Southeast Transportation Consortium

Final Report 636

Development of a Guidebook for Determining the Value of Research Results

by

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13. Abstract
Measuring the value of research is vital for transportation agencies to justify the process efficiency and quality of state research programs. Also, there is a growing need for aggregating the research benefits of each state at the national level in order to develop and support requests for future federal funding for transportation research. The objective of this project is to develop a guidebook that will provide a consistent approach for measuring and documenting the value of completed research for the use of all STC research sections. To obtain this goal, data were collected through a comprehensive literature review and nationwide survey to state DOTs in the United States. Data analysis was conducted to identify research categories/subcategories, benefit categories/subcategories, and benefit measures. A mapping table was then developed to allow users to determine data types associated with the benefit measures. Finally, a quantification method was developed that can calculate the benefit of each completed research. As a result, state DOTs will be able to use a scalable, flexible, and consistent method to compare the value of various completed research projects. The significance of these findings also serves as a baseline for state DOTs whom previously had no indications of the progress of their projects towards their targets.

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator/Manager

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Special Studies Research Manager

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Southeast Transportation Consortium

The RAC Region II has initiated a collaborative research program consortium through the Transportation Pooled Fund (TPF) Program. The research program is called the Southeast Transportation Consortium (STC) and is intended to encourage coordination among member states, as well as provide resources and management of collaborative studies. The Consortium intends to address high priority transportation research topics of common interest to the southeastern and adjoining states. Louisiana serves as the lead agency in the STC.

Directorate Implementation Sponsor

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Abstract

Measuring the value of research is vital for transportation agencies to justify the process efficiency and quality of state research programs. Also, there is a growing need for aggregating the research benefits of each state at the national level in order to develop and support requests for future federal funding for transportation research. However, only a small number of state Departments of Transportation (DOTs) currently use quantification procedures to determine the value of transportation research. According to the results of a survey conducted by the latest Southeast Transportation Consortium (STC) study, "STC Synthesis of Best Practices for Determining the Value of Research Results," a minimal number of state DOTs utilize evaluation guidelines, although almost 70% of the respondents to the survey answered that they have tried to evaluate the quantitative and qualitative benefits of their research projects.

The major obstacles that prevent state DOTs from developing research value evaluation approaches include: data scarcity for the measures selected to estimate research benefits; difficulty in accurately describing the intangible benefits and interpreting the qualitative benefits; unknown benefits at the time of a research value evaluation, which are quantifiable only years after the research is completed; the diversity of the attributes of research projects, which requires a variant form of the methods and measures for estimating the research benefits; and different perspectives of grasping the value of research exists between the interested groups (e.g., public agencies, political leaders, communities, and researchers). Therefore, it is important to provide solutions to overcome, or at least minimize, the described obstacles through the application of alternative measures and quantification methods based on the availability of data and the research output types to successfully develop a systematic, transparent, and practical guidebook for state DOTs.

The objective of this project is to develop a guidebook that will provide a consistent approach for measuring and documenting the value of completed research for the use of all STC research sections. To obtain this goal, data were collected through a comprehensive literature review and nationwide survey to state DOTs in the United States. A thematic analysis was applied on the collected data to capture the meaningful patterns of three main categories: Research Category, Benefit Category, and Benefit Measures. These categories eventually developed a quantifiable value for all the data types. A mapping table was then developed to allow users to determine a data type. These

values were then used to determine the benefit of the research by using them in a quantification method. The quantification method has a range of cases that can occur based on the amount of information available in the project. This information represents the availability of historical data, target value, and performance value, which ultimately will define the accuracy of the value of research.

Finally, a quantification method was developed that can calculate the benefit of each completed research. As a result, state DOTs will be able to use a scalable, flexible, and consistent method to compare the value of various completed research projects. The significance of these findings also serves as a baseline for state DOTs whom previously had no indications of the progress of their projects towards their targets.

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Table of Contents

List of Tables

List of Figures

Introduction

The mission of the U.S. Department of Transportation (DOT) and state DOTs can be summarized as follows: providing a fast, safe, efficient, and environmentally-sound transportation system in order to enhance the quality of life and facilitate economic growth. To achieve this mission, the federal government allocated a total budget of $90.98 billion, including the surface transportation reauthorization of $73.6 billion, to the U.S. DOT in FY 2015 (U.S. DOT 2015). Also, according to the National Association of State Budget Officers (NASBO), the average spending proportion of the states for transportation in FY 2014 was estimated as 7.7% or approximately $34 billion (NASBO 2015). The research programs of state DOTs are intended to improve the understanding of local, regional, and statewide problems in all areas of transportation and to find solutions to those problems so that transportation agencies can establish more effective, strategic planning based on the federal transportation appropriations. Therefore, the mission of state transportation research programs generally includes, at a minimum, promoting safety; reducing congestion and improving mobility; preserving the environment, preserving the existing transportation system; improving the durability and extending the life of transportation infrastructure; and improving goods movement (23 U.S. Code 508). For each purpose, state DOTs develop research topics, which may employ fundamental, applied, and/or social science research as well as develop and apply new technologies and federal and state agencies' budgets. According to a report prepared by the Office of Management and Budget (OMB), the federal budget proposed for transportation research and development for FY 2017 is $1,065 million to advance the nation's strategic goals for a transportation system (OMB, 2016).

Every year, the U.S. Department of Transportation (DOT) and state DOTs fund millions of dollars in research to cope with transportation issues, improve the quality of lives, and facilitate economic growth. As a key to the research funding management, measuring the benefits of the research results is indispensable to justify the efficiency and quality of their research programs (Zmud, Paasche, Zmud, Lomax, Schofer, & Meyer, 2009; Ellis, Degner, O'Brien, & Peasley, 2003; Concas, Reich, & Yelds, 2002; Hartman, 2001; Anderson, 2010; Worel, Clyne, & Jensen, 2008; Sabol, 2001). Unfortunately, many state DOTs have not truly measured the impacts of their transportation research projects on the transportation system due, in large part, to a lack of comprehensive and implementable quantitative and/or qualitative methods to determine the value of transportation research projects (Schuler, 2010). A recent survey's results revealed that 88% of the state DOTs did not have any guideline or method to evaluate the quantitative or qualitative benefits of their research projects; further clarification indicated that the 12% remaining that provided responses misunderstood the questions and also did not have any guideline or method (Ashuri, Shahandashti, & Tavakolan, 2014). As a result, a scalable, flexible, and consistent method is missing that applies benefit measures and quantification procedures considering data availability for measuring and documenting the value of the completed research projects.

Literature Review

A comprehensive literature review for existing practices, guidelines, and publications was conducted to collect the information required for determining the value of transportations research results. The main data collected include:

- Research categories and the criteria to classify future research projects
- Research output types which define the measures for research value quantification
- The mission/objectives of a state research program
- Benefit categories and measures for each benefit
- Data types required to estimate measures
- Best and alternative evaluation methods based on the availability of data
- Methods to determine research value based on the evaluated benefits
- Documenting methods for easy communication

The data collected were synthesized for the five main data types such as research areas, benefit categories, benefit measures, source of data, and methods used to quantify the value of research. First, the research areas at which most of the investigated state DOTs categorize to develop research are:

- Traffic
- Transport safety
- Environment
- Road design
- Pavement and materials
- Geotechnical
- Bridge/structure
- Maintenance and facility preservation
- Hydraulic and hydrology

Second, the most frequent benefit categories used in the quantification procedures are:

- Improved mobility
- Improved safety
- Improved environment
- Customer satisfaction

- Improved infrastructure
- Expedited project delivery
- Improved technology
- Improved knowledge

Third, the benefit measures that are frequently observed for the quantification procedures include:

- Reduction in travel time delay
- Reduction in crashes
- Dollar savings due to reduction in crashes
- Reduction in vehicle emission
- Dollar savings due to reduction in emissions
- Dollar savings by offering free services to the customers
- Crash modification factors
- Benefit-cost ratio
- Reduced installation time of the bridge deck
- Dollar savings due to use of durable materials/products
- Dollar savings due to reduction in number of traffic signals
- Dollar savings due to use of less materials and resources
- Sponsored university students

Fourth, the state DOTs utilize the data required for the benefit measures from:

- Surveys to principal investigators and users
- Regular data inspection such as crash rates, traffic congestion, etc.
- Field experiments
- Engineering judgment based on historical data such as material unit cost, value of time, etc.
- Data obtained from the simulation software

Lastly, the methods used by state DOTs to evaluate the research values are:

- Scaling techniques based on 3- or 5-point scales
- Benefit-cost estimation
- Dollar benefit analysis (savings due to materials or enhanced performance and cost of avoidance)
- Benefit analysis based on experimental and before/after study

- Computer simulations

Most of these data were found at the reports and guidelines of state DOTs. The objectives, research categories, benefit categories and measures, and quantification methods and required data of these public documents are summarized as follows:

Utah DOT—Measuring the Benefits of Transportation Research in Utah

Objectives

Utah DOT conducted a study to measure the benefits of transportation research in order to justify the expenditure of transportation funding and to determine the most appropriate use of the available budgets. The study objectives were as follows:

- 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.

