avoided lane closures equates to a potential annual savings of $115,464,000 in public user road costs, due to reduced travel delay.

13. Reduced Administrative Costs

13.1 Methods for Determining the Value of Research on Reduced Administrative Costs

Only one project was found that determined the value of research on Reduced Administrative Costs. This research used Benefit (Dollar) / Cost (Dollar) Analysis for determining the value of research. Figure 5.30 shows the method used for determining the value of research on reduced administrative costs in conjunction with the research project that has utilized this method.

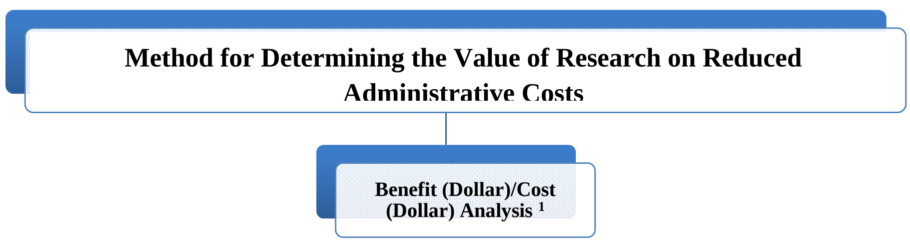

Figure 5.30 Method Used for determining the value of research on Reduced Administrative Costs

Note:
[1]"Winter Operations Geographic Positioning Systems and Automatic Vehicle Location" sponsored by Iowa DOT

13.1.1 Benefit (Dollar)/Cost (Dollar) Analysis for Determining The value of research on Reduced Administrative Costs

Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates the benefits and the costs of to reduced administrative costs in terms of dollar values. For instance, the research project entitled "Winter Operations Geographic Positioning Systems and Automatic Vehicle Location" sponsored by the Iowa DOT, studied the benefits and expected costs of an integrated Geographic Positioning Systems and Automatic Vehicle Location (GPS/AVL) system. The research project calculates dollar values of both reduction in administrative costs (realized through reduced paperwork) and system costs.

13.2 Measures for Determining the Value of Research on Reduced Administrative Costs

Reduced Paperwork is the measure used by the identified project for determining the value of research on reduced administrative costs.

13.3 Data Sources for Determining the Value of Research on Reduced Administrative Cost

An agency's total paperwork cost is the only data source used by the identified project for determining the value of research on reduced administrative costs.

14. Materials and Pavements

Examining all the identified examples in the area of Materials and Pavement shows that the value of research on Materials and Pavement are represented in the other areas, such as Reduced Construction, Operations, and Maintenance Costs, increase service life, and engineering design improvement. Figure 5.31 shows how various transportation agencies demonstrated the value of their research on Materials and Pavement through identifying the impact of research in the other areas. Figure 5.31 shows benefit areas used for determining value of materials and pavements research in conjunction with research projects that have utilized these methods.

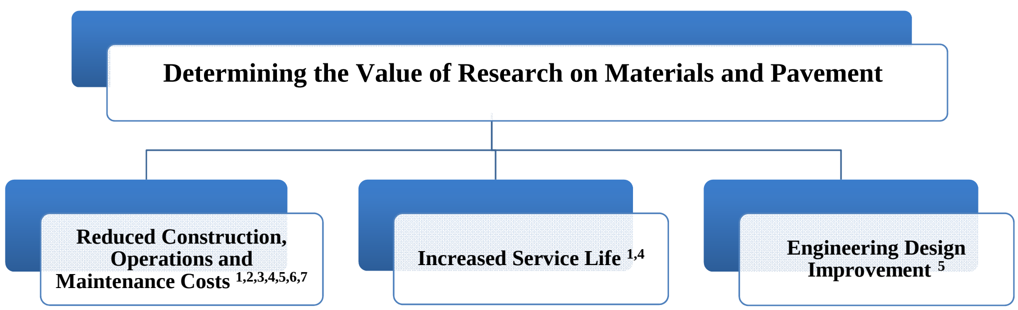

Figure 5.31 Benefit Areas related to the value of research on Materials and Pavement

Notes:
[1]"Evaluation of Ternary Cementitous Combinations" sponsored by Louisiana DOTD
[2]"Accelerated Loading Evaluation of Subbase Layers in Pavement Performance" sponsored by Louisiana DOTD
[3]"Mechanistic Flexible Pavement Overlay Design Program" sponsored by Louisiana DOTD
[4]"Cost Effective Prevention of Reflective Cracking of Composite Pavement" sponsored by Louisiana DOTD
[5]"Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements" sponsored by Texas DOT
[6]"Investigation of the use of tear-off shingles in asphalt concrete" sponsored by Virginia Department of Transportation
[7]"Performance of Virginia's Warm-Mix Asphalt Trials" sponsored by Virginia Department of Transportation
[8]"Examination of an implemented asphalt permeability specification" sponsored by Virginia DOT

In previous sections, the authors extensively described how transportation agencies demonstrated the value of these research projects. For example, in the research project, entitled "Evaluation of Ternary Cementitous Combinations" sponsored by Louisiana DOTD, the value of research on

Materials and Pavement was realized through reduction in construction, operations, and maintenance costs. In this research, it was shown that cement mixtures containing up to 70 percent fly ash and slag show concrete test results that are comparable to those obtained from control mixtures containing no supplemental cementitious materials. Cost-benefit analysis showed potential material cost savings around $25,000 per lane-mile when replacing 70 percent Portland cement with fly ash and slag.

15. Intelligent Transportation Systems

15.1 Methods for Determining the Value of Research on Intelligent Transportation Systems

Only one project was found that determined the value of research on Intelligent Transportation System. This research used analysis of dissemination of research output for determining the value of research. Figure 5.32 shows the method used for determining the value of research on Intelligent Transportation System in conjunction with the research project that has utilized this method.

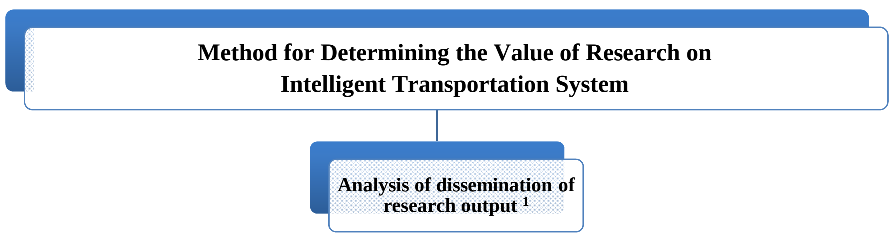

Figure 5.32 Method Used for determining the value of research on Intelligent Transportation system

Note:
[1]"Systems Engineering Guidebook" sponsored by Caltrans and FHWA

15.1.1 Analysis of dissemination of research output for Determining the Value of Research on Intelligent Transportation System

Analysis of dissemination of research outputs refers to the investigation of penetration of research outputs, such as guidelines, tools, and software pieces, in the research and practice communities. For example, in the project sponsored by Caltrans and FHWA, entitled "Systems Engineering Guidebook," the dissemination of the research output into the research and practice communities is measured. The statistics on acquisition during the first 2 years (2007 to 2009) of operation were used to attest to the usefulness of the System Engineering Guide Book (SEGB):

- "When introduced in January and February 2007, the SEGB document was downloaded 21,955 times and was ranked #2 of the top 20 Most Downloadable Files within FHWA in each month.

- From March 2007 to December 2008 (22 months), the ranking of the SEGB document downloads has consistently been around #4 in Most Downloadable Files. In December 2008, it was still ranked #4 of agency downloadable documents.
- There have been more than 141,072 SEGB document downloads during the 24 month period (three of the months, statistical data was unavailable).
- During the first two months of web access in 2007, the SEGB home page was listed as one of the 500 Most Popular Web Pages within FHWA.
- Popularity has grown—in each of the last 6 months of 2008, as many as three different web pages of the SEGB site appeared in the listing of the 500 Most Popular Web Pages.
- The SEGB web pages Process View,' 'Glossary,' and 'Design Specification Template' have been frequently accessed.
- For February 2012, two of the SEGB pages were number 205 and 322 on FHWA's top 500 hits pages for all FHWA Web sites."

15.2 Measures for Determining the Value of Research on Intelligent Transportation System

Four measures have been used by the identified project for determining the dissemination of the research output. These measures are shown in Figure 5.33.

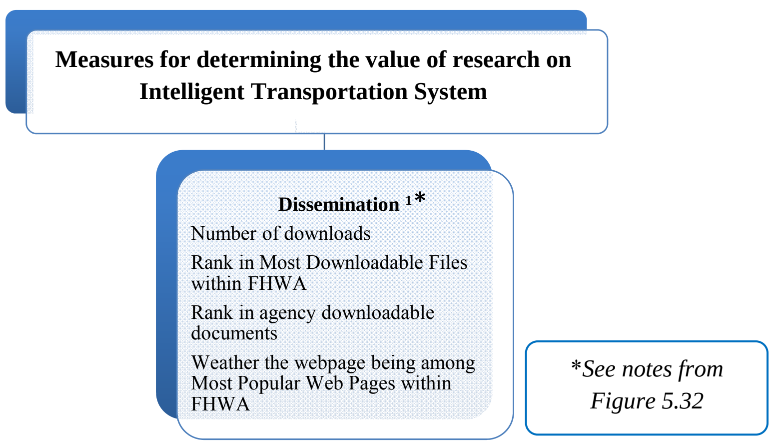

Figure 5.33 Measures for determining the value of research on Intelligent Transportation System

15.3 Data Sources for Determining the Value of Research on Intelligent Transportation System

A few data sources have been used to evaluate dissemination of the output of the identified research project. These data sources are presented in Figure 5.34.

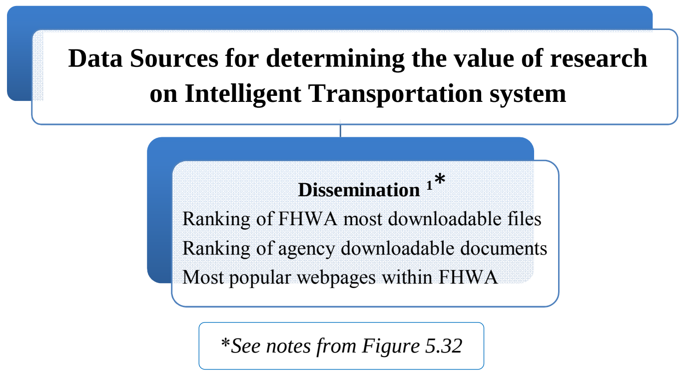

Figure 5.34 Data Sources for determining the value of research on Intelligent Transportation System

CHAPTER SIX
CONCLUSIONS

The literature review helped identify the areas of benefits of transportation research projects. Conducting surveys helped capture the state of knowledge and practice in determining the value of research in departments of transportation. It also helped collect best examples for determining the value of research. Content analysis of the collected best examples helped find methods, measures and data sources used to determine the value of transportation research in several areas of benefit.

6.1 Areas of benefits

Based on the literature review, it was found that the impact of transportation research projects has been studied in the following areas:

- Safety
- Environmental sustainability
- Improved Productivity and Work Efficiency
- Traffic and Congestion Reduction
- Reduced Construction, Operations and Maintenance Costs
- Management and Policy
- Customer Satisfaction
- System Reliability
- Expedited Project Delivery
- Engineering Design Improvement
- Increased Service Life
- Reduced User Cost
- Reduced Administrative Costs
- Materials and Pavements
- Intelligent Transportation Systems

6.2 Summary of findings of the first survey

The first survey resulted in several findings. These finding are:

- Several transportation agencies sponsored research projects to develop a systematic approach for assessment of the value of transportation research. Several research reports related to the topic of this study (assessing the value of research) were identified from responses to the first survey. These reports were collected and analyzed. The research reports sponsored by various transportation agencies are the following:

- Florida DOT (Two research reports)
  - Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (2003)
  - Valuing the Benefits of Transportation Research: A Matrix Approach (2002)
- Ohio DOT (Two research reports)
  - Evaluation of ODOT Research and Development Implementation Effectiveness (1988)
  - Benefit-Cost Analysis of Transportation Research Projects (1992)
- Kentucky DOT (One research report)
  - Research report: Value of research: SPR projects (2001)
- Utah DOT (One research report)
  - Measuring the benefits of transportation research in Utah
- Minnesota DOT (One research report)
  - Economic benefits from road research (2008)
- National Cooperative Highway Research Program (NCHRP)
  - Performance Measurement Tool Box and Reporting System for Research Programs and Projects, NCHRP Project 20-63
  - RPM
  - Communication matters: a guidebook published by National Cooperative Highway Research Program (NCHRP), Report 610, Available from Transportation Research Board (TRB) (2009)
- Transportation Research Board
  - Research Pays Off
- American Association of State Highway and Transportation Officials (AASHTO)
  - Research Impacts: Better - Cheaper – Faster

- It was found that most states have future/present plans to quantify the value of research projects.
- There is no formal guideline for assessing the benefits of research reports.
  - Although several methods are proposed for quantifying the benefits of research projects in the research reports collected in the first survey, there is not any formal guideline or formal method to evaluate the quantitative and/or qualitative benefits of research projects in State DOTs.
- The evaluation methodology should not be too long and too complex.
  - It should be easy to follow.
- Collection and distribution of good evaluation examples can be extremely helpful.
- Based on the survey results, flexibility is the key for designing any guideline to assess research benefits.
  - Several classifications of areas of research projects and the corresponding benefits
  - Several methods for assessing the value of research benefits
  - Several measures for assessing the value of research benefits

- Developing a training program for researchers and DOT personnel is vital.
- Communication of research benefits is important.
- Data scarcity for evaluation of research benefits is a significant challenge.
- AASHTO high value research projects and TRB "Research pays off" documents summarize valuable examples of State DOT's attempts towards quantifying research benefits.
- There are fewer attempts for quantifying benefits that are hard to put dollar values on.
- Based on the survey results, flexibility is the key for designing any guideline to assess research benefits.
  - Several classifications of areas of research projects and the corresponding benefits
  - Several methods for assessing the value of research benefits
  - Several measures for assessing the value of research benefits

6.3 Summary of Findings of the Second and Third Survey

The second and third surveys resulted in several findings. These finding are presented here.

6.3.1 Identified Methods to Determine the Value of Research

Several methods were identified for determining the value of research on different areas of benefit. These methods have been used by various transportation agencies to determine value of different research projects that have impacts on various benefit areas. Table 6.1 summarizes these methods along with areas of benefits for which these methods have been utilized to determine the value of research. Table 6.1 shows for what research projects each valuation method has been applied. It can be seen that benefit (dollar)/cost (dollar) analysis and benefit (dollar) analysis are the most widely used methods to determine the value of research across all benefit areas. Before and after study, assumption-based estimation, and benefit (dollar)/cost (dollar) analysis have most frequently used by transportation agencies to determine value of safety research. Field experiments, lab experiments, and benefit (dollar) analysis are most often used by transportation agencies to determine the value of research on environmental sustainability. Assumption-based estimation and benefit (dollar) analysis are most frequently used by transportation agencies to determine the value of research on improved productivity and work efficiency. Transportation agencies used one of benefit (dollar) analysis, benefit (dollar)/cost (dollar) analysis, and life cycle cost analysis to determine the value of research. In a few research areas (i.e., engineering design improvement, reduced user cost, and materials and pavement), the value of research was determined by showing the value of research on the other areas of benefit.