Benefit Categories and Benefit Measures

In general, benefits and corresponding measures are identified as follows:

- Asset Management: contribution ($) to the management of UDOT's assets
- User Impacts: Reduction ($) in impacts to the travelling public.
- Safety: Improvement ($) in the safety of the travelling public, UDOT and/or contractor employees.
- Quality of Life: Improvement ($) in the quality of life of residents and visitors to the state, including aesthetic beauty, convenience, comfort, and security.
- Environmental: Improvement ($) in the quality of the natural environment.
- Level of Knowledge: Level of knowledge expansion ($) in proposed research area.
- Administration and Policy: Improvement ($) in administrative, management, and policy decisions.

Method and Data

- Form a Technical Advisory Committee (TAC): A TAC, comprised of research managers and others who are likely to use the findings, is formed to provide input during the program evaluation effort.
- Select Projects for Evaluation: Projects are selected for evaluation. An attempt is made to evaluate all projects, but because some research is not fully implemented immediately after the project is complete, it may be necessary to allow a period of time between project completion and the assessment of the benefits. If a project is noted as "benefits not known at this time", the project is re-visited during the next evaluation effort.
- Compile a List of Projects to be Evaluated: A list of projects to be evaluated is compiled, including project title; key champion; project manager; project cost; and deliverables received. Projects are classified into the following types: Infrastructure Related Research, Operations Related Research, or Policy Related Research (per Report No. UT-10.01 prepared in 2010, 41 projects were evaluated, which were completed during 2006, 2007, and 2008).
- Evaluator Meets with Project Champions to Collect Benefits Data: For each project, an evaluator meets with the key champion and others familiar with the research products. A plan is outlined for estimating benefits and total costs. A "Benefits Assessment Form" is used to collect and document benefits. The evaluator guides the key champion through the evaluation process by collecting input using the "Benefits Assessment Form" and calculating benefits.
- Calculate Project Benefits: The evaluator calculates project benefits, using data and input from the project champion. Assumptions and calculations are conservatively estimated, in order to maintain a credible benefits value.
- Assign a Grade to Each Project: To assess the benefits as improved operations, a grade is assigned to each project based on the following descriptions:
  - A = Major impact- Enhanced operations (specification, policy, standard, 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
- Calculate Benefit-Cost Ratios: A benefit-cost ratio is calculated to assess cost saving benefits for each individual project. In addition, benefit-cost ratios are

calculated for each project type and for the total three-year period. Benefit-Cost Ratio = Total Financial Benefit ($) / Total Project Cost ($).

Florida DOT - Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables

Objectives

According to this research report, the mission of the research program at Florida DOT (FDOT) has been to improve and protect Florida's transportation system through the ethical scientific conduct of research that increases global knowledge of products, processes, and practices to transfer information and to encourage the implementation of research results. The objective of this research was to develop a flexible evaluation system to assess the benefit of various research projects.

Research Categories

- Construction
- Environmental Management
- Materials and Testing
- Operations
- Planning
- Public Transit
- Roadway Design
- Safety
- Structural Engineering
- Traffic Operations

Benefit Categories

Qualitative benefits categories:

- Improvements to Knowledge Base
- Improvements to FDOT Infrastructure (Organizational and Process Structures)
- Improvements to Quality of Life
- Improvements to FDOT Management and Policy

Economic benefit categories that are utilized are as follows:

- Improved Work Efficiency
- Reduced Material Costs
- Reduced User Cost
- Reduced Maintenance Cost
- Reduced Construction Cost
- Reduced Operational Cost

Method and Data

- Develop a scoring system for qualitative benefits: The following numerical scale is included in the initial evaluation form: "1" = Project Did Not Meet Expectations, "2" = Project Meets Expectations, and "3" = Project Exceeds Expectations. Evaluation consisted of scoring the project with regard to specific benefit listing in each of the functional areas.
- Create benefit evaluation form: An initial research/benefit evaluation form was created based on the investigation of current practice and literature. The forms are distributed to the project Principal Investigators (PI) and the FDOT project coordinators to jointly rate the project and indicate the project contributions ($).
- Calculate benefit-cost: Benefit-cost is calculated based on feedback received form the PI and project coordinator to determine the savings per unit by comparing the cost prior to implementation with the expected cost after implementation. Total savings is estimated by multiplying the unit savings by the estimated total number of units. Future cost savings should be converted to present values using appropriate interest rate values (this rate is the value established and used by the FDOT for all planning calculations). Estimated benefit-cost ratio = present value of total cost saving/present value of cost of research.

NCHRP-Web-Only Document 127: Performance Measurement Tool Box and Reporting System for Research Programs and Projects

Objectives

The objective of this project was to create a research performance (RPM) system that integrates a balanced and broadly applicable set of research performance measures and tools to assist practitioners in applying these measures to their research projects and programs. RPM system is composed of a web site, RPM-Web, and a complementing CD-ROM tool box called RPM-Tools.

Benefit Measures

There were 20 research performance measures collected through a review of literature relevant to transportation research and other associated research areas. These performance measures included outcome, output, efficiency, resource allocation, and stakeholder metrics. Performance measures are listed below:

- Return on investment or benefit-cost ratio
- Lives saved
- Construction, maintenance, and operations cost savings
- Reduction in crashes
- Reduction in system delays
- Positive environmental impact
- Quality of life enhancement
- Safety enhancement
- Level of knowledge increased
- Management tool or policy improvement
- Public image enhancement
- Technical practices or standards upgrades
- Leadership
- Percent of projects/products implemented
- Percent of projects completed on time
- Percent of projects completed within budget
- Number of contractors
- Number of contractor partnerships
- Percent of satisfied customers

- Contribution to the overall mission of the department

Method and Data

RPM-Web offers the user three methodologies for estimating benefits. Every benefit estimation method involves statistical data and the assumptions. The Resource Collection described above is one source for necessary statistical information obtained from the most knowledgeable individuals within the agency. The three methodologies RPM-Web offers are:

- Current Minus Future Method: This method requires two determinations of costs, fatalities, and/or numbers of crashes.
- Direct Difference Method: This method is particularly well-suited for use when the research project provides estimated benefits per application of the research product, or when the expected benefits per application can be estimated after the research project is completed.
- Percent Improvement Method: This method is ideal when the research project determines a percentage improvement to be expected in costs, fatalities and/or numbers of crashes, or when a percentage improvement can be estimated after the research project is completed.

Minnesota DOT - Benefits of MnROADPhase-II Research

Objectives

This project was to assess the benefits in the core areas including: design guide, innovative construction, preventative maintenance, recycled materials, rehabilitation, surface characteristics, and continued support of non-pavement research using the MnROAD site.

Benefit Categories and Measures

- Economic lifecycle cost analysis based on construction costs and discount rates;
- Cost benefit of avoidance (learning from mistakes)
- Savings in maintenance costs
- Reduced noise from quieter pavements (environmental cost)

- Savings in materials costs
- Savings from extending pavement service life

Methods and Data

The methodology aims at analysis of the benefits based on various approaches listed below:

- Direct: savings due to either materials or enhanced performance. Monetary benefits are quantifiable estimates
- Indirect: new or streamlined construction processes that save time and/or improvement to quality, improvements to performance due to enhanced quality, benefits difficult to quantify
- Avoidance: learn from mistakes; MnROAD is more conducive to risk-taking; benefits difficult to quantify; benefits obtained by avoiding the same mistakes elsewhere; difficult to quantify
- Demonstration: technology transfer through demonstration of procedures, process, or equipment; instill confidence in users to try something new; difficult to quantify benefits

New Jersey DOT—Research Implementation Report

Objectives

The intent of this report was to identify the quantitative and qualitative benefits of New Jersey DOT (NJDOT) research projects that were completed in 2007. Benefits were defined as technology transfer; enhancements; cost savings and economic impact; improvement of safety; and reduction of labor time for the customers, known as champions.

Benefit Categories and Measures

- Enhancements (aesthetic, efficiency/effectiveness, environmental, and safety)
- Cost savings and economic impact
- Technology transfer

Method and Data

University principal investigators were interviewed by email, telephone, or in-person on the outcomes of their research projects. It was expected that the investigators would report on additional studies and projects that had been generated as a consequence of this initial work. Since the information was not always available, NJDOT customers were identified by the investigators for each project. Interviews were arranged with the customers to establish not only benefits, but follow up activities that happened as a result of the research. When required, NJDOT project managers were also contacted to provide background information.

Utah DOT - Measuring the Benefits of Transportation Research in Utah

Benefit Measures

- Dollar savings
- Benefit-cost ratio

Method and Data

- Net present value that compares the amount invested today to the present value of the future savings from the implemented research.
- Benefit-cost analysis for estimating the strengths and weaknesses of alternatives that satisfy transactions, activities, or functional requirements for a project. It is used to determine options that provide the best approach for the adoption and practice in terms of benefits in labor, time and cost savings.
    - Benefit-cost ratio attempts to summarize the overall value for money of a project or proposal. BCR = Present Value of Total Savings (Benefits) / Present Value of Cost of Research.
    - Total Savings (Estimated Savings over a period of Years – Cost of Implementation)
    - Payback Period is calculated by counting the number of years it will take to recover the budget invested in a project.
- Payback period (Years) = Project Cost / Cost Savings per Year.

Ohio DOT—Evaluation of ODOT Research and Development Implementation Effectiveness

Objectives

One major objective of this research project was to determine the extent of implementation and effectiveness of research results; determine the dollar value of benefits (if possible) and compare with costs.

Benefit Categories

- Dollar savings
- Benefit-cost ratio
- Project grade/score (qualitative measure)

Method and Data

Evaluation of the research project was done based on the following criteria:

- Implement ability: Assigning a grade between 0 and 100 to a project by the researcher, the liaison representatives, or by the investigator after studying the final report and the implementation forms. A 0 means the research projects didn't have any implementable findings, while the 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 implement ability. 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 implement ability in a percentage term. The mean value of the variable IE was 80. A 90% confidence interval was computed and resulted in: 66 < mean (IE) < 94."

Texas DOT—2016 University Handbook-Chapter 6

Benefit Categories and Measures

- Level of knowledge
- Management and policy
- Quality of life
- Customer satisfaction
- Environmental sustainability
- System reliability
- Increased service life
- Improved productivity and work efficiency
- Expedited project delivery
- Reduced administrative costs
- Traffic and congestion reduction
- Reduced user cost
- Reduced construction, operations, and maintenance cost
- Materials and pavements
- Infrastructure condition
- Freight movement and economic vitality
- Intelligent transportation systems
- Engineering design improvement

- Safety

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

Objective

The key objective of this study was to evaluate and demonstrate the economic benefits of the Alabama Service and Assistance Patrol program (ASAP) to travelers in the Birmingham region. These benefits include those associated directly with the motorist assistance rendered as a part of ASAP, as well as indirect benefits associated with reduced delay, improved safety, and reduced environmental impacts.

Research Category

- Traffic, transport safety, environment

Benefit Categories

- Improved mobility, improved safety, improved environment, customer satisfaction

Data Type

- Travel time value, average vehicle occupancy
- Crash reduction rates from literature, economic value of crash reduction rate from literature
- Vehicle miles traveled, vehicle type
- Vehicle miles traveled, vehicle type, reduction in emission obtained from the simulation software, economic value of emission reduction
- The average value of service per assist, the number of assists per year

Method

- Traffic simulation
- Benefit analysis by converting accident reduction rates to dollar values
- Traffic simulation

- Benefit analysis by converting accident reduction rates as well as emission reduction to dollar value
- Benefit analysis by converting the number of assists per year to dollar savings

Measures

- Reduction in delay
- Dollar savings due to reduction in crashes
- Reduction in emission
- Dollar savings due to reduction in emission and accident cost
- Dollar savings by offering free services to customers

California DOT—Mobile Work Zone Barriers

Objective

To reduce the traffic delay and reduce traffic interruption

Research Category

- Traffic

Benefit Categories

- Improved Mobility

Data Type

- Field data (Mobile barrier set up and break down time)

Method

- Experimental

Measures

- Reduction in travel delay

FHWA—Rural Road Low Cost Safety Improvements

Objective

To evaluate the safety effectiveness of several low-cost safety strategies presented in the NCHRP

Research Category

- Road design

Benefit Categories

- Improved safety

Data Type

- Pavement width, lane width

Method

- Statistical analysis

Measures

- Crash modification factor (CMF)

Florida DOT—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

Objective

To evaluate safety and operational benefits of using wider outside lane than inside lane on multiline roadways.

Research Category

- Road design

Benefit Categories

- Improved safety

Data Type

- Field data (crash data), inside lane width

Method

- Before after study, regression model

Measures

- Reduction in number of crashes

Florida DOT—Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (Example 1)

Objective

Investigation has resulted in revision to current Superpave asphalt pavement material specifications with regard to course aggregates. A revised and more flexible aggregate specification will permit the use of some Florida aggregates and reduce the need for imported materials. Local materials are available at less cost than the imported materials. The result is a predicted savings in the cost of Superpave asphalt paving.

Research Category

- Materials

Benefit Categories

- Improved Infrastructure

Data Type

- Lower course aggregate price, Savings per TN of Superpave Asphalt, Total Superpave Quantity in TNs, Present Value of the Future Savings I = 5%

Method

- Benefit cost analysis

Measures

- Benefit cost ratio

Florida DOT—Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (Example 2)

Objective

This research has developed a wireless system for transmitting driving data of interest from precast concrete piles while they are being driven. Sensors and a transmitting unit are cast into the pile at the plant, thereby eliminating instrumentation and wiring the pile at the project site. Transmitted data is received on a portable computer at the site. Driving and capacity analysis can be made in real time. Currently, the construction contractor is paid to drive the test piles at a higher cost than regular production piles because of the additional time required. The product of this research is a test pile that can be installed at the same driving cost as a regular production pile.

Research Category

- Geotechnical

Benefit Categories

- Improved Infrastructure

Data Type

- The production unit of Lineal Feet (assuming a 40-foot pile), Production Pile Average Unit Price, Quantity of Test Piles, Present Value of Future Savings, I = 5%

Method

- Benefit cost analysis

Measures

- Benefit cost ratio

Florida DOT—Review, Analyze and Develop Benefit Cost/Return on Investment Equations, Guidelines and Variables (Example 3)

Objective

The results of this study suggest that current noise barrier wall criteria may be modified to provide for a lower wall height that will also meet noise control requirements. Research recommendations indicate that barrier wall heights can be reduced by 1.5 feet. Lower wall heights are expected to result in lower construction cost for new walls.

Research Category

- Environment

Benefit Categories

- Improved environment

Data Type

- The production unit of square feet of noise barrier wall, the average unit cost for noise barrier wall, present value of future savings, I = 5%

Method

- Benefit-cost analysis

Measures

- Benefit-cost ratio

Louisiana DOTD—Mechanistic Flexible Pavement Overlay Design Program

Objective

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

Research Category

- Pavement and material

Benefit Categories

- Improved infrastructure

Data Type

- Pavement mile, material quantity, pavement life, construction cost

Method

- Benefit cost analysis

Measures

- Benefit cost ratio

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

Objective

To develop, construct, and evaluate a lightweight fiber-reinforced plastic (FRP)-wrapped balsa wood bridge deck system

Research Category

- Bridge/structure

Benefit Categories

- Expedited project delivery
- Improved infrastructure

Data Type

- Field data

Method

- Simulation by finite element analysis

Measures

- Reduced installation time (number of days)
- Dollar savings due to durable materials

Louisiana DOTD—Investigation of Low Temperature Cracking in Asphalt Pavements (Phase-II)

Objective

To develop the test methods and specification criteria that will allow the selection of fracture resistant asphalt mixtures and binders at low temperatures

Research Category

- Pavement and material

Benefit Categories

- Improved infrastructure

Data Type

- Pavement lane mile, average cost of pavement per mile number of cracks

Method

- Benefit dollar analysis by comparing the new and traditional pavements

Measures

- Dollar savings due to use of durable pavement

Illinois DOT- Development and Application of Safety Performance Functions for Illinois

Objective

To 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 the best candidates for safety improvements

Research Category

- Environment

Benefit Categories

- Improved safety

Data Type

- Crash data, average annual daily traffic (AADT), beginning station, county, ending station, functional class, inventory (key route), median type, number of lanes, segment length, township, urban code

Method

- Statistical analysis

Measures

- Reduction in crashes

Iowa DOT—Winter Operations Geographic Positioning Systems and Automatic Vehicle Location

Objective

To evaluate the performance of the trucks equipped with Geographic Positioning Systems and Automatic Vehicle Location during winter

Research Category

- Environment

Benefit Categories

- Improved safety/improved mobility

Data Type

- Discount rate, life cycle, number of vehicles installed with AVL, total number of vehicles, loaded labor cost per hour, lane miles covered per storm (per truck), annual number of storm events, average labor hours per storm event (per vehicle), operating cost per mile (excluding labor), estimated minutes doing paperwork per storm (per vehicle), total storm event crashes (per season), average cost per crash

Method

- Benefit-cost analysis

Measures

- Benefit-cost ratio

NCHRP—Performance Measurement Tool Box and Reporting System for Research Programs and Projects (Example 1)

Objective

- Traffic signal warrant verification

Research Category

- Traffic engineering

Benefit Categories

- Improved mobility

Data Type

- Discount rate, average cost of installation of traffic signal, estimated number of reduction in traffic signals

Method

- Benefit analysis by comparing before/after situation

Measures

- Dollar savings due to reduction in the number of traffic signals

NCHRP—Performance Measurement Tool Box and Reporting System for Research Programs and Projects (Example 2)

Objective

To evaluate structural steel design tool

Research Category

- Structure

Benefit Categories

- Improved infrastructure

Data Type

- Anticipated life of product, discount rate, average composite salary rate of engineering staff ($50/hr.), average number of steel structure designed, number of hours of engineering design

Method

- Benefit analysis

Measures

- Dollar savings due to number of hours saved per steel structural design

Objective

The primary objective of this research was as follows:

- To develop a guidebook that will provide a consistent approach for measuring and documenting the value of completed research for the use of all STC research sections.