Table 6.1 Summary of the categories of the methods

Areas of Benefit	Benefit Analysis									Benefit (Dollar) Analysis	Benefit (Dollar) /Cost (Dollar) Analysis	Life Cycle Cost Analysis	Analysis of Dissemination of research output
	Before and After Study	Statistical Analysis	Simulation Analysis	Assumption-based Estimation	Field Exp.	Lab Exp.	Revenue Estimation Modeling	Surveys	Benefit in other areas				
Safety	7,10,24,25,41	10	5,10	1,3,27,28	8					3,5,41	1,11,27,28		
Environmental Sustainability	24		1	4	26,35,36	6,13,31, 35				1,4,6,13, 26,36			
Improved Productivity and Work Efficiency				3,15,23,37	14,20					3,15,20,23,37	11		
Traffic and Congestion Reduction	24,25		27,28,40		3					3	1,27,28		
Reduced Construction, O&M Costs										6,14,21,23,25,26,, 29,30,34, 35,36,37, 38,39,42	11,13,18, 28	16,33	
Management and Policy							9						
Customer Satisfaction					1			25			1		
System Reliability				4									
Expedited Project Delivery													
Engineering Design Imp.		12	30						8	8,30			

Increased Service Life		26			19,32	16,33				19,32		16,33	
Reduced User Cost									1,3,5,11. 27,28				
Reduced Administrative Cost											11		
Materials and Pavements									13,16,18, 19,30,32, 34,38				
ITS													2

[1] "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" by Alabama DOT

[2] "Systems Engineering Guidebook by DOT" by California DOT

[3] "Mobile Work Zone Barrier" by California DOT

[4] "A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit" by Connecticut DOT

[5] "Rural Road Low Cost Safety Improvements" by FHWA

[6] "Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions" by Florida DOT

[7] "Operational and Safety Impacts of Restriping Inside Lanes of Urbane multilane Curbed Roadways to 11 Feet or Less to Create Wider Outside Curb Lanes for Bicyclists" by Florida DOT

[8] "Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)" by Georgia DOT

[9] "Assessment of the Impact of Future External Factors on Road Revenues" by Georgia DOT

[10] "Improving Safety in High-Speed Work Zones: A Super 70 Study" by Indiana DOT

[11] "Winter Operations Geographic Positioning Systems and Automatic Vehicle Location" by Iowa DOT

[12] "Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts" by Louisiana DOTD

[13] "Evaluation of Ternary Cementitous Combinations" by Louisiana DOTD

[14] "Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction" by Louisiana DOTD

[15] "Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance" by Louisiana DOTD

[16] "Accelerated Loading Evaluation of Subbase Layers in Pavement Performance" by Louisiana DOTD

[17] "Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance" by Louisiana DOTD
[18] "Mechanistic Flexible Pavement Overlay Design Program" by Louisiana DOTD
[19] "Cost Effective Prevention of Reflective Cracking of Composite Pavement" by Louisiana DOTD
[20] "Implementation of Rolling Wheel Deflectometer (RWD) in PMS and Pavement Preservation" by Louisiana DOTD
[21] "A Sensor Network System for the Health Monitoring of the Parkview Bridge Deck" by Michigan DOT
[22] "Economic benefits resulting from road research performed at MnROAD" by Minnesota DOT
[23] "MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery" by Mississippi DOT
[24] "Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri" by Missouri DOT
[25] "Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document" by Missouri DOT
[26] "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule" by Missouri DOT
[27] "Placement of Detection Loops on High Speed Approaches to Traffic Signals" by North Carolina DOT
[28] "Freeway Ramp Management Strategies" by Pennsylvania DOT
[29] "Use of Fine Graded Asphalt Mixes Project 0-6615" by Texas DOT
[30] "Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements" by Texas DOT
[31] "Retrofitting Culverts and Fish Passage-Phase II" by Utah DOT
[32] "Examination of an implemented asphalt permeability specification" by Virginia DOT
[33] "Analysis of Full-Depth Reclamation Trial Sections in Virginia" by Virginia DOT
[34] "Investigation of the use of tear-off shingles in asphalt concrete" by Virginia DOT
[35] "Recycling of Salt-Contaminated Stormwater Runoff for Brine Production" by Virginia DOT
[36] "An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options" by Virginia DOT
[37] "Geotechnical Data Management at the Virginia Department of Transportation" by Virginia DOT
[38] "Performance of Virginia's Warm-Mix Asphalt Trials" by Virginia DOT
[39] "Field Comparison of the Installation and Cost of Placement of Epoxy-Coated and MMFX 2 Steel Deck Reinforcement: Establishing a Baseline for Future Deck Monitoring" by Virginia DOT
[40] "Bituminous Surface Treatment Protocol" by Washington DOT
[41] "Development and Application of Safety Performance Functions for Illinois" by Illinois DOT
[42] "Development of Procedures for Determining the Axial Capacity of Drilled Shafts Founded in Illinois Shale" by Illinois DOT

6.3.2 Identified Measures to Determine the Value of Research

Various measures were identified for determining the value of research on different areas of benefits. These measures were categorized for each area of benefit. For example, the identified safety measures were classified into three major categories that address different aspects of transportation safety: "crashes and injuries," "cost saving," and "others." After analyzing the identified categories of measures, it is concluded that the measure categories can be placed in one of the following groups:

- Measure categories specific to areas of benefits
    - For instance, "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" research project used the reduction in occurrence rate of secondary crashes to determine value of safety research.
- "Cost Savings" measures
    - For instance, "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" research project used dollar benefits of the reduction in occurrence rate of secondary crashes to determine value of safety research.
- "Others" measures
    - For instance, "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" research project used "motor vehicle shift to the outside through lane" to characterize the value of safety research.

Table 6.2 summarizes all the measures used for determining the value of research.

Table 6.2 summary of the measures

Areas of Benefit	Measures specific to the area of benefit	Cost saving measures	Others
Safety	Number of crashes saved Reduction in occurrence rate of secondary crashes Reduction in total crashes including: Injury crashes; Rear-end crashes; Angle crashes Percent reduction (A marginal 10 percent reduction) of crashes Reduction in crashes (fatal, with injury, and property damage only) Saving by avoiding cost of potential crashes (Assumed 5% saving) Reduction in number of crashes	Dollar benefits of reduction in occurrence rate of secondary crashes Dollar benefits of reduction in crashes	Reduction in time for set-up and breakdown of a lane closure Lateral separation between the motor vehicle and bicyclist Motor vehicle shift to the outside through lane Motor vehicle outside through lane usage Motor vehicle speeds before, during and after passing bicyclist Reduction in daily deer movements in response to fencing Number of stops reduction
Environmental Sustainability	Reduction in emission outputs (HC, CO, Nox) Reduction in the amount of Nitrogen getting out of turf CO2 emissions reduction	Dollar savings due to reduction in emission outputs (HC, CO, Nox) Reduction in anticipated fine due to amount of Nitrogen getting out of turf	Fish passages Amount of reuse of the stormwater runoff Deer-vehicle collisions reduction

	Reduction in emissions (carbon dioxide, carbon monoxide, oxides of nitrogen, unburned hydrocarbons and particular matter) Fuel consumption saving Energy savings due to use of LEDs	Cost savings due to CO_2 emissions reduction Disposal cost saving by recycling of salt-contaminated stormwater Cost savings due to reduction in deer-vehicle collisions Cost savings due to use of LEDs
Improved Productivity and Work Efficiency	Time of set-up and breakdown of a lane closure Reduction in percentage of lane closures Reduced installation time Time saving Productivity	Dollar benefits of reduction in percentage of lane closures Reduced material costs Reduced labor costs Reduced equipment costs Reduced paperwork Cost savings
Traffic and Congestion Reduction	Reduction in delay to the traveling public Reduction in percentage of lane closures Travel time reduction Reduce of navigation errors and light violation Reduction in intersection delay and number of stops Average annual traffic	Cost savings of the motorists due to the reduction in delay Dollar benefits for motorists due to reduced delay attributed to reduction in percentage of lane closure Dollar benefits attributed to reduction in intersection delay and number of stops Total dollar value of time savings attributed to reduction in total delay
Reduced Construction, O&M Costs		Cost savings due to reduction in amount of annual fertilizer Cost savings due to Energy savings Reduced material costs Reduced labor costs Reduced equipment costs Reduced paperwork costs Reduced operation cost Disposal cost saving by recycling of salt-contaminated stormwater Cost savings due to reuse of the stormwater runoff Cost reduction due to deer-vehicle collisions reduction Annualized cost Saved cost of the pavement rehabilitation Construction Cost savings Reduced material cost Cost saving due to reduction in use of asphalt mixes Reduced direct and indirect cost
Management and Policy	Revenue level	
Customer Satisfaction	Number of services provided to motorists Enhanced public perceptions	Savings of the motorists due to the service
System Reliability	Comparative reliability in percentage Average mean distance between failures	
Engineering Design Imp.	Reduction in daily deer movements in response to fencing Resistance factors (side, tip, and	Cost savings using new design

	total resistance factors) under a target reliability index Increase of flexibility by optimal thickness and the combination of aggregates and binder types Reduction on the use of asphalt mixes	
Increased Service Life	Increased Service Life	Cost savings Annualized cost Saved cost of the pavement rehabilitation
Reduced Administrative Cost		Cost savings due to reduced paperwork
ITS	Number of downloads Rank in Most Downloadable Files within FHWA Rank in agency downloadable documents Weather the webpage being among Most Popular Web Pages within FHWA	

6.3.3. Identified Data Sources to Determine the Value of Research

Various data sources were identified for determining value of measures that have been used to research on the areas of benefits. These data sources were categorized corresponding to measures used to determine the value of research in each benefit area. After analyzing the identified categories of data sources, it is concluded that the data sources can be generally placed in one of the following groups:

- Literature (Scholarly papers, databases, reports, etc.)
    - For instance, in the project sponsored by Connecticut Department of Transportation, entitled "A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit," reliability of buses (after the project is implemented) was drawn from the literature and used to estimate reliability benefits (Lowell 2000 A,B,C)

- Data provided by DOTs, FHWA, TRB, AASHTO (Performance records, etc.)
    - For instance, in the research project entitled "Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts," a database of drilled shaft load tests from Louisiana Department of Transportation and Development (LADOTD) were used.
- Data provided by manufacturers
    - For instance, in the research project entitled "A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit," data provided by manufacturers of transit buses were used to determine the value of research.

- Outcomes of surveys
    - For instance, in the research project entitled "Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document," survey was used to collect public perception about the project.
- Outcomes of lab experiments
    - For instance, in the research project sponsored by the Louisiana DOTD entitled "Accelerated Loading Evaluation of Subbase Layers in Pavement Performance," outcome of lab experiments were used to evaluate service life of subbase layers.
- Outcomes of field experiments
    - For instance, the research project sponsored by the Alabama DOT, entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" used field data to evaluate services provided for customers.
- Outcomes of simulation studies
    - For instance, the research project entitled "Improving Safety in High-Speed Work Zones: A Super 70 Study" and sponsored by Indiana DOT used output of simulation studies as one of the sources to determine safety value of research.
    - Assumptions (Based on judgment, experience, literature, etc.)
- Assumptions (Based on judgment, experience, literature, etc.)
    - For instance, in the project, entitled "Geotechnical Data Management at the Virginia Department of Transportation", it was estimated that on average, the use of this technology would cut in half the time required to gather and process borehole data, resulting in approximately 16 person-hours of savings.

6.3.4. Research Path Forward

There is a need to conduct research to develop a systematic and transparent approach to determine value of transportation research. The proposed approach should be both scalable and flexible, and easy to understand and follow.

The proposed methods and measures should not prohibit innovative ways to objectively determine the value of research. There is a need to develop a guidebook that

- Classifies types of research projects
- Recognizes potential areas of impact;
- Recommends appropriate methods based on research types and areas of impact;
- Recommends proper measures to determine the value of research;
- Describes required data for determining the value of research; and
- Recommends appropriate data collection process throughout research development and implementation.

Flexibility is the key to create such a guidebook. A proper guidebook should facilitate communicating the value of research. Current practices and research reports collected here can be a good starting point to develop such a guidebook. Last but not least, training is a key to succeed in implementing a proper guide for determining the value of research across all transportation agencies.

It is worth to make a distinction between two types of reports by state DOTs that evaluated “value of research.” In the first type, the research itself produced the value, while the research contributed to the value in the second type. For example, a pre/post study of an implemented project may or may not be able to attribute the value or benefit of the research to the benefits generated by the implementation. Both types of reports are included in this study.

REFERENCES

AASHTO MAP-21 Analysis (2012), http://map21.transportation.org/Documents/SCOPM%20Performance%20Management%20Analysis%20and%20Summary%20v2.pdf, Last retrieved: 4/21/2013.

Diefenderfer, B.K. and A.K. Apeagyei (2011), Analysis of Full-Depth Reclamation Trial Sections in Virginia, Report No: FHWA/VCTIR 11-R23

Donaldson, B.M. and A.K. Moruza (2010), An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options, Report No: FHWA/VTRC 10-R7

Ellis, Degner, O'Brien and Peasley (2003), Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables, Final Research Report, Prepared for Florida Department of Transportation, http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_OP/FDOT_BD013_rpt.pdf, Last retrieved: 4/21/2013.

Elseifi, M. and R. Bandaru (2010), Cost Effective Prevention of Reflective Cracking of Composite Pavement, Report No: FHWA/LA.11/478.

Elseifi, M.A., A.M. Abdel-Khalek, and K. Dasari (2012), Implementation of Rolling Wheel Deflectometer (RWD) in PMS and Pavement Preservation, FHWA/11.492

Fitch, G.M., V.O. Graver, and J.A. Smith (2008), Recycling of Salt-Contaminated Stormwater Runoff for Brine Production, Report No: FHWA/VTRC 08-R17

Friedman, D. (2000), Clean Fuel Technologies for Transit Buses, Presented at the Transportation Research Board Annual Meeting, January 10, 2000, McLean, VA

United States General Accounting Office (1999), Mass Transit, Use of Alternative Fuels in Transit Buses, GAO/RCED-00-18, December 1999

Gautreau, G.P., Z. Zhang, and Z. Wu (2008), Accelerated Loading Evaluation of Subbase Layers in Pavement Performance, Report No: FHWA/LA.09/468

Georgia Department of Transportation (2006), BenefitAnalysis for the Georgia Department of Transportation NaviGAtor Program, Project No. NH-7713-00(010), August, 2006.

Hawkins, P.A. (1993), Evaluation of the South West Freeway Motorist Assistance Program in Houston, Report No. TX-94/1922-IF, Texas Transportation Institute, College Station, Texas, 1993.

Lowell, D. (2000A), NYCT Operating Experience with Hybrid Transit Buses, World Bus and Clean Fuel Summit, Los Angeles, CA, June 2000

Lowell, D. (2000B), Clean Diesel Demonstration Program, World Bus and Clean Fuel Summit, Los Angeles, CA, June 2000

Lowell, D. (2000C), NYCT Clean Fuel Bus Programs, WMATA Alternative Fuels Workshop, July 6, 2000

Long, S., R. Qin, A. Gosavi, C.H. Wu, R. Tom, and C. Noll (2011), Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule, Report No: OR11.015

NAVC (2000), Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project, February 15, 2000

Norton, P., D. Rodgers, and D. Smith (2000), Natural Gas Buses-Separating Myth from Fact, Presented at the South Coast Air Basin Alternative Fuel and Electric Transit Bus Workshop, CA.

Rupnow, T.D. (2012), Evaluation of Ternary Cementitious Combinations, Report No: FHWA/LA.11/486

Rupnow, T.D. and P. Icenogle (2011), Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance, Report No: FHWA/LA.11/479

Sharp, S.R. and A.K. Moruza (2009), Field Comparison of the Installation and Cost of Placement of Epoxy-Coated and MMFX 2 Steel Deck Reinforcement: Establishing a Baseline for Future Deck Monitoring, Report No: FHWA/VTRC 09-R9

Tavakoli, A. and C.S. Collyard (1992), Benefit-Cost Analysis of Transportation Research Projects, Final Research Report, Prepared for Ohio Department of Transportation.

TCRP 38, Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, National Academy Press, 1998

Turochy, R.E. and S.L. Jones (2009), An Evaluation of the Benefits of the Alabama Service and Assistance Patrol, FINAL REPORT Project 930□635

Transportation Research Board Research Pays Off website, http://www.trb.org/Publications/RPObySubjectAreas.aspx, Last retrieved: 4/21/2013.

Wu, Z. and K. Gaspard (2009), Mechanistic Flexible Pavement Overlay Design Program, Report No: FHWA/LA.08/454

APPENDIX A SURVEY 1: EMAIL DRAFT

Dear Sir/Madam,

The Economics of Sustainable Built Environment (ESBE) Lab, at Georgia Institute of Technology, is conducting a study on behalf of the Southeast Transportation Consortium (STC) and the Louisiana Transportation Research Center (LTRC). This study is intended to synthesize best practices for determining the value of research results.

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. Your input is very important to us, and it will help us to identify, assess and document the best practices for determining the value of research results. This survey will take just a few minutes to complete and your participation is completely voluntary. Thank you for your assistance.

Should you require any assistance in completing the survey, please contact Dr. Baabak Ashuri (Phone: 404-385-7608, Email: baabak.ashuri@coa.gatech.edu).

Sincerely,
Dr. Baabak Ashuri,
Principle Investigator

Name:
Organization:
Email:
Phone:

1. Have you ever tried to determine the quantitative and/or qualitative benefits and values of your research projects?
Yes No
If the results of your findings were documented, would you please provide the link or attach the document?

2. Do you have any guideline or method to evaluate the quantitative and/or qualitative benefits of your research projects?
Yes No
If yes, would you please provide the link or attached the related documents?

3. Have you ever used RPM (Research Performance Measures) website for evaluating and documenting the benefits of your research projects?

Yes No
If yes, do you consider it as a valuable tool?
Yes No

4. What quantitative and/or qualitative benefit metrics are used by your transportation agency for determining the value of research projects?
(e.g., overall cost savings, reduced congestion, increased safety)

5. Do you have any present/future plans to quantify research benefits?
Yes No
If yes, would you please inform us about your overall plan in 1-2 sentences?

6. Have you ever conducted any study to determine the value of research projects?
Yes No
If yes, would you please provide the link or attached the related documents?

7. Are you interested to participate in a follow-up survey?
Yes No
Thank you for your participation and please feel free to leave additional comments below.

APPENDIX B SURVEY 2: EMAIL DRAFT

Subject: Follow up - Survey about Best Practices for Determining the Value of Research Results

Dear …,

As you may recall, I am working with the Southeast Transportation Consortium (STC) and the Louisiana Transportation Research Center (LTRC), on research aimed to synthesize best practices for determining value of research results. Last year you were gracious enough to respond to a survey about best practices for determining value of research results. At this time we are looking to follow up to collect examples on the quantification of research results in specific areas. Would you please fill in the following table?

Thank you again for your time,

Areas	**Have you ever quantified the impact of any research project in the specified areas?**
Safety	Yes If yes, would you please provide us with the example? No
Environmental Sustainability	Yes If yes, would you please provide us with the example? No
Management and Policy	Yes If yes, would you please provide us with the example? No
Infrastructure Condition	Yes If yes, would you please provide us with the example? No
Traffic and Congestion Reduction	Yes If yes, would you please provide us with the example? No
Quality of life	Yes If yes, would you please provide us with the example? No
Freight movement and Economic Vitality	Yes If yes, would you please provide us with the example? No
Customer Satisfaction	Yes If yes, would you please provide us with the example? No
System Reliability	Yes If yes, would you please provide us with the example? No
Expedited Project Delivery	Yes If yes, would you please provide us with the example? No
Engineering Design Improvement	Yes If yes, would you please provide us with the example? No
Increased service life	Yes

	If yes, would you please provide us with the example? No
Improved productivity and work efficiency	Yes If yes, would you please provide us with the example? No
Reduced User Cost	Yes If yes, would you please provide us with the example? No
Reduced administrative costs	Yes If yes, would you please provide us with the example? No
Reduced Construction, Operations and Maintenance Cost	Yes If yes, would you please provide us with the example? No
Materials and Pavements	Yes If yes, would you please provide us with the example? No

Sincerely,
Dr. Baabak Ashuri, Principle Investigator

APPENDIX C SURVEY 3: EMAIL DRAFT

Subject: A question regarding your research project titled "…"

Dear …,
The Economics of Sustainable Built Environment (ESBE) Lab, at Georgia Institute of Technology, is conducting a study on behalf of the Southeast Transportation Consortium (STC) and the Louisiana Transportation Research Center (LTRC). This study is indented to synthesize best practices for determining the value of research results.
We saw your interesting research project titled "…" when we were reviewing an AASHTO document introducing high value research projects. Would you please provide us with further details on the background calculations for quantifying the benefits of this research?
Thank you for your time in advance and please feel free to leave additional comments below. Should you require any assistance in completing the survey, please contact Dr. Baabak Ashuri (Phone: 404-385-7608, Email: baabak.ashuri@coa.gatech.edu).
Sincerely,
Dr. Baabak Ashuri, Principle Investigator

APPENDIX D EXAMPLES FOR DETERMINING THE VALUE OF RESEARCH

Alabama Department of Transportation (ALDOT)

An Evaluation of the Benefits of the Alabama Service and Assistance Patrol

California Department of Transportation (Caltrans)

Systems Engineering Guidebook

Mobile Work Zone Barrier

Connecticut Department of Transportation

A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit

Federal Highway Administration (FHWA)

Rural Road Low Cost Safety Improvements

Florida Department of Transportation (FDOT)

Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions

Operational and Safety Impacts of Restriping Inside Lanes of Urbane multilane Curbed Roadways to 11 Feet or Less to Create Wider Outside Curb Lanes for Bicyclists

Georgia Department of Transportation (GDOT)

Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)

Assessment of the Impact of Future External Factors on Road Revenues

Illinois Department of Transportation (IDOT)

Development and Application of Safety Performance Functions for Illinois

Development of Procedures for Determining the Axial Capacity of Drilled Shafts Founded in Illinois Shale

Indiana Department of Transportation (INDOT) and Federal Highway Administration

Improving Safety in High-Speed Work Zones: A Super 70 Study

Iowa Department of Transportation (DOT)

Winter Operations Geographic Positioning Systems and Automatic Vehicle Location

Louisiana Department of Transportation and Development (LADOTD)

Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts

Evaluation of Ternary Cementitous Combinations

Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction

Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance

Accelerated Loading Evaluation of Subbase Layers in Pavement Performance

Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance

Mechanistic Flexible Pavement Overlay Design Program

Cost Effective Prevention of Reflective Cracking of Composite Pavement

Implementation of Rolling Wheel Deflectometer (RWD) in PMS and Pavement Preservation

Michigan Department of Transportation (MDOT)

A Sensor Network System for the Health Monitoring of the Parkview Bridge Deck

Minnesota Department of Transportation (MnDOT)

Economic benefits resulting from road research performed at MnROAD

Mississippi Department of Transportation (MsDOT)

MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery

Missouri Department of Transportation (MoDOT)

Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri

Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document

Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule

North Carolina Department of Transportation (NCDOT)

Placement of Detection Loops on High Speed Approaches to Traffic Signals

Pennsylvania Department of Transportation (PennDOT)

Freeway Ramp Management Strategies

Texas Department of Transportation (TxDOT)

Use of Fine Graded Asphalt Mixes Project 0-6615

Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements

Utah Department of Transportation (UDOT)

Retrofitting Culverts and Fish Passage-Phase II

Virginia Department of Transportation (VDOT) / Virginia Center for Transportation Innovation and Research

Examination of an implemented asphalt permeability specification

Analysis of Full-Depth Reclamation Trial Sections in Virginia

"Investigation of the use of tear-off shingles in asphalt concrete"

Recycling of Salt-Contaminated Stormwater Runoff for Brine Production

An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options

Geotechnical Data Management at the Virginia Department of Transportation

Performance of Virginia's Warm-Mix Asphalt Trials

Field Comparison of the Installation and Cost of Placement of Epoxy-Coated and MMFX 2 Steel Deck Reinforcement: Establishing a Baseline for Future Deck Monitoring

Washington State Department of Transportation (WSDOT)

Bituminous Surface Treatment Protocol

Alabama Department of Transportation (ALDOT)

Research project:

- "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol"
- Sponsored by Alabama DOT
- The Alabama Service and Assistance Patrol (A.S.A.P.) is a freeway service patrol operated by the Alabama Department of Transportation in the Birmingham region of Alabama.
- This patrol of service vehicles travels continuously on approximately 112 miles of freeway on weekdays, and responds to incidents such as crashes, and vehicle breakdowns, rendering assistance from basic services to motorists to temporary traffic control.

Research objectives:

- Estimate the economic values of these benefits in order to conduct an evaluation of the economic effectiveness of the program.

Areas of benefits:

- Traffic and Congestion Reduction (Mobility benefits)
- Environmental sustainability
- Safety
- Customer Satisfaction
- Decreased User Costs

Method for determining the value of research:

- A key principle developed early in this study was the merit of viewing the potential benefit in each category as a range of possible values rather than a single value.
- Due to the lack of complete certainty associated with assumptions, a range of values, rather than a single value, seems appropriate.
- For each category, a range of estimated benefits, as well as a most likely or average value is developed and then translated into monetary values.
- To arrive at a benefit-cost ratio to quantify the economic effectiveness of the A.S.A.P. program, these benefit ranges are summed across the categories and then divided by the program's costs.
- The estimations of benefits for categories of benefits are elaborated in the following slides.

Method for determining the mobility benefits

- Measure: Reduction in delay to the traveling public
- Traffic simulation program CORSIM was used to estimate overall delay in vehicle-hours.

- Travel time values were selected based upon the literature review and engineering judgment.
- Average vehicle occupancy were selected based on literature review and local field studies.
- With five duration reductions, five travel time values, six average vehicle occupancy values, a total of 4,500 benefit values were calculated.
- A total yearly benefit estimate of the ASAP program was calculated by multiplying the range of benefit values calculated for a single incident by the total number of assists per year.

Method for determining the safety benefits

- Measure: reduction in the occurrence of secondary crashes
- Literature was used to select the secondary crash rates.
- Literature was used to select secondary crash reduction rates.
- A range for secondary crash avoidance was calculated based on the selected secondary crash rates and secondary crash reduction rates and total number of incidents attended to by the A.S.A.P. program.
- Literature was used to select the economic value of reduction in an occurrence of a secondary crash.
- Potential number of crashes avoided was converted to an economic benefit using the value of reduction in the occurrence of secondary crashes.

Method for determining the environmental benefits

- The emission outputs from CORSIM simulation was used.
- The value of saved emissions was determined from average industry standards (Stamatiadis et al., 1997; Skabardonis et al., 1998).
- The dollar value for the possible emission reductions were calculated.

Method for determining the customer service benefits

- Literature was used for the value of customer service per assist.
- The value of benefit per assists was applied to assists recorded by A.S.A.P. during the study year.

Summary of Results

Benefits Category	High Estimate	Low Estimate	Most Likely
Mobility	23.4	1.7	9.2
Safety	7.8	1.0	4.3
Environmental	0.1	0.1	0.1
Customer Service	1.7	0.9	1.3

Copyright of Turochy and Jones (2009)

Measures:

- Reduction in occurrence rate of secondary crashes and the corresponding dollar benefits
- Reduction in emission outputs (HC, CO, Nox) and corresponding dollar benefits
- Reduction in delay to the traveling public
- Number of services provided to motorists
- Savings of the motorists due to the service

Data sources:

- Traffic simulation software is used for calculating mobility measures and emission outputs.
- Assistance rendered and on program costs provided by "Third Division office of the Alabama Department of Transportation".
- Literature is used for
  - Value of traveling time
  - Average vehicle occupancy
    - Field studies that were conducted in 2006 by the Regional Planning Commission of Greater Birmingham at two locations on Interstate 65
- Secondary crash rates
  - Study of the service patrol in the Los Angeles area (Moore et al., 2004)
  - A study of two years of the service patrol in southeastern Wisconsin
- Secondary crash reduction rates
  - A study of the Hoosier Helper program in northwestern Indiana
  - A comprehensive study of the benefits of the service patrol in the Hudson Valley region of New York State
- Economic value of reduction in secondary crashes:
  - NHTSA report entitled, "The Economic Impact of Motor Vehicle crashes 2000" (Blincoe et al., 2002)
- Value of reduction in emission
  - Average industry standards (Stamatiadis et al., 1997; Skabardonis et al., 1998)
- Field data (Number of services provided to motorists)
- Value of customer service per assist
  - Literature review (GDOT 2006; Hawkins 1993)

California Department of Transportation (Caltrans)

Research Project:

- "Systems Engineering Guidebook"
- Sponsored by: Caltrans and FHWA

Research objectives:

1. Develop a Systems Engineering Guidebook for ITS projects,
2. Conduct training classes to disseminate that information, and
3. Integrate the use of a Systems Engineering Process into Caltrans standard Project Delivery processes, procedures, and manuals.

Areas of benefit:

- ITS

Method for determining the value of research:

- Analysis of dissemination of research output.

The statistics on usage during the first 2 years (2007 to 2009) of operation attest to the usefulness and use of the SEGB.

- When introduced in January and February 2007, the SEGB document was downloaded 21,955 times and was ranked #2 of the top 20 Most Downloadable Files within FHWA in each month.
- From March 2007 to December 2008 (22 months), the ranking of the SEGB document downloads has consistently been around #4 in Most Downloadable Files. In December 2008, it was still ranked #4 of agency downloadable documents.
- There have been more than 141,072 SEGB document downloads during the 24 month period (three of the months, statistical data was unavailable).
- During the first two months of web access in 2007, the SEGB home page was listed as one of the 500 Most Popular Web Pages within FHWA.
- Popularity has grown—in each of the last 6 months of 2008, as many as three different web pages of the SEGB site appeared in the listing of the 500 Most Popular Web Pages.
- The SEGB web pages 'Process View', 'Glossary', and 'Design Specification Template' have been frequently accessed.
- For February 2012, two of the SEGB pages were number 205 and 322 on FHWA's top 500 hits pages for all FHWA Web sites.

Measures:

- Number of downloads
- Rank in Most Downloadable Files within FHWA

- Rank in agency downloadable documents
- Weather the webpage being among Most Popular Web Pages within FHWA

Data Sources:

- Ranking of FHWA most downloadable files
- Ranking of agency downloadable documents
- Most popular webpages within FHWA

Research Project:
- “Mobile Work Zone Barrier”
- Sponsored by California Department of Transportation

Research objectives:
- To protect highway workers from moving traffic.

Areas of Benefit:
- Safety
- Traffic and Congestion Reduction
- Improved Productivity and Work Efficiency
- Reduced Construction, Operations and Maintenance Costs
- Decreased User Costs

Methods for determining the value of research:
- Benefit analysis
  - Assumption-based estimation
    - Currently, the set-up and breakdown of a lane closure requires approximately three hours with current safety measures. In contrast, the device requires only 10-20 minutes each for set-up and break-down.
    - Caltrans generally closes one or more lanes in order to provide a safe work zone around its workers, thus resulting in increased congestion and traffic delays.
    - The maintenance crew currently using the device found that it has eliminated approximately 15% of the lane closures previously required to perform necessary maintenance.
- Benefit (Dollar) Analysis
  - The number of avoided lane closures equates to a potential annual savings of $115,464,000 in public user road costs, due to reduced travel delay.

Measures:
- Time of set-up and breakdown of a lane closure
- Reduction in percentage of lane closures and corresponding dollar benefits for motorist due to reduced travel delays

Data Sources:
- Collected field data

Connecticut Department of Transportation

Research Project:

- “A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit”
- Sponsored by Connecticut Department of Transportation

Research objectives:

- Review the state of the art in current and emerging bus propulsion technology in terms of availability, emissions, reliability, and cost;
- Presents detailed analyses and comparisons for the more promising technologies;
- Set forth various bus purchase programs, including their benefits and impacts, for the period 2003 to 2008; and
- Suggest bus purchase strategies.