To achieve the research objective, the specific aims of the work proposed were therefore as follows:

- Investigate all possible aspects (e.g., state DOT organizational structures, state/national transportation missions, research objectives, and research attributes such as qualitative or quantitative) to develop a list of research project categories in a hierarchical structure and to prepare the criteria for determining the research types of future projects.
- Define the parameters required for determining the values of research projects in relationship tables/diagrams.
- Develop a straightforward decision matrix to guide public agencies from a starting point (research categories) to an end point (measure quantification methods) with examples.
- Develop a rating method to determine research values by integrating all of the qualitative and quantitative measures.

Scope

The synthesis concluded that the need exists to develop a systematic and transparent approach to determining the value of transportation research. The approach should be scalable, flexible, and easy to understand. A guidebook will be required to accommodate and measure the value of research from multiple types of projects. The guidebook needs to incorporate a well-defined process that delivers results in a simple and easily applied manner.

Through this project, a consistent method for determining the value of research will be developed with the understanding that research categories and subcategories are very diverse. The focus will be to develop various measures in order to easily evaluate the majority of the research performed by state DOTs all around the nation. The process for determining the measures will be done to ensure maximum coverage of all research areas done throughout the STC. Because of the uniqueness of this project, multiple steps will be taken that allow the STC to evaluate selected phases before moving on to the next phase. All the preliminary steps lead into the development of a guidebook that provides guidelines and worked examples for the use of the STC members.

Methodology

Data Collection (Literature and Discovery Search)

The aim of the literature review and discovery search was to review the existing practices, guidelines, and publications in order to collect information required for determining the value of transportations research results. The primary data collected through the research activities include:

- Research categories and the criteria to classify future research projects.
- Research output types which define the measures for research value quantification.
- The mission/objectives of a state research program.
- Benefit categories and measures for each benefit.
- Data types required to estimate measures.
- Best and alternative evaluation methods based on the availability of data.
- Methods to determine research value based on the evaluated benefits.

To collect the information described above, the literature review and discovery search first focused on the publications of completed and ongoing studies conducted by state DOTs, federal agencies, and private research institutions as well as journals that relate to determining the value of research. The discovery search also visited websites of all U.S. research programs (e.g., the second Strategic Highway Research Program [SHRP2], National Cooperative Highway Research Program [NCHRP], and Every Day Counts [EDC] initiative) and state DOTs to understand research areas and retrieve mission statements, which were utilized to develop the benefit categories. This task also required conducting surveys on state DOTs to investigate the existing practices and procedures as well as future plans to evaluate research values. Two separate consecutive nationwide surveys followed to obtain corresponding and missing data. The information collected by the survey is important for the gap analysis in order to develop a comprehensive, practical, and compatible guideline for state DOTs to determine research values. Therefore, the survey questions were developed based on, at a minimum, the following information:

- Documenting methods for easy communication.
- A list of the research categories in use in a state DOT.

- Well- and ill-established categories in terms of the quantification processes suggested in this proposal.
- Reasons for the well- and ill-established categories, for example:
    - Data availability (e.g., data existence, difficulties in interpreting)
- Resource (e.g., staff, technique, system) availability
- Research categories that should be further developed

Survey-1 was designed to capture the states' knowledge and practices in determining the value of transportation research, which included information such as the research categories used by state DOTs, the quantification process for measuring completed research values, and the current and future plans of state DOTs to develop quantification processes. To collect the information, a total of five questions were developed. The questions were carefully reviewed by the technical advisory committee (TAC) of this research. A web-based questionnaire platform was utilized for the questions, which helped increase the response rates. The list of surveyees for Survey-1 was obtained from the American Association of State Highway and Transportation Officials Research Advisory Committee (AASHTO RAC) website to whom the link to the web-based survey questionnaire was. The questions developed are as follows:

- Does your organization categorize research projects in research areas?
- Have you ever developed any quantification process to measure and document the value of completed research?
- Would you please provide the link or attach the related documents?
- Do you have any present/future plans to develop any quantification process to determine the value of research benefits?
- May we follow up with you to obtain more information in the future?

Survey-2 was a follow-up survey to collect additional information, such as criteria for development of research categories, benefit categories, benefit measures, and similar challenges for use in gap analysis and development of quantification procedures. Similar to Survey-1, all the questions in Survey-2 were carefully reviewed by the TAC of this research, and a web-based questionnaire platform was utilized for the questions. The surveyees list used for Survey-1 was also used to deliver Survey-2. To collect the information for Survey-2, a total of four questions were developed as listed below:

- If your organization has research categories to develop research projects and uses criteria to classify the research categories, please list the criteria in the textbox below; otherwise, skip this question.

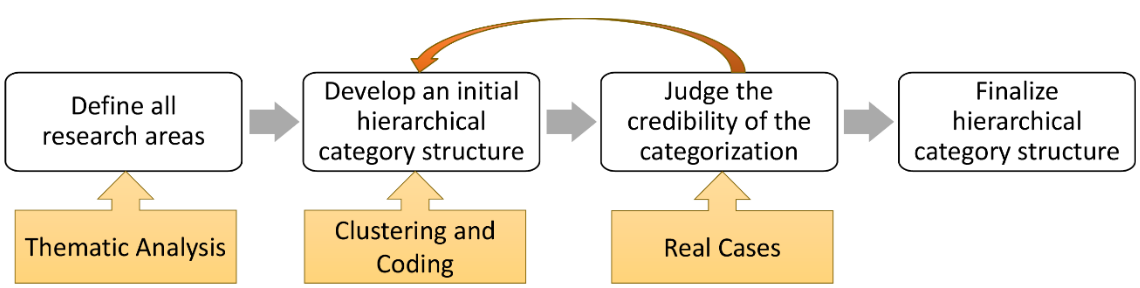
- If your organization has ever used benefit categories (e.g., improved safety, improved mobility, etc.) to determine the value of transportation research results, please list them in the box below; otherwise, skip this question.
- If your organization has ever used qualitative/quantitative measures for each of the benefit categories listed in question 2, please list them in the box below; otherwise, skip this question. (You can write up to three measures for each benefit category)
- If your organization has ever experienced any challenge/constraints to using the measures, please explain the challenges/constraints in the box below.

Both surveys were implemented to fulfill the goal of the entire project. Only the data about the present study from the surveys were used.

Development of Research Categories and Subcategories

The purpose of developing research categories and subcategories was to standardize research areas being used by state DOTs. In the traditional categorization approach, categories should be clearly defined based on the similar properties of objects to be grouped, mutually exclusive, and collectively exhaustive (Johnson and Christensen, 2014). To address the three characteristics of developing categories, a hierarchical structure for the research categories needs to be constructed. The categories in a hierarchical structure are then organized into different levels in which discrete subcategories share a set of properties of a higher-level category. Therefore, as shown in Figure 1, the procedures to develop research categories and subcategories were utilized for maximum coverage of the most researched areas in a hierarchical classification.

Figure 1. Development of research categories and subcategories



First, based on the information collected in the literature and discovery search, the research areas that were in a nonhierarchical structure were identified, and the descriptions for the research areas were developed to capture the meaningful patterns in each research area through thematic analysis. The captured patterns were utilized to define the horizontal and vertical relationships among the research areas to develop an initial hierarchical category structure by clustering and coding. Coding is the process of assigning symbols or names to clustered research areas for categorization (Miles and Huberman, 1994). Then, the credibility of the initial category structure was tested with a sample of actual research projects in order to answer the following critical questions:

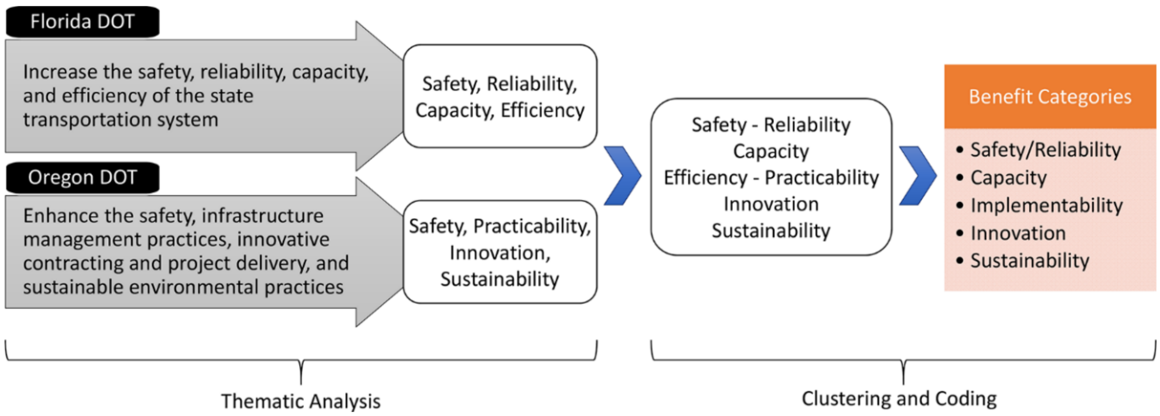
- How distinct is each category from the other categories?
- How inclusive is the hierarchical category structure for the maximum coverage of the research areas developed among the state DOTs in the STC?
- How simple is the hierarchical category structure?

If the initial hierarchical category structure was found to meet the criteria, the research activities in this task proceeded to the final hierarchical category structure; otherwise, the second and third research activities in Figure 1 were repeated until the questions were adequately addressed.

Development of Benefit Categories/Subcategories and Measures

In general, a research value is an evaluation of the impact (called outcomes) of research viewed within a narrowly defined community (Hofmeister, 2011). Measures can be defined as the metric used to determine research values. The success of research programs is supported by high-value research projects. Therefore, the development of a list of measures started by identifying all possible objectives, which were redefined and grouped to create new “benefit categories and subcategories” that were suggested to clearly understand the properties of the measures. Benefit categories and subcategories are the keys to the development of benefit measures. We utilized thematic analysis, as well as clustering and coding approaches, to generate benefit categories and subcategories. Figure 2 graphically presents the steps to create benefit categories. Florida DOT’s research program aims to increase the safety, reliability, capacity, and efficiency of the state transportation system. The research program of Oregon DOT intends to enhance the performance (e.g., safety, infrastructure management practices, innovative contracting and project delivery, and sustainable environmental practices) of the state’s transportation system. The thematic analysis captures a set of words from the two state DOTs, and then these words are clustered and assigned by category names.

Figure 2. Hypothetical example for steps to create benefit categories

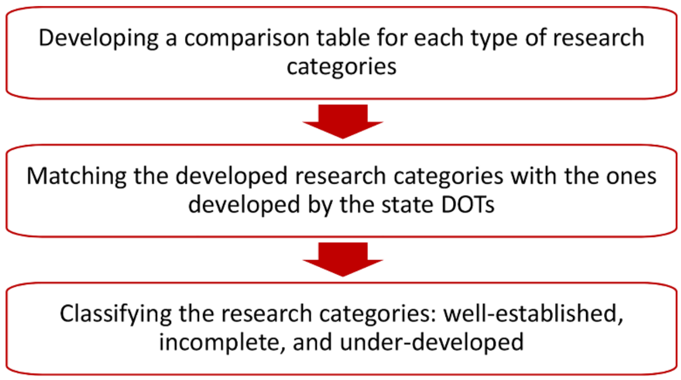


Benefit measures are generally defined as functional key performance indicators to monitor the operation and management progress of transportation systems. Consequently, the benefit measures are also utilized as the indicators to make well-informed decisions to establish a long-term strategic goal for safe and reliable transportation systems. State DOTs develop various research initiatives to overcome the current and future challenges in transportation systems by introducing cost-effective technologies/techniques and innovative, cutting-edge knowledge. It implies that the benefit measures to evaluate the performance of transportation systems also should be applied to determining the value of transportation research. Therefore, various benefit measures were investigated through a comprehensive literature review and the analysis of the data obtained from Survey-2, considering the benefit categories and subcategories.

Gap Analysis

The gap analysis was conducted on the existing research value assessment processes being used by state DOTs. Three separate lists of research subcategories based on the existence of formal guidelines and examples to determine the value of research projects are as follows: 1) research subcategories with formal procedures (well-established research subcategories), 2) research subcategories with procedures but need to be reproduced (incomplete research subcategories), and 3) research subcategories without formal procedures (under-developed research subcategories). The gap analysis was conducted based on the results in the previous steps (i.e., development of research categories/subcategories and benefit categories/subcategories) by comparing the project categories and corresponding measures with existing quantification processes and examples already developed by other state DOTs or agencies. Therefore, the method for gap analysis consisted of the following three steps as shown in Figure 3.

Figure 3. Steps for gap analysis



Evaluation Method

The development of an evaluation method is essential to assist state DOTs in assessing the value of completed research based on the data types estimated. Computing the value of research is vital, and DOTs have struggled to justify the process efficiency and quality of state research programs. There is an increasing need for a compatible measuring scale of research benefits in order to develop and support requests for future federal funding for transportation research (Krugler et al. 2006). Therefore, an evaluation method was developed considering the aspects as follows:

- The evaluation method should be easy in the sense of the development of the equation that would finally be used to calculate the research values of projects.
- The evaluation method should be simple enough to be applied throughout a wide range of DOT projects.
- The evaluation method should be capable of encompassing many variations of state DOT projects to create a universal compatible measuring scale.

Discussion of Results

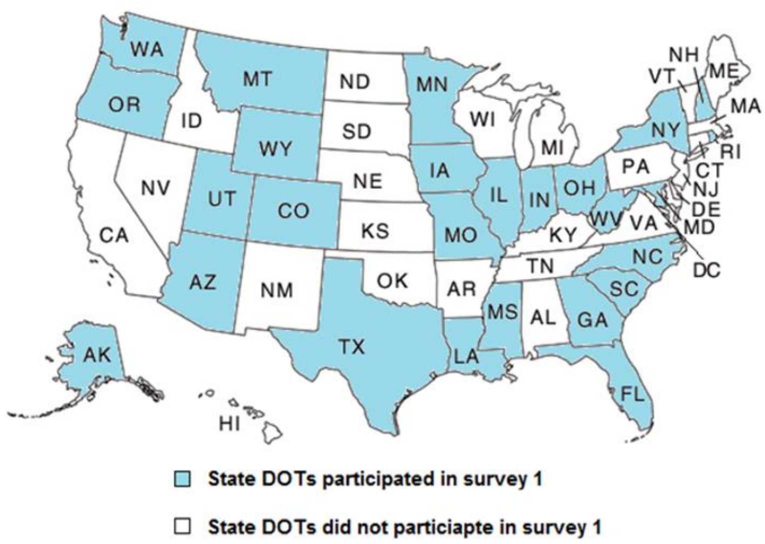
Data Collection through Surveys

Survey-1 was conducted to capture the state of knowledge and practice in determining the value of research in DOTs, while Survey-2 was conducted to collect the examples of benefit categories and corresponding measures used by the state DOTs. The screenshots of both surveys and corresponding responses are included in Appendix A1 and A2 for Survey-1, and Appendix B1 and B2 for Survey-2.

Survey-1 Statistics

A total of 27 state DOTs finally participated in this survey as graphically displayed in Figure 4. The District of Columbia DOT participated in this survey but is not displayed in the map due to its size.

Figure 4. State DOTs Participated in Survey-1



Question 1: Does your organization categorize research projects in research areas?

Out of 27 respondents to the first survey, eighteen individuals provided the list of research categories that they use in their organization (Table 1). The response rate to the survey of all 50 state DOTs is 54%. Table 1 represents the research categories provided by the responded state DOTs. It is very impressive that Washington DOT utilizes very granular research categories compared to other state DOTs. It is also interesting to observe that the Louisiana DOTD and Indiana DOT have the research category for the research by special requests.