Areas of Benefit:

- Environmental Sustainability
- System Reliability

Methods for determining the value of research:

- Assumption-based estimation
- Cost (Dollar) / Benefit (Dollar) Analysis

Measures:

- Reduction in emissions (carbon dioxide, carbon monoxide, oxides of nitrogen, unburned hydrocarbons and particular matter)
- Comparative reliability in percentage
- Average mean distance between failures

Data Sources:

- Data from manufacturers of transit buses
- EPA WEBSITE, BUS AND TRUCK EMISSIONS for Emissions
- Northeast Advanced Vehicle Consortium (NAVC 2000) for diesel, diesel-electric hybrids, electric, and CNG for Emissions
- Norton, Pre 1994 for Emissions
- Norton, 1994-present for Emissions
- GAO, 1999 for Emissions
- Friedman, 2000 for Emissions
- TCRP Report 38 for costs of vehicles

- Trolley bus costs from Transportation Planning Handbook, Second Edition, Institute of Transportation Engineers, 1999
- LOWELL 2000A and Lowell, 2000B and Lowell 2000C for reliability and energy efficiency

Federal Highway Administration (FHWA)

Research Project:

- "Rural Road Low Cost Safety Improvements"
- Sponsored by Federal Highway Administration (FHWA)

Research Objectives:

- To evaluate the safety effectiveness of several low-cost safety strategies presented in the National Cooperative Highway Research Program (NCHRP)

Areas of Benefit:

- Safety
- Reduced User Costs

Methods for determining the value of research:

- Statistical analy Rural Road Low Cost Safety Improvements sis:

Pavement Width (m)	3.05-m Lanes	3.35-m Lanes	3.66-m Lanes
7.92	1.00	0.99	0.96
8.53	1.00	0.99	0.97
9.14	1.00	0.99	0.97
9.75	1.00	0.95	0.94
10.36	1.00	0.78	0.81
10.97	1.00	0.95	0.95

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  - The Crash Modification Factors (CMFs) represent the expected percent change in target crashes compared with a configuration with 3.05-m (10-ft) lanes for given total paved widths (the most safety-effective configuration for a given paved width is indicated by the lowest CMF)
    - As an example, the adjusted CMFs were 1.00, 0.95, and 0.94 for the 3.05-, 3.35-, and 3.66-m (10-, 11-, and 12-ft) lane configurations respectively, using the 9.75‑m (32-ft) paved width
    - The 3.66-m (12‑ft) lane configuration is associated with the lowest CMF; therefore, a 3.66-m (12-ft) lane with a 1.22-m (4-ft) shoulder is the most safety-effective configuration within the 9.75-m (32-ft) paved width group
  - Results of CMFs calculation yield a reduction of 6 crashes per year. Estimated crash costs are then applied to the expected change in crashes to estimate the annual dollar savings

        - Assuming a long-term expected crash experience of 100 target crashes per year for the base condition, the configuration with 3.66-m (12-ft) lanes and 1.22-m (4-ft) shoulders would yield a reduction of 6 crashes per year
    - However, crash costs typically vary by State but can be estimated from the recent FHWA crash cost guide when State-specific crash cost data are not available

Measures:

- Cost saving
- Crash Modification Factors (CMF)
    - Total crashes including: Injury crashes; Rear-end crashes; Angle crashes

Data Sources:

- Geometric, traffic, and crash data were obtained for the entire population of rural, two-lane, undivided road segments in Pennsylvania (1997–2001 and 2003–2006) and Washington (1993–1996 and 2002–2003)

Florida Department of Transportation (FDOT)

Research project:

- "Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions"
- Sponsored by: Florida DOT
- Local water management district directs FDOT District to reduce nitrogen in surface waters by 18,472 pounds per year.
- FDOT needs to purchase Total Maximum Daily Load credits at a cost of $500,000-$1,000,000 per year for 20 years if it is unable to meet the reduction target.

Research objective:

- Provide a scientific basis for quantifying the reduction in nutrient losses from highway slopes due to changes in fertilization practices.

Areas of benefit:

- Environmental Sustainability
- Reduced Construction, Operations and Maintenance Costs

Method for determining the value of research:

- Lab experiments using a custom designed field scale test bed and rainfall simulator
- Benefit (Dollar) Analysis

Benefit (Dollar) analysis:

- FDOT showed that they could meet 85% of their target reduction by stopping annual fertilizing.
- The amount of nitrogen that was getting out of the turf and into the water was quantified by various tests conducted at the University of Central Florida using field-scale rainfall simulator and test bed.
- FDOT could save $150,000 per year in fertilizer
- FDOT could save 85% of the anticipated fine ($1M per year),
    - This is equivalent to $850,000 per year.

Measures:

- Reduction in anticipated fine
- Reduction in amount of annual fertilizer
- Reduction in the amount of Nitrogen getting out of turf

Data sources:

- Outcome of lab experiments using a custom designed field scale test bed and rainfall simulator
- Anticipated fine from the local water management district

Research project:

- "Operational and Safety Impacts of Restriping Inside Lanes of Urbane multilane Curbed Roadways to 11 Feet or Less to Create Wider Outside Curb Lanes for Bicyclists"
- Sponsored by: Florida DOT

Research objective:

- Evaluate safety and operational benefits of using wider outside lane than inside lane on multiline roadways.

Area of benefit:

- Safety

Methods for determining the value of research:

- Field study for the analysis of operational benefits
- Analysis of safety benefits using crash data

Analysis of operational benefits

- Using video collected at several sites in Florida
- Analyzing more than 200 video taped passing events at 12 different sites
    - Collecting data for one to two hours during peak hours in each site
- Measures of effectiveness:
    - Lateral separation between the motor vehicle and bicyclist
    - Motor vehicle shift to the outside through lane
    - Motor vehicle outside through lane usage
    - Motor vehicle speeds before, during and after passing bicyclist

Results of the analysis of operational benefits:

- Descriptive statistics, 95% confidence intervals, and regression modeling showed that
    - lateral spacing between motor vehicles and bicyclists was strongly influenced by outside lane width.
    - Motorists passed closer to bicyclists when the outside lane was narrower, the inside lane was occupied, the passing vehicle was smaller, and the bicyclist was male.
    - Vehicles were more likely to move into an inside lane when the outside lane was narrower, when lane changing conditions were unrestricted, or when the cyclist was female.
    - There was a tendency for motorists to shift to the inside lane after realizing there was a bicyclist downstream.
    - Generally, motorists reduced speed when passing bicyclists.

Analysis of safety benefits and corresponding results:

- The research was conducted using Crash data archived by Florida DOT
- The research showed that all types of crashes (fatal, with injury, and property damage only) decreased as the outside lane width increased to greater than 12 feet, demonstrating that asymmetrical striping could be a feasible method to increase safety on roadways lacking adequate space for dedicated bicycle lanes.

Measures:

- Safety
    - Lateral separation between the motor vehicle and bicyclist
    - Motor vehicle shift to the outside through lane
    - Motor vehicle outside through lane usage
    - Motor vehicle speeds before, during and after passing bicyclist
    - Reduction in crashes (fatal, with injury, and property damage only)

Data sources:

- Site data collection using video collected at several sites in Florida
- Crash data archived by Florida DOT

Georgia Department of Transportation (GDOT)

Research Project:

- "Development and Evaluation of Devices Designed to Minimize Deer-vehicle Collisions (Phase II)"
- Sponsored by: Georgia DOT

Research Objective:

1. evaluated the behavioral responses of captive white-tailed deer to visual and physical barriers designed to minimize deer-vehicle collisions; and
2. determined the effects of exclusion fencing on movements of free-ranging deer, and
3. further tested visual capabilities of deer; all as related to potential mitigation strategies for deer-vehicle collisions.

Areas of benefit:

- Safety
- Engineering Design Improvement

Method for determining the value of research:

- Benefit analysis (In terms of both "Dollar value" and "Reduction in daily deer movements in response to fencing")

Benefit Analysis:

- The team tested the efficacy of several fencing designs and that of a layer of rip-rap rock for restricting movements of captive deer.
- Woven-wire fences >2.1-m tall and 1.2-m woven-wire fences with a top-mounted outrigger were most effective.
- Daily deer movements in response to fencing were reduced by 98% and 90% for the 2.4-m and outrigger designs, respectively.
- The overall cost of the outrigger design installation was 20% less than the standard 2.4 woven-wire design installation ($3,200/mile).

Measures:

- Reduction in daily deer movements in response to fencing
- Cost savings using new design

Data sources:

- Field experiments

Research project:

- “Assessment of the Impact of Future External Factors on Road Revenues”
- Sponsored by Georgia DOT

Research Objective:

- Identify those factors that affect state highway revenues in Georgia
- Develop a conceptual framework of the key factors that influence highway revenues
- Develop a model to assess the implications on revenues of changes in a variety of factors that have been shown to influence overall revenue levels

Areas of Benefit:

- Management and Policy

Methods for determining value of research:

- Benefit analysis through revenue estimation model
    - This research develops a model that can be used to assess the implications of changes in a variety of factors that have been shown to influence overall transportation revenue levels.
    - These factors include (but are not limited to) oil production, fuel efficiency, clean energy, public transit, etc., in the “all-of-the-above” energy policy currently pursued by the White House administration.
    - Factors affecting fuel tax revenue
        - Vehicle Fuel Efficiency
        - Vehicle Miles Traveled
        - Fuel Prices
        - Tax revenue
    - The model is intended to be a “revenue estimation toolbox” that allows GDOT planners and budget officials to assess quickly how different scenarios could impact future fuel tax revenue in Georgia.
    - For example, with respect to fuel efficiency technology, the reduction in revenues from electric and hybrid vehicles entering the fleet over the next decades was investigated. The analysis showed that the reduced motor fuel tax revenues due to this market entrance would be in the tens of millions of dollars annually in future years, and potentially hundreds of millions when measured in decades.

Measures:

- Revenue levels

Data Sources:

- Oil production, fuel efficiency, clean energy, public transit, Taxes

Illinois Department of Transportation (IDOT)

Research Project:

- "Development and Application of Safety Performance Functions for Illinois"
- Sponsored by Illinois DOT

Research Objective:

- Evaluate and implement state specific safety performance functions (SPFs). SPFs provide a realistic and accurate prediction of crash frequency, severity, type, etc. This allows IDOT to identify high incident areas and decide which areas are best candidates for safety improvements.

Areas of benefit:

- Safety

Method for determining the value of research:

- Benefit and after analysis
- Benefit (dollar) analysis

Measures:

- Saved lives and injuries
- Cost savings

Data sources:

- Field data

Research Project:

- “Development of Procedures for Determining the Axial Capacity of Drilled Shafts Founded in Illinois Shale”
- Sponsored by Illinois DOT

Research Objective:

- Develop Procedures for determining the axial capacity of drilled shafts founded in Illinois shale.

Areas of benefit:

- Reduced Construction, Operations and Maintenance Cost

Method for determining the value of research:

- Assumption-based estimation
- Benefit (dollar) analysis
  - “Over a five year-period (i.e., 2007-2011), the Illinois Department of Transportation’s annual budget for pile foundation systems has been approximately constant at $12 million per year, while over the same time period, use of drilled shafts has increased from less than $1 million per year to almost $6.5 million per year. Assuming future years use of drilled shafts will average 6.5 million dollars a year (conservatively assuming no growth) and using the historical fact that 1/3 of the drilled shaft cost has been for drilling in rock, if the new design method developed by the findings of this research reduces the depth in rock by 20%, the cost savings would be 0.43 million/yr in construction costs. This cost savings were calculated by IDOT staff.”

Measures:

- Construction cost savings

Data sources:

- Field data

Indiana Department of Transportation (INDOT) and Federal Highway Administration

Research project:

- "Improving Safety in High-Speed Work Zones: A Super 70 Study"
- Sponsored by: Indiana DOT
- Super 70 was a high-speed six-mile construction project in 2007 on a heavily traveled interstate I-70 in the central area of Indianapolis.

Research objective:

- Estimate the safety effect of traffic management and enforcement countermeasures applied during the nine-month using advanced econometric models of safety applied to half-an-hour intervals and before-and-after studies.

Areas of benefit:

- Safety

Methods for determining the value of research:

- Advanced modeling of safety in short time intervals and on relatively short road segments with logistic regression
    - to estimate the impacts of individual safety countermeasures and other safety variables that need to be accounted for to avoid estimation bias, and
- Before-and-after study
    - to estimate the overall change in safety in the work zone impact area and its components over time measured with longer periods of several months.
- Simulation

Results:

- The single most successful management strategy was rerouting heavy vehicles (13+ tons) on alternative interstate routes.
- The second significant source of safety benefit was jointly generated by police enforcement, reduced speed, and other traffic management strategies.
- The safety benefit generated by the two sources was estimated to be 100 crashes saved inside the work zone during the nine months of the road construction.

Measures:

- Number of crashes saved inside the work zone during the nine months of the road construction

Data sources:

- Crash dataset: Indiana State Police Crash Data Records

- Traffic dataset: Detectors set up by INDOT
- Geometry dataset: Google Earth and Super 70 work zone drawing
- Weather dataset: National Climatic Data Center
- Maintenance dataset: Super 70 work zone drawing
- Enforcement dataset: Super 70 work zone activity log

Iowa Department of Transportation (DOT)

Research project:

- "Winter Operations Geographic Positioning Systems and Automatic Vehicle Location"
- Sponsored by: Iowa DOT

Research objective:

- Study the benefits and expected costs of an integrated GPS/AVL system with tangible benefits:
    - Agency
        - Reduced material costs
        - Reduced labor costs
        - Reduced equipment costs
        - Reduced paperwork
    - User (Motorists)
        - Improved safety

Areas of benefit:

- Safety
- Improved Productivity and Work Efficiency
- Reduced Construction, Operations and Maintenance Costs
- Reduced Administrative Costs

Methods:

- Cost (Dollar)/Benefit(Dollar) ratio

Project parameters

- Discount Rate 5 %
- Life cycle (years) 12 years
- Number of vehicles installed with AVL 700
- Total number of vehicles 1,470
- Loaded labor cost per hour (shop rate) $36.00
- Lane miles covered per storm (per truck) 120
- Annual number of storm events 23.4
- Average labor hours per storm event (per vehicle) 16
- Operating cost per mile (excluding labor) $19.80
- Estimated minutes doing paperwork per storm (per vehicle) 20
- Total storm event crashes (per season) 11,333
- Average cost per crash $33,700

Costs calculations

Initial Costs					
Items	**Unit rate ($)**	**# of units**	**Unit**	**Amount ($)**	**Notes**
In vehicle unit	$4,000.00	700	vehicles	$2,800,000.00	Assumption: 700 snow plow trucks 12 years and younger available for install
Base station - initial investment per computer	$0.00	110	computers	$0.00	Garages currently outfitted
Communications setup	$0.00	1	lump sum	$0.00	
Infrastructure Investment	$0.00	1	lump sum	$0.00	
System lump sum initial investment	$50,000.00	1	lump sum	$50,000.00	System interface/IT
Training	$5,000.00	1	locations	$5,000.00	
Leased Comm's per year per truck	$600.00	700	trucks	$420,000.00	Air cards
				Total initial expenditure:	**$3,275,000.00**	

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Annual Operating and Maintenance Costs					
Items	**Unit costs per year**	**# of units**	**Unit**	**Amount ($)**	**Notes**
Software costs (e.g. recurring annual fee)	$0.00	110	computers	$0.00	
Communications (e.g., phone bills)	$600.00	700	vehicles	$420,000.00	Air cards
Maintenance - in vehicle unit	$50.00	700	vehicles	$35,000.00	General
Maintenance - base station	$0.00	110	computers	$0.00	
Administrative costs	$3,000.00	1	lump sum	$3,000.00	
Training	$50.00	110	maintenance units	$5,500.00	
			Total Annual O&M Costs:	**$463,500.00**	

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Benefit calculations

Agency Benefits					
Items	**Subtotal**	**Savings (%)**	**Description**	**Amount ($)**	**Notes**
Reduced operating cost	$48,353,760.00	7%	Equipment operating cost	$3,384,763.20	
Reduced paperwork	$93,600.00	10%	Paperwork cost	$9,360.00	
Salt	$19,578,837.00	10%	Salt Savings	$1,957,883.70	
			Total Annualized Benefit:	**$5,352,006.90**	

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User (Motorist) Benefits					
Items	**Subtotal**	**Savings (%)**	**Description**	**Amount ($)**	**Notes**
Improved safety	$181,867,667.00	5.00%	Material cost	$9,093,383.35	
			Total Annualized Benefit:	**$9,093,383.35**	

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Benefit-Cost Ratio

- 17.3

Measures:

- Saving by avoiding cost of potential crashes (Assumed 5% saving)
- Reduced material costs
- Reduced labor costs
- Reduced equipment costs
- Reduced paperwork

Data sources:

- Cost of crashes provided by agency
- Cost of material provided by agency
- Operating costs provided by agency
- Cost of paper work provided by agency
- Assumed 5% saving by avoiding cost of potential crashes
- Assumed 10% salt savings
- Assumed 7% reduction in operating cost
- Assumed 10% reduction in paperwork

Louisiana Department of Transportation and Development (LADOTD)

Research project:

- "Calibration of Resistance Factors Needed in the LRFD Design of Driven Piles and Drilled Shafts"
- Sponsored by: Louisiana Transportation Research Center

Research objective:

- Calibrate the resistance factors for the different design methods of axially loaded driven piles and drilled shafts needed in the LRFD design methodology.