Table 1. Research categories provided by responded state DOTs

State DOTs	Research Categories
Arizona	Materials, Structures, Roadway, Construction, and Maintenance | Traffic, Safety, Intelligent Transportation Systems, and Transportation System Management and Operations | Planning, Policy, and Communication | Environmental
Colorado	Structure, Geotechnical, and Hydraulics | Environmental and Water Quality | Material and Pavement | Safety, Maintenance, and Planning
Florida	Construction | Environmental Management | Geotechnical | Maintenance | Materials | Planning | Public Transportation | Roadway Design | Safety | Structures | Traffic Engineering and Operations/ITS | Turnpike
Georgia	Mobility | Asset Management | Safety | Work Force & Policy Development
Illinois	Construction | Environment | Pavement Design, Management, and Materials | Planning | Public and Intermodal Transportation | Safety Engineering | Structures, Hydraulics, Geotechnical | Sustainability | Traffic Operations, Roadside Maintenance
Indiana	Pavement | Materials | Construction | Geotechnical | Technical Services | Safety | Highway Maintenance | Special requests from the Executive staff | Traffic | Financial and Asset Management
Iowa	Safety | Pavement | Maintenance | Bridge and Structure | Human Factors | Intelligent Compaction/Construction
Louisiana	Pavements | Asphalt Materials | Concrete Materials | Geotechnical | Structures | ITS | Safety | Special Studies
Minnesota	Materials & Construction | Traffic & Safety | Maintenance Operations | Bridges & Structures | Policy & Planning | Multimodal | Environmental | Administration | Federal Program Support
Montana	Bridge and Hydraulics | Environment | Highways | Maintenance | Planning | Traffic | Safety
New Hampshire	Aeronautics | Bridges | Construction | Environment | Geotechnical | Maintenance | Materials | Pavements | Traffic | Transit
North Carolina	Planning/Programming, Policy/Transit | Environment & Hydraulics | Pavement, Maintenance, & Materials | Traffic, Safety, & Roadway Design | Structures, Construction, & Geotechnical
Ohio	Administration | Aerial | Construction | Environmental | Geotechnical | Hydraulic | Maintenance | Materials | Pavements | Planning | Policy Development | Roadway | Safety | Structures | Traffic
Oregon	Structures | Maintenance & Operations | Active and Sustainable Transportation | Traffic Safety/Human Factors | Construction, Pavements, & Materials | Planning/Economic Analysis | Geotechnical, Hydraulics & Environmental
Texas	Construction & Maintenance | Safety & Operations | Structures & Hydraulics | Planning & Environmental | Strategic Planning
Utah	Materials | Maintenance | Structures | Geotechnical | Traffic Management and Safety | Planning | Asset Management | Preconstruction | Environmental and Hydraulics | Transportation Innovation | Public Transportation
Washington	Traffic Operations | ITS/Congestion | Maintenance Operations | Freight Mobility | Passenger Rail | Tolling | Innovative Partnerships | Emergency Management | Environment | Planning | Bicycle/Pedestrian | Aviation | Public Transportation | Noise | Air Quality | Hydraulics & Storm Water | Pavements & Materials | Construction |

State DOTs	Research Categories
	Practical Solutions | Multimodal Planning | Highway Geometric Design | Design Safety | Utilities | Right of Way (ROW) | Real Estate | Roadside Features & Landscape | Computer Aided Engineering (CAE)
West Virginia	Safety/Traffic | ITS/GIS | Pavements | Geotechnical | Freight | Structures | Maintenance | Construction | Environmental | Materials | Legal/Personnel/Civil Rights | Transportation Finance | Planning/Transportation/Air Quality

Question 2: Have you ever developed any quantification process to measure and document the value of completed research?

Question 3: Would you please provide the link or attach the related documents?

Questions 2 and 3 are related. Out of 27 respondents to Survey-1, 14 state DOTs stated that they developed their quantification processes to determine the value of transportation research results in Question 2. The rest of the state DOTs answered "No" as shown in Figure 5. In addition, 11 state DOTs provided links where the relevant documents can be retrieved, or the state DOTs attached the documents (see Table 2). The document of the Arizona DOT is an implementation report which provides information regarding the extent to which research projects have been implemented or are inactive. The documents obtained from the Colorado and Wyoming DOTs present the resultant impacts of the research projects, but there are no examples for the quantification of research values. Florida DOT provided a survey link for determining the value of research. The survey was created by project managers to investigate the outcomes of the research projects. The Utah and Texas DOTs presented their reports to determine the value of transportation research. The West Virginia DOT provided a research manual that shows the research categories and procedures to develop state-needed research projects. The Missouri, Montana, and Indiana DOTs provided their reports that contain examples for the quantification of research value. On the other hand, one state DOT, Oregon, provided comments on how to assess research projects. They mentioned that completed projects are assessed and identified as one of the four categories: changed agency practice, validated current agency practice, project objectives were met but the result was inconclusive, and others (e.g., failed projects).

Figure 5. State DOTs that responded to question 2

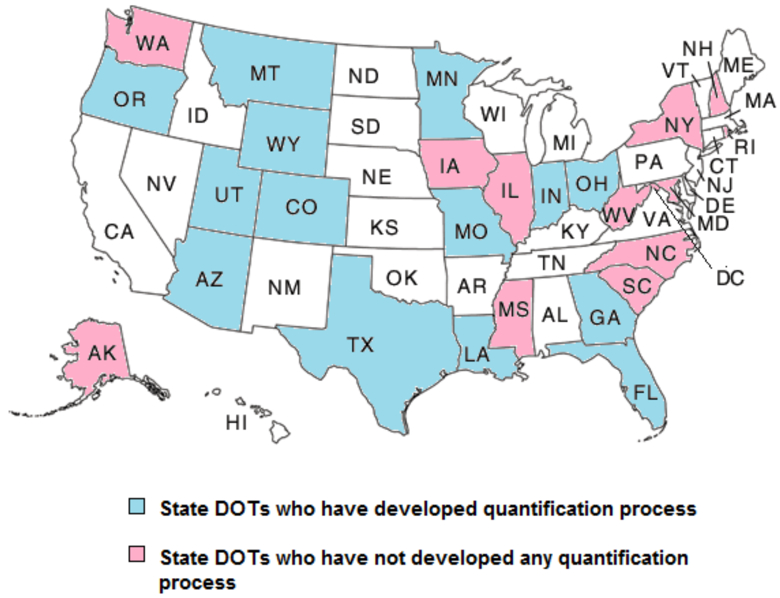
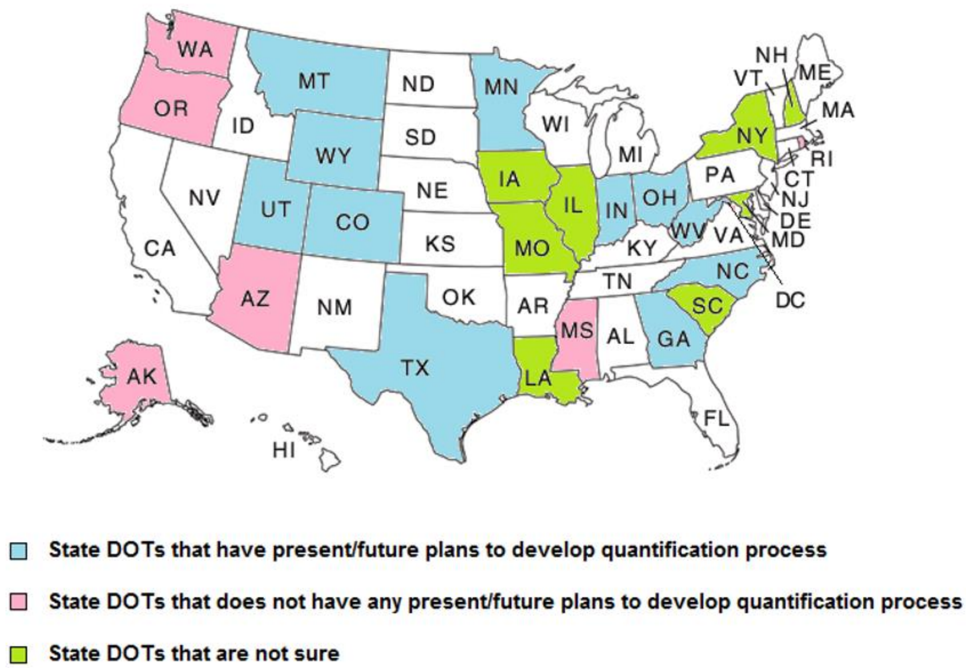


Table 2. Summary of document and links submitted by the state DOTs

State	Documents/Link
Arizona	Implementation of Research at the Arizona Department of Transportation SPR-727
Colorado	Excel file (Implementation report)
Florida	- Survey link (https://www.surveymonkey.com/r/QN99X58?sm=pi g9usTI8%2f56Wl ZAgmHC4g%3d%3d) - Other link not working (http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_PL/FDOT_BDK77_977-24_rpt.pdf)
Indiana	- Quantification method: Determining the value of research for transportation in Indiana - An example of quantification of value: Use of Dynamic Cone Penetration and Clegg Hammer Tests for Quality Control of Roadway Compaction and Construction - SPR-3009)
Missouri	- Example of quantification of value: The Value of Missouri Transportation Research-Fiscal Year 2011 - The Value of Missouri Transportation Research-Fiscal Year 2012
Montana	- A link to an Example of quantification of value: http://www.mdt.mt.gov/other/webdata/external /research/docs/research_proj /rest_area/pm_report.pdf
Oregon	- They provided comments regarding a research project assessment