Areas of benefit:

- Engineering Design Improvement

Method for determining the value of research:

- Statistical reliability analyses
- 53 PPC piles that were tested to failure and 26 drilled shaft load tests were collected and used in the statistical reliability analyses to calibrate the resistance factors of the different design methods.

Results:

- It was found that local resistance factors were about 10 percent higher than those recommended by AASHTO, which will be translated into cost savings, specifically in the design of driven piles and drilled shafts.

Measures:

- Resistance factors (side, tip, and total resistance factors) under a target reliability index

Data sources:

- A database of 16 cases of drilled shaft load tests from Louisiana Department of Transportation and Development (LADOTD) archives
- A database of 15 drilled shafts from state of Mississippi

Research project:

- "Evaluation of Ternary Cementitous Combinations"
- Sponsored by Louisiana DOTD

Research objectives:

- To show that cement mixtures containing up to 70 percent fly ash and slag exhibit concrete test results that are comparable (or better) than those obtained from control mixtures containing no supplemental cementitious materials

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Environmental sustainability
- Materials and Pavements

Methods for determining the value of research:

- Benefit (Dollar) / Cost (Dollar) analysis for quantifying benefits on reduced construction, operations and maintenance costs and materials and pavements:
    - Cost-benefit analyses indicate potential material cost savings around $25,000 per lane-mile when replacing 70 percent Portland cement with fly ash and slag
        - For the purposes of the cost benefit analysis, a cubic yard of paving concrete was assumed to contain 475 lb. of cementitious material
        - Following table shows the estimated cost and potential savings, in dollars per mile, for two high Supplementary Cementitious Materials (SCM) replacement mixtures compared to the standard 20 percent fly ash mixture routinely used on LADOTD paving projects

Mixture Design	Cementitious Materials Cost ($/mile)	Potential Savings per Mile ($)	Potential Savings per Mile (%)
80TI-20C	$90,566	N/A	N/A
40TI-30G100S-30C	$72,453	$18,113	20.0
30TI-35C-35F	$65,409	$25,157	27.8

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    - The cost of this research project was $233,544. Using the savings (benefit), a cost benefit ratio of about 13 and 21 may be realized for the slag – fly ash and class C – class F fly ash ternary mixtures, respectively.
- Benefit CO2 reduction analysis:
    - Production for each ton of Portland cement for concrete pavement emits 0.92 tons of carbon dioxide. As byproducts of other industries, emissions due to production

of fly ash and slag are negligible from the viewpoint of concrete pavement construction

- For the purposes of the CO2 reduction analysis, a cubic yard of paving concrete was assumed to contain 475 lb. of cementitious material
- Following table shows the estimated CO2 load and potential CO2 savings, in tons, for three high SCM replacement mixtures compared to the standard 20 percent fly ash mixture routinely used on LADOTD paving projects
- A reduction of 300 tons of CO2 is equivalent to removing about 8500 vehicles from the road every year.

Mixture Design	CO_2 Load for the 2007-2008 Bid Years (Tons)	Potential CO_2 Savings (Tons)	Potential CO_2 Savings (%)
80TI-20C	144,531	N/A	N/A
40TI-30G100S-30C	79,456	65,075	43.9
40TI-30G120S-30F	82,321	62,210	41.8
30TI-35C-35F	50,098	94,433	62.5

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Measures:

- Cost saving
- CO2 emissions reduction

Data Sources:

- Laboratory experiment

Research project:

- "Development and Performance Assessment of an FRP Strengthened Balsa-Wood Bridge Deck for Accelerated Construction"
- Sponsored by LTRC, LADOTD, and International Bank for Reconstruction and Development (IBRD)

Research objectives:

- To develop, construct and evaluate a lightweight FRP-wrapped balsa wood bridge deck system
  - Long-term performance monitoring integrity of the FRP-wrapped Balsa wood bridge deck system
  - The strains in the transverse direction of the deck and the longitudinal direction of the individual girders
  - Bridge deck–girder interface bond integrity

Areas of Benefit:

- Improved Productivity and Work Efficiency
- Reduced Construction, Operations, and Maintenance Cost

Methods for determining the value of research:

- Benefit analysis:
  - Fast installation
    - The deck was replaced in ½ a day
- Cost saving
  - The new deck is corrosion free and maintenance free
  - Cost benefit is estimated at $96,000 per bridge
- Safety
  - The smooth surface also reduces concern for personal injury to local pedestrians and bikers

Measures:

- Reduced material cost
- Reduced installation time

Data Sources:

- Field data analysis and simulation by finite element analysis

Research project:

- "Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance"
- Sponsored by Louisiana DOTD

Research objectives:

- To characterize the results of the surface resistivity test for concrete specimens compared to the rapid chloride permeability of concrete specimens

Areas of Benefit:

- Improved Productivity and Work Efficiency

Methods for determining the value of research:

- Cost benefit analysis:
    - The cost to conduct the research was used as the cost factor, and the benefit was determined using personnel and equipment savings

Equipment	Initial Cost ($)	Number of Man Hours Required	Technician Hourly Wage or Cost per Test ($)
ASTM C 1202	$18,000.00	8.0	$500.00
Surface Resistivity	$2,800.00	0.33	$23.38

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Measures:

- Cost Saving

Data Sources:

- Laboratory data analysis

Research project:

- “Accelerated Loading Evaluation of Subbase Layers in Pavement Performance”
- Sponsored by Louisiana DOTD

Research objectives:

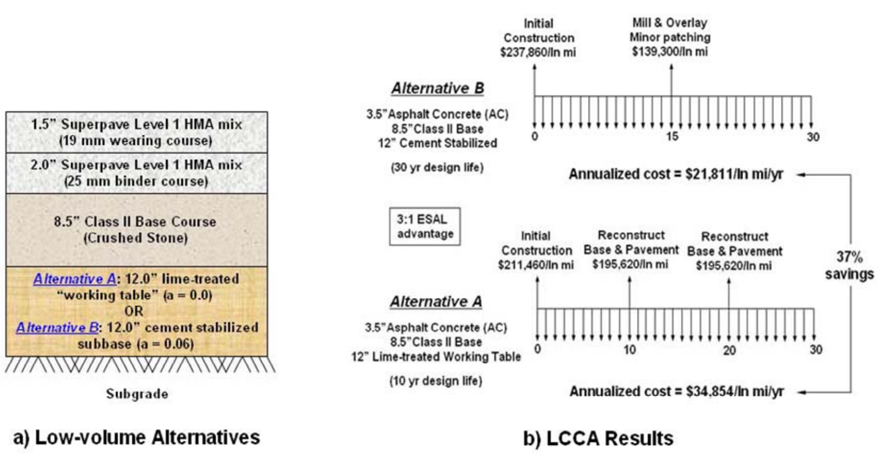
- To explore and develope of a methodology to build reliable subgrade layers stabilized with cementitious agents at various field moisture contents so that a treated subgrade layer would not only provide a working table for pavement construction but could contribute to the overall pavement structural capacity

Areas of Benefit:

- Increased Service Life
- Materials and Pavement
- Reduced Construction, Operations, Maintenance costs

Methods for determining the value of research:

- Life cycle cost analysis:
    - Clays with lime and silts with cement will create stronger foundations for pavement structure as compared to the raw natural soil in terms of:
        - Cement Stabilization
        - Lime Stabilization
        - Lime-Fly Ash Stabilization
    - Subbase in lieu of a lime-treated working table layer will create a 37 percent annualized cost savings for low-volume and 31 percent cost savings for high volume pavement structures in Louisiana using a 12-in. cement stabilized soil



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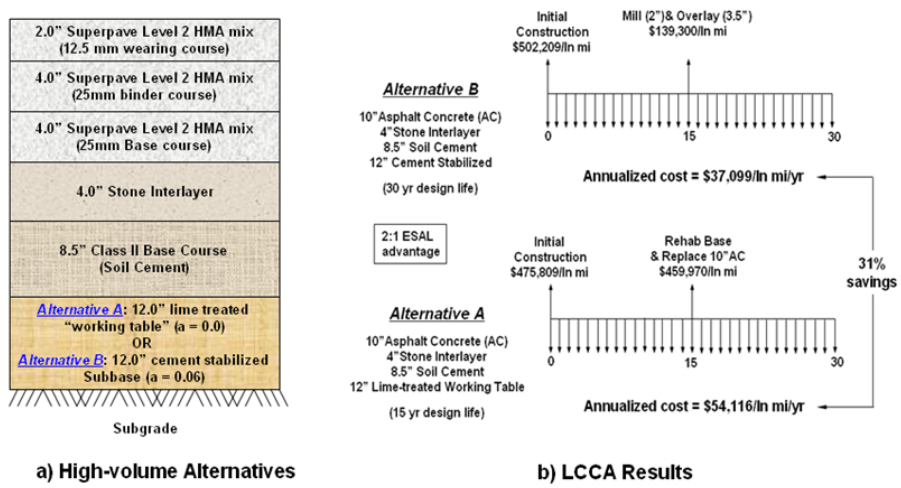

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Measures:

- Service life
- Annualized cost

Data Sources:

- The laboratory and field study for finding design life

Research project:

- "Evaluation of Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance"
- Sponsored by Louisiana DOTD

Research objectives:

- To characterize the results of the surface resistivity test for concrete specimens compared to the rapid chloride permeability of concrete specimens

Areas of Benefit:

- Improved Productivity and Work Efficiency
- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Benefit analysis:
    - The change in QA procedure significantly reduces the testing time from two days to less than five minutes.
    - The surface resistivity test is also conducted at 28 days of age instead of 56 days of age thus allowing for contractors to get paid for the permeability pay item and ship their product earlier in the case of precast concrete suppliers

- Benefit (Dollar) / Cost (Dollar) analysis:
    - The cost to conduct the research was used as the cost factor, and the benefit was determined using personnel and equipment savings
        - The implementation project cost benefit analysis accounts for other factors such as mileage and travel time when compared to the preliminary cost benefit analysis
        - After implementation into the District Laboratory, the travel time was reduced about by 66 percent thus increasing the cost savings. Taking into account one trip per week for three months, or about 12 trips, the technician time savings is about $117 per week or a total savings in travel time of about $1,400. The mileage savings is about $70 per week, assuming 140 miles saved per week times $0.50 per mile. The total mileage savings comes to about $840.

Equipment	Initial Cost ($)	Number of Man Hours Required	Technician Hourly Wage or Cost per Test ($)
ASTM C 1202	$18,000.00	8.0	$500.00
Surface Resistivity	$2,800.00	0.33	$23.38

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Measures:

- Time saving to do Quality Control and Quality Assurance tests
- Cost saving to do Quality Control and Quality Assurance tests

Data Sources:

- Field project (Caminada Bay Bridge project)
- Laboratory studies

Research project:

- "Mechanistic Flexible Pavement Overlay Design Program"
- Sponsored by Louisiana DOTD

Research objectives:

- To develop an overlay design method/procedure that is used for a structural overlay thickness design of flexible pavement in Louisiana based upon
  - (1) In-situ pavement conditions
  - (2) Non-destructive test (NDT) methods

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Materials and Pavement

Methods for determining the value of research:

- Benefit analysis:
  - It indicates 1993 AASHTO NDT procedure generally over estimated the effective structural number for the existing asphalt pavements in Louisiana, which would result in an under-designed overlay thickness

Project	Overlay thickness (in.)		MEPDG verified results	
	LADOTD	Proposed	LADOTD	Proposed
I-12W	3.4	1*	AC Permanent Deformation Fail	AC Permanent Deformation Fail
I-12E	3.4	1*	AC Permanent Deformation Fail	AC Permanent Deformation Fail
LA-28W	3.3	3.3	AC Permanent Deformation Fail	AC Permanent Deformation Fail
LA-28E	3.3	4.4	AC Permanent Deformation Fail	Pass
LA-74W	2.4	3.5	Pass	Pass
LA-74E	2.4	4.8	Pass	Pass
LA-44S	1*	1*	Pass	Pass
LA-44N	1*	1*	Pass	Pass

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- Benefit (Dollar) / Cost (Dollar) analysis
  - The cost/benefit analysis revealed that, as compared to the current LADOTD component analysis method, the proposed NDT-based overlay design method would potentially save millions of dollars in the flexible pavement rehabilitation in Louisiana

Alternatives	Length (miles)	Unit Prices ($)	Quantity (ton)	Construction Costs ($)
A: LADOTD Plan (2" mill/4.5" overlay)	10.541	80 per ton	73,467	5,877,324
B: Proposed Method (2" mill/2" overlay)	10.541	80 per ton	32,652	2,612,144
Total Construction Cost Savings (A – B)				$3,265,180

Comparison of initial construction costs in I-12 (as an example) Copyright of Wu and Gaspard (2009)

Project No.	Route	Length Miles	DOTD Plan	Proposed	Difference	Quantity (ton)	Cost Savings ($)
			Overlay(in.) +mill (in.)	Overlay (in.) +mill (in.)	AC Thickness (in.)		
1	LA 527NB	3.788	2+1	1.7+1	0.3	411	32,854
2	LA 137	7.11	2.75+2	1.3+1	1.45	3992	319,347
3	US 165	7.311	0.75"AC	0.0	0.75	2010	160,791
4	LA 15	5.46	2.75+2	1.2+2	1.6	3340	267,224
5	LA28EB	7.293	2+1.75	1.0+1.75	1.0	2739	219,131
6	LA 28WB	7.293	2+1.75	1.0+1.75	1.0	2739	219,131
7	LA 3127N	5.58	3.5+2	1.8+2	1.7	3630	290,381
8	LA 3127S	5.58	3.5+2	2.3+2	1.2	2593	207,415
9	LA 37N	5.44	3.5+1.5	2.2+1.5	1.3	2717	217,377
10	LA 37S	5.44	3.5+1.5	1.9+1.5	1.6	3328	266,245
11	LA 28	6.7	4.5+2	4+2	0.5	1297	103,770
12	LA 44EB	7.54	3.5+2	1.6+2	1.9	5547	443,762
13	LA 44WB	7.54	3.5+2	1.8+2	1.7	4963	397,050
14	I-12EB	10.541	4.5+2	2+2	2.5	20407	1,632,590
15	I-12WB	10.541	4.5+2	2+2	2.5	20407	1,632,590
Total		103.157					6,409,658

Analysis of cost saving for over-designed projects (Copyright of Wu and Gaspard (2009))

Project #	Route #	Length (miles)	LADOTD Design Plan overlay + mill	Under-designed Difference	Pavement Life (years)	Total Saving ($)
1	LA 173	6.416	3.5+0.5	-0.6	5.6	241,864
2	LA 173	6.416	3.5+0.5	-0.4	6.5	245,739
3	LA 527	3.788	2+1	-0.7	6.3	120,978
4	LA 27	16.96	2.5+2	-0.4	8.7	544,454
5	LA 27	16.96	2.5+2	-0.5	6.8	588,206
6	LA 101	3.115	4+3	-0.8	6.3	84,046
7	LA 101	3.115	4+3	-1.2	4.3	67,214
8	US 84	8.004	2.5+0	-0.5	7.8	257,071
9	US 84	8.004	2.5+0	-1.1	4.8	189,717
10	LA 74	3.35	3.5+2	-0.9	5.7	88,691
11	LA 74	3.35	3.5+2	-2.3	2.8	10,926
Total		79.478				2,537,246

Analysis of cost saving for under-designed projects (Copyright of Wu and Gaspard (2009))

Measures:

- Cost saving

Data Sources:

- Field data: Data selected from fifteen overlay rehabilitation projects located throughout Louisiana with different traffic levels

Research project:

- "Cost Effective Prevention of Reflective Cracking of Composite Pavement"
- Sponsored by Louisiana DOTD

Research objectives:

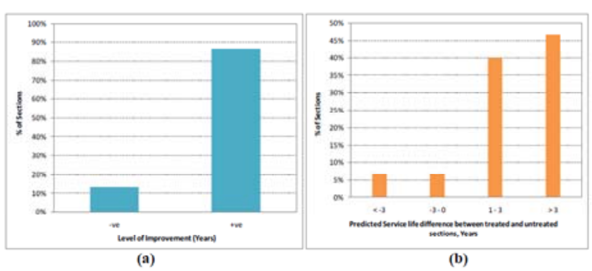
- To evaluate and compare different reflective cracking control treatments by evaluating the performance, constructability, and cost-effectiveness of pavements built with these treatments across the state
    - The performance of 50 different sites that were constructed with various treatments was evaluated for a period ranging from 4 to 18 years
    - Among various treatments that were analyzed, saw and seal, and chip seal as a crack relief interlayer showed the most promising results in terms of performance and economic worthiness

Areas of Benefit:

- Increased Service Life
- Reduced Construction, Operations and Maintenance Costs
- Materials and Pavement

Methods for determining the value of research:

- Field experiments
    - Direct comparisons between the predicted service lives of treated sections were made with those of untreated sections.