State	Documents/Link
Texas	- Excel file for calculation of benefit-cost ratio - A report on determining the value of research results
Utah	- Link to a guideline: https://www.udot.utah.gov/main/uconowner.gf?n=1339002847990478
West Virginia	- Research manual
Wyoming	- Self-evaluation report (Implementation report)

Figure 6. State DOTs for present/future plans to develop quantification processes



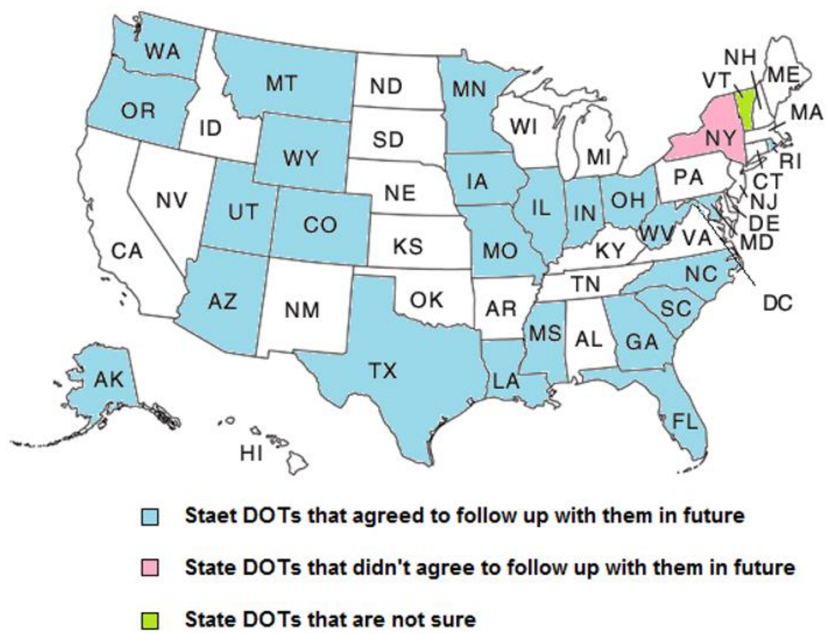
Question 4: Do you have any present/future plans to develop any quantification process to determine the value of research benefits?

For this question, 11 state DOTs of 27 respondents stated that they have present/future plans to develop a quantification process as shown in Figure 6. Also, eight state DOTs (IA, IL, LA, MO, NH, NY, MD, and SC) answered “Not Sure” for any present/future plans to develop quantification process at the time when the survey was conducted.

Question 5: May we follow up with you to get more information in the future?

This question was asked in case the research team requires a follow-up contact to get more details based on the data analysis results of Survey-1. A total of 25 state DOTs agreed to this question as shown in Figure 7.

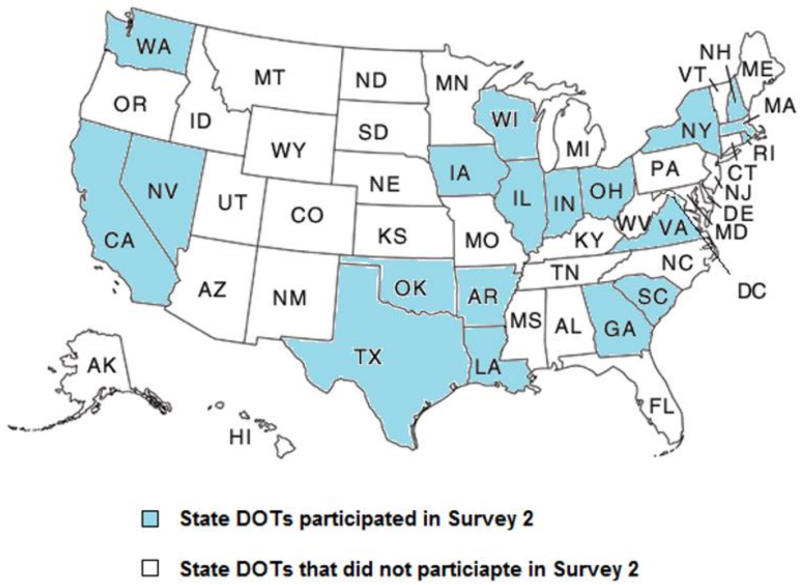
Figure 7. State DOTs (including DC) who agreed to follow-up in future



Survey-2 Statistics

The list of the surveyees that was used for Survey-1 was also re-used to deliver Survey-2. A total of 20 state DOTs, which represents the response rate of 40%, participated in the survey. All these state DOTs are graphically displayed in Figure 8. The District of Columbia DOT participated in this survey but is not displayed in the map due to its size. The screenshots of Survey-2 questionnaire and corresponding responses can be found in Appendices B1 and B2, respectively.

Figure 8. State DOTs (including D.C.) participated in survey-2



Question 1: If your organization has research categories to develop research projects and uses criteria to classify the research categories, please list the criteria in the textbox below; otherwise, skip this question.

This question was initially designed to find common criteria for research categorization among state DOTs. A total of 14 state DOTs answered this question as shown in Figure 9. However, as shown in Table 3, some of the inputs provided by the state DOTs (GA, LA, TX, VA, WA, and WI) are related to research categories or research benefits rather than research categorization criteria. In addition, the New York DOT clearly mentioned that they do not have any criteria used to categorize research projects. These inappropriate answers left only seven state DOTs available for the data analysis. The Nevada and Rhode Island DOTs consider the state goals and state needs, respectively. The California and Illinois DOTs utilize advisory committees to develop research categories. The Arizona and Indiana DOTs stated that they develop research categories based on the department's strategic focus areas and specialty areas, respectively. Lastly, the Washington DC DOT considers the agency's organizational structure. It appears that there is no single common criterion used for most of the responding state DOTs to categorize research. However, if the criteria provided by AZ, CA, IL, and IN are established in the consideration of states' goals or needs at the end, it would be possible to conclude that the other six DOTs (AZ, CA, IL, IN, NV, and RI) categorize research based on the strategic goal of their individual state to address its current/future needs.

Figure 9. States that Responded to Survey 2

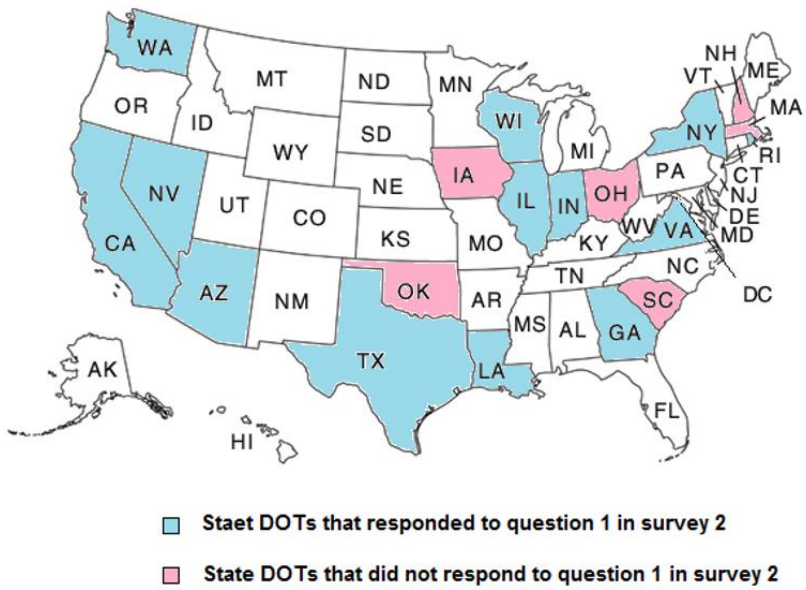


Table 3. The information provided by state DOTs for question 1 of Survey-2

State DOT	Answer
AZ	Department's strategic focus areas
CA	Research steering Committees
DC	Agency organizational structure
GA	Mobility, Safety, Policy / Workforce Development, and Asset Management
IL	Technical Advisory Groups
IN	Based on the specialty areas
LA	Policy and Planning, Special Studies, Pavements (both asphalt and concrete are included as well as our Accelerated loading program), Asphalt Materials, Concrete Materials, Structures, ITS, Safety, and Geotech.
NV	State goals
NY	We do not
RI	State needs
TX	Construction and Maintenance Planning and Environmental Safety and Operations Structures and Hydraulics Strategy and Innovation
VA	Bridge structures and materials, pavement structures and materials, safety, system operations and congestion mitigation, planning, environmental stewardship and

State DOT	Answer
	sustainability, non-destructive testing and evaluation methodologies, data analytics to better make informed decisions
WA	Strategic, Enterprise risk, benefit, implementation
WI	Flexible pavements, rigid pavements, structures and geotechnics

Question 2: If your organization has ever used benefit categories (e.g., improved safety, improved mobility, etc.) to determine the value of transportation research results, please list them in the box below; otherwise, skip this question.