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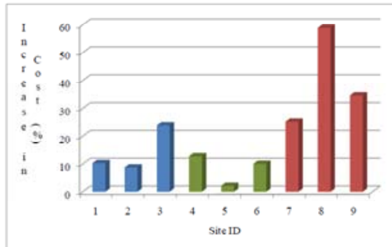
-
    - Cost data for the high strain reflective crack relief interlayer (STRATA®) as well as for HMA overlays were obtained from actual bid items for each project.
        - The majority of the sections indicated that STRATA® is not as costeffective compared to regular HMA overlays



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Findings:

- The majority of the sites showed a positive improvement due to the use of saw and seal
- Forty percent of the sections showed an improvement from 1 to 3 years and 47 percent of the evaluated sections showed an improvement from 4 to 12 years. The average level of improvement to the pavement service life due to the use of saw and seal was 4 years
- The vast majority of the sections (80 percent) indicated that saw and seal is cost-effective as compared to regular HMA overlays. The increase in cost of overlay due to usage of saw and seal treatment ranged from 0.5 to 21 percent
- The majority of the sites showed a positive improvement due to the use of chip seal
- Twenty-five percent of the sections showed an improvement from 1 to 3 years and 33 percent of the evaluated sections showed an improvement from 4 to 10 years. The average level of improvement to the pavement service life due to the use of chip seal was 2 years
- The vast majority of the sections (75 percent) indicated that chip seal is cost-effective as compared to regular HMA overlays. The increase in cost of overlay due to usage of chip seal treatment ranged from 10 to 71 percent

Measures:

- Increased pavement service life
- Cost savings

Data Sources:

- Filed data (District surveys, the LADOTD databases and pavement management system data)
- Cost data for the high strain reflective crack relief interlayer (STRATA®) as well as for HMA overlays were obtained from actual bid items for each project.

Research project:

- "Implementation of Rolling Wheel Deflectometer (RWD) in PMS and Pavement Preservation"
- Sponsored by Louisiana DOTD

Research objectives:

- To develop and validate a direct and simple model for determining the pavement Structural Number (SN) using RWD deflection data
  - The relationship between the average RWD surface deflection and the peak Falling Weight Deflectometer (FWD) deflection was investigated

Areas of Benefit:

- Improved Productivity and Work Efficiency

Methods for determining the value of research:

- Benefit analysis:

Item	Units	FWD	RWD
FWD and RWD Daily Cost	$ per day	$4,200	$10,500
FWD and RWD Daily Productivity - Interstate	ln-mi per day	30	250
FWD and RWD Daily Productivity - Secondary	ln-mi per day	20	150
FWD and RWD Daily Productivity - Local Roads	ln-mi per day	15	100
Per Mi Cost - Interstate and Multilane Primary Routes	**$ per ln-mi**	**$140**	**$42**
Per Mi Cost - Primary and Secondary Two-Lane Routes	**$ per ln-mi**	**$210**	**$70**
Per Mi Cost - Local Rural Routes	**$ per ln-mi**	**$280**	**$105**
Traffic Control - Interstate and Multilane Primary Routes	$ per day	$3,200	n/a
Traffic Control - Primary and Secondary Two-Lane Routes	$ per day	$1,600	n/a
Traffic Control - Local Rural Routes	$ per day	$800	n/a
Traffic Control - Interstate and Multilane Primary Routes	$ per ln-mi	$107	n/a
Traffic Control - Primary and Secondary Two-Lane Routes	$ per ln-mi	$80	n/a
Traffic Control - Local Rural Routes	$ per ln-mi	$53	n/a
Combined FWD and Traffic Control - Interstate and Primary Routes	**$ per ln-mi**	**$247**	**$42**
Combined FWD and Traffic Control - Primary and Secondary Routes	**$ per ln-mi**	**$290**	**$70**
Combined FWD and Traffic Control - Local Rural Routes	**$ per ln-mi**	**$333**	**$105**

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  - Results from the table:
    - While the daily cost of RWD is greater than that for FWD, RWD has a much higher daily productivity than FWD and it does not require traffic control.
    - While both test methods report similar trends in deflection measurements, the applications of each test method remain different.
    - While RWD is recommended as a screening tool at the network level to identify structurally deficient sections, the FWD may be applied as a more accurate structural evaluation tool, by assessing the structural capacity of the pavement and by conducting a complete back calculation of layer moduli to assist in overlay design.

Measures:

- Decrease of traffic interruption or increase of safety along tested road segments
- Productivity

Data Sources:

- A detailed field evaluation of the RWD system in Louisiana in which 16 different test sites representing a wide array of pavement conditions were tested

Michigan Department of Transportation (MDOT)

Research Project:

- "A Sensor Network System for the Health Monitoring of the Parkview Bridge Deck"
- Sponsored by: Michigan DOT
- In 2008 MDOT built a four-span, three-lane bridge using rapid construction techniques.
- Piers, abutments, I-beam girders, and full-depth deck panels were all prefabricated off-site.

Research Objective:

- Compare the costs, construction time and work flow with traditional construction techniques.
- Instrument the prefabricated deck panels with a structural health monitoring system and record strain and temperature data for the one-year period following completion of the bridge.

Areas of benefit:

- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Benefit (Time and Cost) Analysis
- Benefit (Performance) Analysis

Methodology for assessing time and cost savings

- A comparison study was carried out to assess the performance of the RBC technique at the Parkview Bridge.
- In this study, the performance for all construction activities was recorded, the productivity was calculated, and an as-built CPM schedule was developed.
- The performance data for the conventional approach were obtained from the Lovers Lane Bridge project, which is spatially and temporally close to the Parkview Bridge, to establish the baseline for the comparison study.
- Step-by-step and element-by-element comparisons were conducted to identify sources for time savings and to quantify such savings by assessing the travelers' user cost savings that were achieved due to the shortening of the construction duration.

Results:

- Side-by-side analysis of rapid and traditional construction techniques showed overall user time savings of 45 days with rapid construction, or a reduction of 42 percent in project duration, compared with traditional techniques.

- The sensor system also performed as intended, demonstrating that each joint between panels behaved according to design specification and that the structure acted as a unit.

Measures:

- Construction time
- Construction cost
- Performance (Temperature and strain of the prefabricated deck)

Data sources:

- Field data collection (Construction time, cost and productivity)
- Data collection using sensors (Temperature and strain data)
- Assumptions

Minnesota Department of Transportation (MnDOT)

Research project:

- "Economic benefits resulting from road research performed at MnROAD"
- Prepared by B. J. Worel, M. Jensen, and T. R. Clyne from MnROAD
- The Minnesota Road Research Project (MnROAD) was built in the early 1990s and has led to positive economic benefits during its initial research phase.
- MnROAD was constructed by the Minnesota Department of Transportation (Mn/DOT) in 1990-1993 as a full-scale accelerated pavement testing facility, with traffic opening in 1994.

Research objectives

- Present a summary of the costs and benefits of the research and construction activities undertaken at MnROAD for both its original Phase-I (1994-2006) and made an attempt to predict future benefits for Phase-II (2007-2017) of MnROAD.

Phase-I costs:

- MnROAD Phase-I (1994-2006) costs were estimated at $44,304,562.
- This takes into account money is invested during the project (1994-2006) (including initial design, construction, environmental impact study, initial pilot projects, pavement sensors and data collection equipment, land along I-94, buildings, and equipment), Operating costs, and Annual research contracted projects .

Phase-I benefits:

- The return on investment starts in the middle of MnROAD's phase-I efforts and continue for a finite period (2012) for this analysis.
- This time frame is assumed (12 years) and neglects additional future benefits that exist past the selected analysis period.
- These benefits are usually cost savings (or potential cost savings) attributed to the research done.
- These benefits does not include the benefits that are hard to put dollar value to.
- Benefit calculation is specific to each pavement research project, such as "Spring Load Restrictions" project .
- Neither national (rest of the states) nor local privately owned pavements were included in the cost savings even though they also gain a benefit through the research findings and updated construction specifications.
- Its benefits were conservative estimated at $33 million per year for six research findings over a 12-year period (2000-2012) valued at $396,000,000.

Phase-I benefits/cost ratio:

- This represents a 8.9/1 benefit/cost ratio if you consider all the costs (construction, staffing, research projects) over the first 12 years of MnROAD and assume the research benefits started at year 6 (2000) and will run at least another 6 years after Phase-I is complete (2012) for this analysis.

Example of benefit analysis for projects in phase 1:

- Spring Load Restrictions
    - In Minnesota there are about 39,000 miles of paved roads that do not meet the 10-ton spring load design standard and therefore should be restricted to lower loads during the spring.
    - The vast majority of these roads are paved with asphalt concrete, which has an annual construction and overlay cost of about $12,000 per mile per year.
        - This cost is based on a present value construction cost of $210,000 per mile, which includes two overlays, a discount rate of 4.5 percent, and a total life of 35 years.
    - A delay in the start of SLR may result in more than one year of life lost before the first overlay and that complete reconstruction may be required after 32 years rather than the projected 35 years.
    - Given these shortened period the actual annual cost would be about $12,500 per mile per year rather than $12,000 per mile per year.
    - Multiplying this $500 per mile per year by the number of miles of restricted roads (most likely to sustain spring damage - about 75 percent of the 39,000) or 29,000 miles.
    - Benefit = $14,000,000 a year (2000 dollars)

Phase-II projected costs:

- A couple of examples of projected costs were calculated.

Phase-II projected benefits:

- A couple examples of projected benefits were calculated and reviewed, but the authors believe that it is too early to predict the real benefits future research will bring.

Mississippi Department of Transportation (MsDOT)

Research project:

- "MsDOT Implementation Plan for GPS Technology in Planning, Design, and Construction Delivery"
- Sponsored by Mississippi DOT

Research objectives:

- To develop a guide for MsDOT implementation of GPS technology, both internally and externally, assisting the agency in the areas of construction specifications, quality control, business policies, and procedures, and cost budgeting
- To present recommendations for specification language regarding contractor use of GPS for Automated Machine Grading (AMG) and the sharing of MsDOT electronic data

Areas of Benefit:

- Improved Productivity and Work Efficiency
- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Benefit analysis:
    - GPS utilization is simply faster than conventional surveying methods, also it:
        - Reduces field crews
        - Replaces aerial photogrammetry new technology (Utilizing GPS) for surveying and layout
        - Reduces number of persons onboard (POB) in field surveys from 898 to 509
        - Reduces errors and omissions
        - Enhances safety for surveys staff and the traveling public

Application	Process Improvement	Resource(s) Saved
Design surveying	Reduces field crews; replaces aerial photogrammetry, reduces facility design-phase duration	Labor count, man-hours, consultants, project duration
Staking	Reduces field crews; reduces iterations; reduces errors	Labor count, man-hours
Machine guidance	Staking iterations, machine operator reliance on physical stakes, physical staking	Labor count, man-hours, project duration, equipment-hours
As-built documentation	Reduces field crews, inspection time	Labor count, man-hours

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    - Saved approximately 20-30 percent on earthwork costs and time
        - Labor resource savings
        - Equipment resource savings
            - Reduction in rework

- Reduction of facility design-phase duration

GPS Application	Replacing	Quantified Savings
Grade checking	Manual method	Up to 66% time savings
Reduction or elimination of stakes	Conventional staking	Up to 85% time savings
Improved material yields/select fills/undercutting	Overruns using manual methods	3% to 6% by volume
Un-interrupted earth moving production-all weather-continuous shifts (including night work)	Day shifts, non-precipitous weather	30% to 50% time savings
RTK, robotics stakeout	Traditional survey stakeout	More than 100% in speed and 66% in staffing (labor count)

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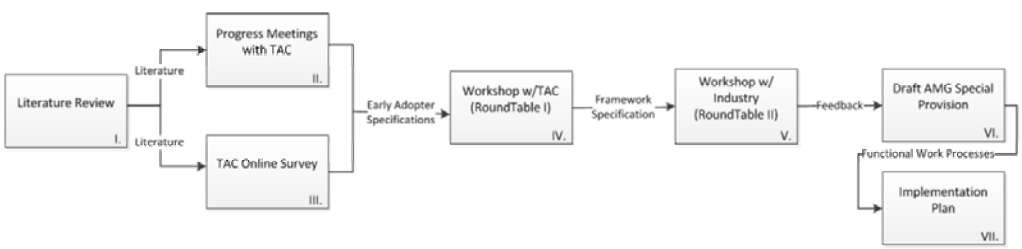
Measures:

- Time saving and cost saving
- Productivity improvement

Data Sources:

- Utilizing workshops with Technology Advisory Committee (TAC) and Progress meetings with MDOT about the implementation of GPS technology for automated machine grading



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Missouri Department of Transportation (MoDOT)

Research Project:

- "Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri"
- Sponsored by Missouri Department of Transportation

Research objectives:

- To increase traffic capacity and improve safety

Areas of Benefit:

- Safety
- Environmental sustainability
- Traffic and Congestion Reduction

Methods for determining the value of research:

- Before-and-after analysis:
    - It compared operational measures taken before implementation of the system to the same measures taken 1 month and 5 months after implementation:
        - Fewer red lights as people travel through the corridor, there will be fewer read-end crashes
        - The change in vehicle emissions (estimated for HC, CO, and NOx) ranged from an increase of 9 percent to a decrease of 50 percent
        - The morning off-peak and noon-peak period in the southbound direction of travel experienced the travel time improvements of over 140 seconds
        - The change in average speed ranged from a decrease of 0.2 mph to an increase of 15.5 mph
    - The evaluation found that travel time through the corridor decreased from 0 percent to 39 percent (as much as 2.5 minutes for some time periods), depending on time of day and direction of travel.

Measures:

- Number of stops reduction
- Average speed
- Travel time reduction
- Fuel consumption saving
- Emission reduction

Data Sources:

- Traffic operational field data collected both before-and-after deployment of the adaptive signal system including:

- Field Study Description
- Travel Time Runs
- Minor-Street Delay
- Turning Movement Count
- Traffic Volume Counts

Research Project:

- "Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13) and Diverging Diamond Lessons Learned document"
- Sponsored by Missouri Department of Transportation

Research objectives:

- To increase traffic capacity and improve safety
- To answer questions on traffic operations, safety and public perceptions

Areas of Benefit:

- Safety
- Traffic and Congestion Reduction
- Customer Satisfaction
- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Simulation of traffic modeling to find an innovative interchange solution in the United States.
- Before-and-after study
    - To compare pre-construction and post-construction crash conditions
    - To Evaluate the operational and safety performance of the first Diverging Diamond Interchange installed in the United States
        - Rear-end type crashes were down slightly that might also be the results of how left turns are handled not under traffic signal control
        - Average vehicular speed at the signalized intersections are decreased
        - Total crashes reduced 46% in the first year of operation and left turn and left turn right angle type crashes were down 72%
        - Recovery time after severe congestion or an incident is considerably reduced
- Survey
    - The public perceptions was collected from the followings:
        - General Public
        - Pedestrians and Bikes
        - Larger Vehicles (Trucks, Recreational vehicles – mobile homes, boats, etc.)
    - Results of survey
        - A very high percentage (80% plus) expressed that traffic flow had improved and traffic delay had decreased;

        - A very high percentage (87%) expressed that crash were more likely to occur within a standard diamond when compared to a DDI;
        - A very high percentage (around 80%) expressed that larger vehicles and pedestrian/bike movements through the DDI were better or similar to a standard diamond interchange;
        - A very high percentage (91%) expressed good understanding on how the interchange operated with the current design of islands, signing, signals and pavement markings.

Findings:

- Loads up to 18 feet wide and 200 feet long successfully moved through Diverging Diamond Interchange (DDI)
- Fewer navigation errors, wrong way movements, and red light violations occurred with the Diverging Diamond Interchange scenarios
- Diverging Diamond Interchange offers a substantial improvement in operations over other interchange types when turning volumes are high

Measures:

- Reduction in number of Crashes
- Enhanced public perception
- Reduce of navigation errors and light violation
- Reduction in construction cost

Data Sources:

- Field Study before-and-after analysis:
    - Performance Measurements (Crash data and severity) based on traffic volumes to compare Pre-construction (4 yrs) and post-construction (1yr) crash conditions
- Data collected using survey

Research project:

- "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule"
- Sponsored by Missouri Department of Transportation

Research objectives:

- To monitor and evaluate the light output of MoDOT's LED traffic signal lights
- To identify best practices and replacement standards for LED traffic signal technology

Areas of Benefit:

- Environmental Sustainability
- Increased Service Life
- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Benefit analysis using filed experiments and statistical analysis:
  - Rates of degradation were statistically analyzed using Analysis of Variance (ANOVA)
    - LEDs improves economic, performance and safety perspective
    - LEDs ensure safety of the traffic
    - LEDs use less energy
    - LEDs have longer life expectancies, require less maintenance and have an overall cheaper life-cycle cost;
  - A failure of an LED indicator could cause negative impacts to the traffic it controls.
- Benefit (Dollar) analysis
  - A summary of results is exhibited in the following table. Based on previous literature review, a 10-year life span is applied in this analysis. An average electric cost \$0.1/kWh (MoDOT Electricity Bill, 3rd quarter 2010) is applied in this analysis. Carbon footprint is considered as one of the benefits of using LEDs. The total CO2 reduction is calculated by multiplying the reduced quantity of kWh produced by LEDs by the average CO2 emissions associated with one kWh generated electricity in Missouri (0.000685lbs/kWh, according to MODOT record). The payback period for a module containing red, yellow and green LED lights is 2.01 year.

	Red	Yellow	Green	Whole Module	Ref
Unit Wattage Save (kw)	0.14	0.136	0.14		ActOne ,2010
Device Cycle Time Percentage	50%	6%	44%	100%	Assumption
Material Cost ($/unit)	57	66	119	242	Anonym, 2003
Installation Labor ($/unit)	15	15	15	45	Leotek, 2010
Total Initial Investment ($/unit)	72	81	134	287	
Annual Maintenance Saving ($/unit)	11	0	11	22	Anonym, 2000
Annual Energy Saving ($/unit)	60.48	7.05	53.22	120.75	$0.1/kwh
Total Annual Savings ($/unit)	71.48	7.05	64.22	142.75	
Payback period (year)	1.01	11.49	2.09	2.01	
Annual CO_2 decrease (tons/unit)	0.41	0.05	0.36	0.83	6.85×10^{-4} tons/kwh MoDOT 2010

Measures:

- Energy savings
- Increase of life expectancies

Data Sources:

- Field data (Site data collection)

North Carolina Department of Transportation (NCDOT)

Research project:

- "Placement of Detection Loops on High Speed Approaches to Traffic Signals"
- Sponsored by: North Carolina DOT (NCDOT) Office of Research

Research objectives:

- Evaluate various systems
    - Base case (standard NCDOT detector placements)
    - Detector-Control System (D-CS)
    - NQ4 system

Areas of benefit:

- Safety
- Traffic and Congestion Reduction
- Reduced User Costs

Methods for determining the value of research:

- Assessment of operation efficiency (Hardware-in-the-loop simulation tests and Field studies)
- Benefit (Dollar)/Cost (Dollar) analysis

Assessment of operational efficiency

- Intersection delay, queue length and number of stops were used as measures of effectiveness (MOEs) to assess the operational efficiency.
- Simulation study
- Field study
    - Data were collected for each alternative system once at a time.
    - Data were collected using detectors, camera and persons.
- Evaluation metrics:
    - Probability of n vehicles being in a dilemma zone at the onset of yellow, n = 0, 1, 2, ..;
    - Probability of n trucks being in a dilemma zone at the onset of yellow, n = 0, 1, 2, ….;
    - Probability that n vehicles violated the red light;
    - Average delay per vehicle, overall and by approach; and
    - Average cycle length.

Cost benefit analysis was used to assess cost effectiveness of alternatives.

- "It is assumed that the life of these systems is 15 years."

Safety

- An estimated percent reduction (A marginal 10 percent reduction) of crashes was assumed due to installation of technologies.
- Crash data for year's 2006, 2007 and 2008 were collected from North Carolina Department of Transportation and the average number of crashes was used for calculating benefits.
- The equivalent unit crash cost is extracted for each county from North Carolina Department of Transportation Traffic Engineering and Safety Systems branch website.

Installation cost

- Labor, equipment, software, and material

Delay

- The average delay due to detection loops at these intersections is estimated based on stopped delay outputs from VISSIM software simulations.
- The delay is converted to an hourly cost value based on estimates obtained for North Carolina.
    - This cost value \$8.70 /vehicle-hour in 1998 (Rister & Graves, 1999) was inflated using 1.3 percent as inflation rate (Inflation Calculator, 2009) to the present year hourly cost value and is equal to \$11.31 /vehicle-hour.
- Average daily traffic (ADT) is extracted for each selected study intersection from North Carolina Department of Transportation traffic survey maps (NCDOT, 2008).
    - It is assumed that 70 percent of this traffic travels during peak hours at these intersections.
    - Only estimated delay cost for this 70 percent of traffic during peak hours is considered in cost benefit analysis.

Findings:

- Optional efficiency:
    - Both in simulation and in the field, D-CS tended to produce shorter cycle lengths (more efficient and responsive operation) and it did a slightly better job of ensuring that no vehicles were in dilemma zones at the onset of yellow.
- Benefit-Cost analysis:
    - BC ratios significantly greater than 1.0 and the ratios were higher for the D-CS system than for the NQ4 system.

Measures:

- Intersection delay, queue length and number of stops
- An estimated percent reduction (A marginal 10 percent reduction) of crashes

- Dollar benefits attributed to reduction in intersection delay, queue length and number of stops

Data sources:

- Outcome of simulation study
- Field study (Data collection)
- Crash data for year's 2006, 2007 and 2008 were collected from North Carolina Department of Transportation
- North Carolina Department of Transportation Traffic Engineering and Safety Systems branch website
- Equivalent unit crash cost is extracted for each county from North Carolina

Pennsylvania Department of Transportation (PennDOT)

Research project:

- "Freeway Ramp Management Strategies"
- Sponsored by Pennsylvania Department of Transportation

Research Objective:

- To determine the best practices available in ramp management that maybe used in Pennsylvania and to evaluate the feasibility and potentially design the concept of a ramp metering demonstration project in PennDOT District 11-0.

Areas of Benefit:

- Safety
- Traffic and Congestion Reduction
- Reduced Construction, Operations and Maintenance Cost

Methods for determining the value of research:

- Simulation
  - Transportation planning and simulation models were used to evaluate travel pattern changes and measures of performance of the I-376 freeway with ramp management strategies in place.
  - Simulation model measures of effectiveness:
    - Tunnel Queue
    - I-376 Throughput
    - I-376 Travel Time
    - I-376 Delay Time
    - Total System Travel Time
    - Total System-wide Stops
    - Spot Queues at Critical Intersection
    - Internal Study Area Travel Times
- Benefit (Dollar) / Cost (Dollar) Analysis
  - Three main user benefits were examined for each option:
    - Value of Time
    - Operating and Ownership Cost
    - Crash Cost
  - Once these benefits were determined, the benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours.
  - Both the user benefits and the capital and operating costs for each year of the expected ramp management project were entered into a basic present value

formula (using a riskless real discount rate and a risk premia) to bring values back to present day dollars.
  - A real rate was used (vs. a nominal rate) because the net benefit calculations were in real terms (i.e. uniflated).
  - A risk premia was used to obtain a risk adjusted discount rate.
  - The total present value benefit to present value cost ratio was then calculated for each ramp management option.

Measures:
- Crash cost saving
- Total value of time savings (attributed to reduction in total delay)
- Operating and ownership cost saving

Data Sources:
- Outcome of the simulation model
- PennDOT iTMS data and PennDOT ATR counts, and number of crashes within the limits of the ramp metering from the data given by PennDOT
- AASHTO User Benefit Analysis for Highways Handbook
- September 2010 AASHTO publication “User and Non-User Benefit Analysis for Highways.”
- http://www.inflationdata.com/, Census (2005-2009 Average) data, "Intelligent Transportation Systems Benefit: 2001
- “Intelligent Transportation Systems Benefits: 2001 Report” by AASHTO

Texas Department of Transportation (TxDOT)

Research project:

- “Use of Fine Graded Asphalt Mixes Project 0-6615”
- Sponsored by Texas Department of Transportation

Research objectives:

- To develop Specifications of wearing surface on high volume roadways for the following three types of thin surfacing:
    - Fine Grade Permeable Friction Course
    - Fine Graded Stone matrix Asphalt
    - Crack Attenuating Layer

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Benefit (Cost saving) analysis:
    - The thin overlay proposed in this study are 20 percent more expensive per ton than traditional dense graded surfacings , but as they can be placed in lift of ¾ to 1inch as opposed to traditional 1.5 to 2 inches the will generate a substantial saving (approx. 30 percent per sq. yard) for the DOT

Measures:

- Cost Saving for replacing the thin overlay proposed in the study

Data Sources:

- Laboratory Evaluation of Micro-Overlay Systems including testing several four slurry overlays for cracking resistance, skid resistance, abrasion resistance, and bond strength

Research project:

- "Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements"
- Sponsored by Texas DOT-Construction, Pavements and Maintenance Research Committee, Research and Technology Implementation Office

Research objectives:

- To develop and recommend a process to integrate the upgraded overlay tester into TxDOT's current mixture design system
- To develop a Hot Mix Asphalt (HMA) overlay thickness design methodology and provide a material selection guide for district use

Areas of Benefit:

- Materials and Pavement
- Engineering Design Improvement
- Reduced Construction, Operations and Maintenance Cost

Methods for determining the value of research:

- Simulation by Use of TxACOL software:
    - To address issues such as where to use high-performance mixes, optimal thicknesses, particularly in the area of jointed flexible concrete pavements where joints must be repaired prior to placing any overlay
    - To produce as minimum 5 percent reduction on the use of asphalt mixes per year due to the improved performance of the overlays
    - To save $15 million savings per year for TxDOT by assisting TxDOT engineers in designing and implementing longer-lasting overlays

Measures:

- Increase of flexibility by optimal thickness and the combination of aggregates and binder types
- Reduction on the use of asphalt mixes

Data Sources:

- Nondestructive testing tools available in Texas, which include ground penetration radar, the falling weight deflectometer, and rolling dynamic deflectometers on 11 mixes commonly used in Texas

Utah Department of Transportation (UDOT)

Research project:

- "Retrofitting Culverts and Fish Passage-Phase II "
- Sponsored by Utah Department of Transportation

Research objectives:

- To better understand the aquatic limitations of installing slip-lined culverts as a means of culvert rehabilitation

Areas of Benefit:

- Environmental sustainability

Methods for determining the value of research:

- Simulation in the laboratory
  - Big size fishes such as brown trout (60 ft long) are considered as the bottle neck size;
  - Each culvert was tested on slopes ranging from horizontal to 5 percent, with a variety of flows at each slope
  - By running a series of trial runs, it was determined which situation was most conducive to fish passage
  - The results provide useful insight into how fish are able to pass through excessive velocity barriers in their natural environment

Measures:

- Fish passages

Data Sources:

- The laboratory tests
  - Mark and Recapture
  - Flow measurements
  - Pebble Count
  - Velocity measurements

Virginia Department of Transportation (VDOT) / Virginia Center for Transportation Innovation and Research

Research Project:

- "Examination of an implemented asphalt permeability specification"
- Sponsored by Virginia DOT
- Because of the susceptibility of many mixtures to the entrance of water, a new permeability specification for approval of asphalt job mixtures was implemented by the Virginia Department of Transportation (VDOT) in 2005 in an attempt to eliminate permeable mixtures.

Research Objective:

- Determine if the contractors had to change the mixture designs so that the mixture would comply with the new permeability requirement and whether the specification produced pavements with acceptable permeability.

Areas of benefits:

- Increased Service Life
- Materials and Pavements

Method for determining the value of research:

- Benefit (Dollar) Analysis

Benefit (Dollar) Analysis

- Contractors were asked to indicate voluntarily whether mixture designs had to be redesigned because of permeability issues.
- Each district materials engineer in the nine VDOT districts was asked to sample and test at least two surface mixtures to determine the level of permeability being achieved in the pavement.
- During 2005, approximately 165,000 tons of hot-mix asphalt that had to be redesigned because of permeability problems was placed at a cost of $7.5 million.
- It is reasonable to assume that the service life would have been shortened by 15 percent because of the high permeability.
- VDOT's savings for 2005 as a result of the new specification would have been 0.15 x $7.5 million = $1,125,000

Measures:

- Tons of hot-mix asphalt that had to be redesigned because of permeability problems
- The service life that would have been shortened because of the high permeability

Data Sources:

- Tons of hot mix asphalt that had to be redesigned provided by:
  - Contractors were asked to indicate voluntarily whether mixture designs had to be redesigned because of permeability issues.
  - Each district materials engineer in the nine VDOT districts was asked to sample and test at least two surface mixtures to determine the level of permeability being achieved in the pavement.
- Assumption that 15% of the service life that would have been shortened

Research project:

- "Analysis of Full-Depth Reclamation Trial Sections in Virginia"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To extend the service life of pavement structures requiring deep rehabilitation and to stretch available funding for this maintenance

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Increased Service Life

Methods for determining the value of research

- The life-cycle cost analysis:
    - It compared a traditional pavement rehabilitation program (based on partial- and full-depth mill and replacement) with one that incorporated FDR

Year	Traditional Approach	Approach Including FDR
0	1% patch, 4-in mill and overlay	2-in mill, FDR and 3-in overlay
8	1% patch, 2-in mill and overlay	---
12	---	1% patch, 2-in mill and overlay
16	1% patch, 2-in mill and overlay	---
22	---	1% patch, 2-in mill and overlay
24	1% patch, 2-in mill and overlay	---
32	1% patch, 4-in mill and overlay	2-in mill, FDR and 3-in overlay
40	1% patch, 2-in mill and overlay	---
44	---	1% patch, 2-in mill and overlay
48	1% patch, 2-in mill and overlay	---
50	Salvage	Salvage

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	Traditional Approach		Approach Including FDR	
Year	Action	Present Cost, $/yd^2	Action	Present Cost, $/yd^2
0	1% patch, 4-in mill and overlay	18.90	2-in mill, FDR and 3-in overlay	19.05
8	1% patch, 2-in mill and overlay	7.08	---	---
12	---	---	1% patch, 2-in mill and overlay	6.06
16	1% patch, 2-in mill and overlay	5.18	---	---
22	---	---	1% patch, 2-in mill and overlay	4.09
24	1% patch, 2-in mill and overlay	3.78	---	---
32	1% patch, 4-in mill and overlay	5.39	2-in mill, FDR and 3-in overlay	5.43
40	1% patch, 2-in mill and overlay	2.02	---	---
44	---	---	1% patch, 2-in mill and overlay	1.73
48	1% patch, 2-in mill and overlay	1.48	---	---
50	Salvage	(1.02)	Salvage	(0.55)
Total		42.80		35.81

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-
    - If the present costs of the traditional pavement rehabilitation approach are multiplied by the total area of the potential FDR sites, the cost over a 50-year life cycle is calculated as $60.95 million ($42.80/yd2). If the present costs of the pavement rehabilitation approach incorporating FDR are multiplied by the total area of the potential FDR sites, the cost over a 50-year life cycle is calculated as $51.00 million ($35.81/yd2)

  - it is feasible that VDOT could save approximately $10 million (approximately $40,000/lanemile) over a 50-year period by implementing an FDR program for those flexible pavements identified on the primary network
  - If these savings are annualized, the potential savings are approximately $463,000/year (approximately $1,850/lane-mile/year)

Measures:

- Saved cost of the pavement rehabilitation
- Increased service life

Data Sources:

- Laboratory Evaluation to estimate service life of pavement structures
- Field Evaluation to apply proposed FDR

Research project:

- "Investigation of the use of tear-off shingles in asphalt concrete"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To evaluate the suitability of using tear-off shingles in asphalt concrete
  - Two base mixes and two surface mixes were produced, and one of the surface mixes was produced by both hot mix and warm mix technology
  - The laboratory tests used to evaluate the mixes were tests to determine conventional gyratory volumetric properties, gradation, and asphalt content; rut tests; fatigue tests; and tests to determine recovered asphalt properties

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Materials and Pavements

Methods for determining the value of research:

- Costs and benefits assessment:
  - The cost savings per ton of plant mix is approximately $3 to $5 when reclaimed shingles are used
  - Assuming an average cost of virgin binder for VDOT's 2009 construction season of approximately $400 per ton, a savings of approximately $3.40 per ton of Hot Mix Asphalt (HMA) would be realized with the use of reclaimed shingles
  - If a savings of $3 per ton could have been realized on one-half of the 400,000 tons of HMA produced last year for VDOT, VDOT would have saved approximately $600,000

Measures:

- Cost saving by replacing reclaimed shingles in asphalt concrete

Data Sources:

- The laboratory tests to evaluate the mixes

Research project:

- "Recycling of Salt-Contaminated Stormwater Runoff for Brine Production"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To determine the possibility of recycling salt-contaminated stormwater runoff for the purpose of producing brine that can be used for pre-wetting of granular NaCl and direct application

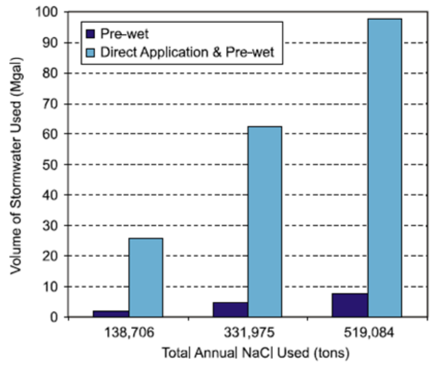
Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Environmental sustainability

Methods for determining the value of research:

- Benefit (dollar) analysis:
    - The annual benefits were calculated as the difference between the costs of disposal of the total annual volume of stormwater runoff accumulated and disposal of the volume remaining after the brine production (water not used for brine generation would still need disposal at cost), plus the savings resulting from the use of the NaCl brine solution instead of CaCl2 or MgCl2 as the pre-wetting solution. For this analysis, a cost of $0.50/gal for the CaCl2 and MgCl2 solutions was assumed.
    - Proper management and reuse of the stormwater runoff for brine creation will not only result in significant savings ($1 million to $6 million annually depending on total annual precipitation), roadway chloride loading will be significantly reduced (35%), fewer fresh water resources will be needed for anti-icing, and the potential for offsite contamination of ground and surface water sources will be decreased.
- Benefit (dollar) analysis:
    - Reuse of the stormwater runoff for brine creation will result in
        - Significant savings ($1 million to $6 million annually depending on total annual precipitation)
        - Roadway chloride loading will be significantly reduced (35%)
        - Fewer fresh water resources will be needed for anti-icing
        - The potential for offsite contamination of ground and surface water sources will be decreased

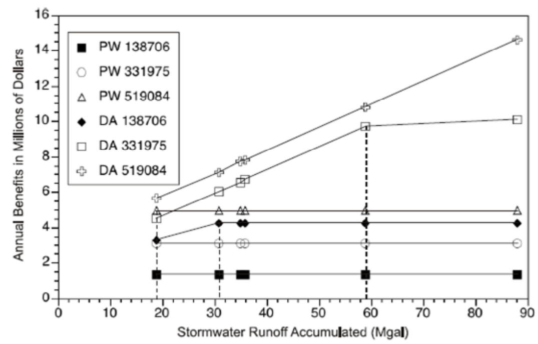
    - The estimated volumes of water that would be used for (1) pre-wetting only and (2) direct application in combination with pre-wetting when assuming the low, average, and high NaCl annual application rates are shown in following figure



Estimated Annual Stormwater Usage for Pre-wetting and Direct Application and Pre-wetting Based on Low, Average, and High 5-Year Total NaCl Application (Copyright of Fitch, Graver, and Smith (2008))

- Benefit (dollar) analysis:
    - The estimated annual benefits for 36 brine use scenarios evaluated at the statewide average disposal cost per gallon are shown in following figure
        - The calculated values range from a low of just over $1 million to a high of over $14 million
        - The lowest value was calculated assuming less than 20 million gallons of stormwater are collected, brine created from this stormwater is used exclusively for the purposes of pre-wetting, and a minimum volume of NaCl (138,706 tons) is applied statewide.
        - The greatest annual benefits were calculated assuming that brine is used for both direct application and pre-wetting purposes, nearly 90 million gallons of stormwater is collected
        - The highest total NaCl volume (519,084 tons) is applied. When assuming average stormwater volume collection and average total NaCl application, the benefits calculated for pre-wetting only versus adding direct application to pre-wetting are approximately $3 million and $6.5 million, respectively

- Benefit (dollar) analysis



Annual Benefits Obtained by Use of Pre-Wetting (PW) or Direct Application (DA) Strategies as Function of Volume of Stormwater Runoff Accumulated and Amount of Road Salt Purchased (Copyright of Fitch, Graver, and Smith (2008))

Findings:

- The optimum conditions for brine production were low hydraulic retention time (high flow rates) and high temperatures
- VDOT appears to capture sufficient volumes of water to meet the majority of its potential brine production needs
- The total suspended solids present in the stormwater runoff did not diminish the quality of the brine in the field tests

Measures:

- Disposal cost saving by recycling of salt-contaminated stormwater
- Amount of reuse of the stormwater runoff

Data Sources:

- Field and lab experiments using bench-scale brine generation equipment

Research project:

- "An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To develop cost-efficient options to address the growing problem of disposing of animal carcasses

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Environmental sustainability
- Safety

Methods for determining the value of research:

- Benefit analysis:
    - Develop a method to allow VDOT maintenance area staff to determine costs incurred for carcass management in order to compare them to the costs of other methods
    - Illustrate cost scenarios using case studies from survey respondents, and create a decision tool to guide the selection of a carcass management method

Case Study[a]	Annual No. of Deer Carcasses	Disposal Facility Cost	Estimated Off-Route Distance to Disposal Facility (mi)	Annual Savings with Compost Windrows[a]	No. of Years to Offset Equipment and Operating Costs		Reallocable Labor-Hours per Year From On-Site Disposal
					Composting Drum	Incinerator[b]	
1	192	No charge	15	$2,225	21.6	-	64
2	150	$32/tom	20	$2,487	17.9	-	67
3	332	$55/ton	25	$7,460	4.4	14.1	184
4	250	$0.50/deer	40	$7,543	4.4	10.6	222
5	200	No charge	30	$4,450	8.1	37.9	133

On-site = either at the maintenance area or along a routine route

a:Savings in labor, fuel, and disposal facility fees are included in the calculation

b: Dashes indicate that current carcass management costs are too low to offset incinerator costs (within the parameters of the model used)

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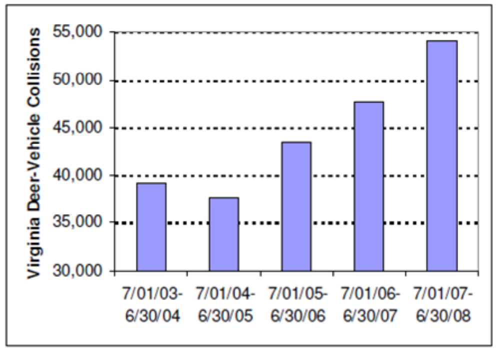
Survey Findings:

- Carcass management methods investigated that removing animal carcasses from the road and properly disposing of them is an essential service on Virginia roadways to decrease animal-vehicle collisions or environmental degradation due to on site burial



Deer-Vehicle Collisions in Virginia 2003-2008
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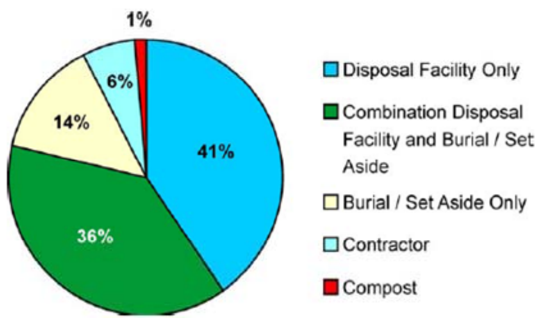

Carcass Disposal Methods Used by VDOT Area Headquarters
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Measures:

- Cost saving
- Environmental degradation reduction as a percentage of site burial
- Deer-vehicle collisions reduction

Data Sources:

- Field study
- Survey data collection

Research project:

- "Geotechnical Data Management at the Virginia Department of Transportation"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To develop a practical, comprehensive, enterprise-wide system for entry, storage, and retrieval of data needed for foundation design data

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Improved Productivity and Work Efficiency

Methods for determining the value of research:

- Benefit cost analysis:
    - Cost savings associated with fully implementing GDBMS are expected to be long term, resulting primarily from increased efficiency of data entry and retrieval
        - It is estimated that on the average, the use of this technology would cut in half the time required to gather and process borehole data, resulting in approximately 16 person-hours of savings at an average rate of $100 per hour (including overhead)
            - It is conservatively estimated that the labor-cost savings would be approximately $600 for each average small- to mid-size bridge project
        - For the past 15 years, VDOT has been approving an average of 102 bridges per year for construction
        - Therefore, the potential cost savings are on the order of $160,000 per year, excluding the consideration of retaining walls, sound walls, and megaprojects

Measures:

- Cost saving
- Time savings

Data Sources:

- Assumptions about benefits

Research project:

- "Performance of Virginia's Warm-Mix Asphalt Trials"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To evaluate the initial two-year performance of three Warm-Mix Asphalt (WMA) trial sections that VDOT installed in 2006. Hot-Mix Asphalt (HMA) sections were used as controls

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs
- Materials and Pavements

Methods for determining the value of research (Cont'd):

- Benefit analysis:
  - Between February and October 2009, VDOT approved maintenance contracts using HMA surface mixtures valued at approximately $101 million
  - If, conservatively, VDOT replaced 10 percent of these mixtures with WMA with beneficial aging characteristics—and the apparent trend of a 1-year reduction in the rate of aging continues, resulting in deferring repaving by a year—VDOT could realize a one-time cost savings of approximately $1.15 million.
  - Calculation is based on benefit incremental of using WMA over HMA:

$$\text{Benefit Increment} = \frac{LCC_{HMA}}{(1+r)^{T_{HMA}}} - \frac{LCC_{HMA}}{(1+r)^{T_{WMA}}}$$

Where

$$LCC = C \times \frac{(1+r)^T}{(1+r)^T - 1}$$

If it is assumed that r = 0.02, THMA = 8, and TWMA = 9, the "benefit" increment (the future cost savings attributable to longer service life) of a single application of WMA can be calculated as:

$$\text{Benefit Increment} = \frac{LCC_{HMA}}{(1.02)^8} - \frac{LCC_{HMA}}{(1.02)^9} = \frac{C_{HMA}}{1.02^8 - 1} - C_{HMA} \times \frac{1.02^{-1}}{1.02^8 - 1} = 0.114 \times C_{HMA}$$

Measures:

- Cost saving to perform Warm-Mix Asphalt in comparison with Hot-Mix Asphalt

Data Sources:

- Three trial sections (Sasobit trial sites) data and Visual surveys including:
  - Historic data
  - Core data
  - Ground penetrating radar scans

Research project:

- "Field Comparison of the Installation and Cost of Placement of Epoxy-Coated and MMFX 2 Steel Deck Reinforcement: Establishing a Baseline for Future Deck Monitoring"
- Sponsored by Virginia Department of Transportation

Research objectives:

- To present that a corrosion-resistant reinforcement, MMFX 2, was more cost effective per unit in a bridge deck than Epoxy-Coated Reinforcing (ECR) steel, when both the anticipated and unanticipated costs of the two materials were estimated for a bridge project in Northern Virginia (Route 123 over the Occoquan River)

Areas of Benefit:

- Reduced Construction, Operations and Maintenance Costs

Methods for determining the value of research:

- Benefit (dollar) analysis:
  - Comparison of Epoxy-Coated Reinforcing (ECR) and MMFX2 cost effective per unit

	Direct Unit Costs, $/lb				Indirect Unit Costs (Deck Seal), $/lb			Total Unit Costs, $/lb	
Type	Bid Price	Labor to Place[a]	Deck Seal	Total Direct Costs	RUC	VDOT Overtime	Police Presence	Excluding RUC	Including RUC
ECR	0.51	0.094	0.296	0.90	1.43-2.00	0.0049	0.0005-0.0017	0.91	2.34-2.90
MMFX 2	0.78	0.088		0.87				0.87	

	Direct Unit Costs, $/lb				Indirect Unit Costs (Deck Seal), $/lb			Total Unit Costs, $/lb	
Type	Bid Price	Labor to Place[a]	Deck Seal	Total Direct Costs	RUC	VDOT Overtime	Police Presence	Excluding RUC	Including RUC
ECR	0.51	0.094	0.296	0.90	1.43-2.00	0.0049	0.0005-0.0017	0.91	2.34-2.90
MMFX 2	0.78	0.088		0.87				0.87	

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RUC: Road User Cost

  - ECR appears to have been far less cost-effective per unit than MMFX 2 when both anticipated and unanticipated costs of ECR in this study are estimated
  - MMFX 2 show both labor productivity and comprehensive in-place cost advantages over ECR in this application

Measures:

- Total Dollar Costs
  - Direct Dollar Costs

        - The cost of the deck reinforcing steel placed in the southbound and northbound lanes of the bridge, including that for bolster reinforcement
        - The cost of the labor to handle, transport, and install the reinforcing steel
        - The cost for the southbound deck seal operation, payable to the prime contractor
    - Indirect Dollar Costs
        - Labor-hours of VDOT Inspector Overtime Spent Monitoring Weekend Operations
        - Value of Police Presence in Work Zones During Deck Sealing Operations
        - Travel Delay Cost to Public Caused by Lane Closures Required for Work Zones

Data Sources:

- Data collected from a full-scale reconstruction of a bridge (Route 123 Bridge)
    - (a) Southbound deck
    - (b) Northbound deck

Washington State Department of Transportation (WSDOT)

Research project:

- "Bituminous Surface Treatment Protocol"
- Sponsored by Washington State Department of Transportation

Research objectives:

- To determine the feasibility of using Bituminous Surface Treatment (BST) resurfacings to maintain flexible pavements with higher levels of traffic than in the past
- To develop a better understanding of the impacts of alternating the application of several BST resurfacings and 45-mm Hot Mix Asphalt (HMA) overlays on a portion of the WSDOT route system

Areas of Benefit:

- Traffic and Congestion Reduction

Methods for determining the value of research:

- Simulation:
    - Utilizing of BST instead of HMA in lower Annual Daily Traffic (ADT)
        - ADT of up to 2,000: Apply BSTs unless they are specifically exempted (such as paving through cities, limited BST routes, etc.)
        - ADT of 2,000 to 4,000: Apply a combination of BST and HMA overlays used interchangeably, depending upon pavement condition. Exemptions are allowed for paving through cities, limited BST routes, etc
        - ADT of greater than 4,000: Apply HMA overlays.
    - Verifying of the feasibility of using BSTs to maintain pavements with higher traffic levels (up to 2,000 ADT) than have been applied in the past

Measures:

- Average Annual Daily Traffic (AADT) and Equivalent Single Axle Load (ESAL) levels

Data Sources:

- Data provided by DOT:
    - Most of the required pavement performance information was obtained from 2002 data within the Washington State Pavement Management System (WSPMS) (Sivaneswaran et al., 2002).
    - Other data were obtained through available literature and interviews with WSDOT personnel