Out of 20 state DOTs, nine state DOTs provided their benefit categories. The state DOTs that responded are displayed in Figure 10. The inputs provided by the state DOTs that responded are summarized in Table 4. The data analysis results based on the inputs in Table 4 show that "Safety," "Mobility," "Infrastructure," "Cost," "Time," "Knowledge," "Life-cycle," and "Sustainability" connected to themes such as "Efficient," "Reliable," "Reduced," "Improved," and "Increased," which were the benefit categories most frequently used by the responding state DOTs.

Figure 10. State DOTs responding to question 2 of survey 2

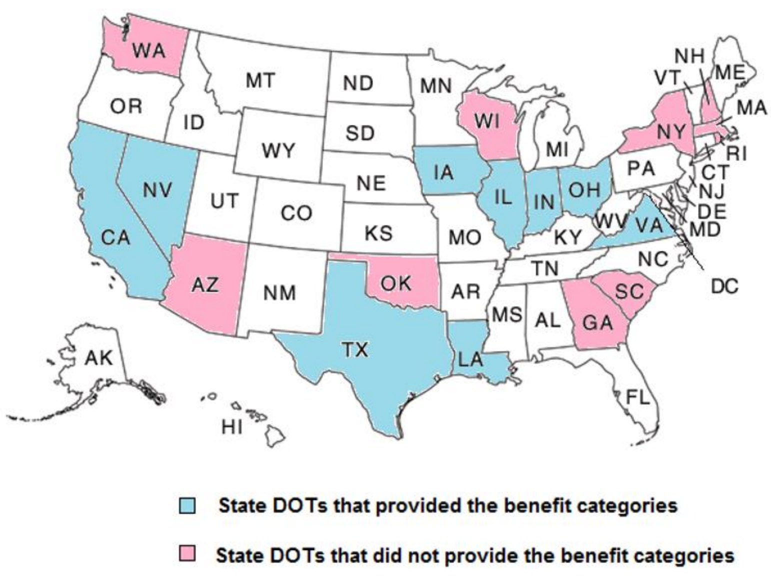


Table 4. Benefit categories of the responding state DOTs

State	Benefit Category
Nevada	Planning for Zero Fatalities; Better Design of Roads and Bridges; Sustainable Infrastructure and Maintenance; Efficient and Safer Traffic Operations; Efficient Multimodal Mobility; Better Project Delivery; Transformative Transportation Technologies
California	Safety/Health; Stewardship and efficiency; Sustainability, Livability and Economy; System performance; Organizational Excellence
Illinois	Construction Savings; Decreases Engineering/Administration Costs; Decrease Lifecycle Costs; Environmental Aspects; Impact on IDOT policy; Increase Lifecycle; Operations and Maintenance Savings; Safety; Technology; User benefits
Indiana	Cost savings; Safety; Mobility/reduced congestion; Quality; Time savings
Virginia	Improved safety; Improved congestion/mobility; longer lasting pavements and structures; Improved inspection/maintenance practices; Strategic health monitoring to improve infrastructure assessment; Improved decisions stemming from data analytics
Louisiana	Improved mobility; Improved safety; longer service life; Improved efficiency (i.e. reduced man hours); Cost-benefit analysis; Life-cycle analysis (LCA); Life cycle cost analysis Improved environmental conditions; Lower initial cost
Iowa	Safety; Mobility; Sustainability; Technology
Ohio	Cost savings; Time savings; Knowledge increase; Leverage (e.g., demonstrating partnership/commitment/compliance); Process improvement; Level of Knowledge; Management and Policy; Quality of Life; Customer Satisfaction
Texas	Environmental Sustainability; System Reliability; Increased Service Life; Improved Productivity and Work Efficiency; Expedited Project Delivery; Reduced Administrative Costs; Traffic and Congestion Reduction; Reduced User Cost; Reduced Construction, Operations, and Maintenance Cost; Materials and Pavements; Infrastructure Condition; Freight movement and Economic Vitality; Intelligent Transportation Systems; Engineering Design Development/ Improvement; Safety

Question 3: If your organization has ever used qualitative/quantitative measures for each of the benefit categories listed in Question 2, please list them in the box below; otherwise, skip this question. (You can write up to three measures for each benefit category).

A total of six state DOTs provided their benefit measures in response to Question 3, which are identified in Figure 11. The benefit measures provided by the responding state DOTs are listed in Table 5. The attributes of these benefit measures are both quantitative and qualitative. For example, California DOT quantitatively measures the number of reduced worker/user fatalities and injuries for the benefit category “Safety/Health,” which also considers the qualitative benefit measure “Promote community health through active transportation.” However, it was observed that some of the benefit categories were not accompanied by any benefit measure, as shown in Table 5.

Figure 11. State DOTs that provided benefit measures

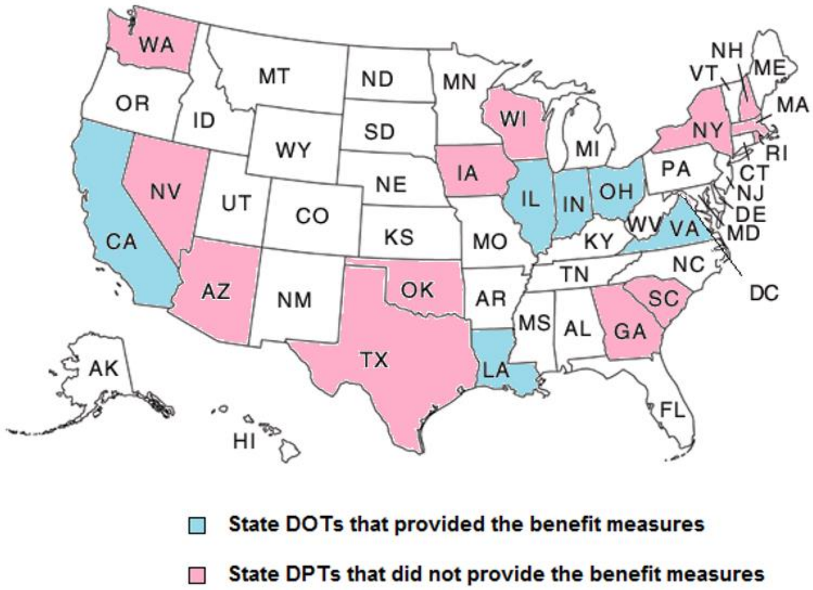


Table 5. Benefit measures given by state DOTs

State	Benefit categories	Measures
California	Safety/Health	Zero worker fatalities; Reduce user Fatalities(F) and injury(I); Delayed reporting of F&I; Promote community health through active transportation
—	Stewardship and efficiency	Effectively manage transportation elements; Efficiently deliver projects and service on time
—	Sustainability, Livability and Economy	Improve quality of life in CA; Reduce Environmental impacts; Improve economic prosperity
—	System performance	Improve travel time reliability; Reduce peak period travel through ITS, strategies; Improve integration and operation of system
—	Organizational Excellence	Promote positive work environment; Increase customer satisfaction; Improve communication
Illinois	Construction Savings	Materials; Labor; Time
—	Decreases Engineering/ Administration Costs	Planning/Design Costs; paperwork

State	Benefit categories	Measures
—	Decrease Lifecycle Costs	Ongoing maintenance costs
—	Environmental Aspects	Pollution; Hazardous waste; Material reduction/recycling
—	Impact on IDOT policy	
—	Increase Lifecycle	
—	Operations and Maintenance Savings	Materials; Labor/time; Equipment
—	Safety	Reduction of crash frequency; Lives saved
—	Technology	Technology transfer; New materials/methods
—	User Benefits	Time (traffic congestion); Money saved to tax payers
Indiana	Cost savings	Benefit-cost ratio; Marginal Internal Rate of Return
—	Safety	Severe crashes on state controlled roads; Impacts of research to safety
—	Mobility/reduced congestion	Travel time reliability; Impacts of research to reduce congestions
—	Quality	Impacts of research to quality of materials
—	Time savings	Impact of research to time savings in testing and construction
Louisiana	Improved mobility	Reduced travel time; Reduced congestion
—	Improved safety	Reduction in crashes; Reduction in lives lost: difficult to get all crash data consistently
—	longer service life	Improved life cycle cost; # years increased
—	Improved efficiency (i.e. reduced man hours)	Reduced man hours to perform a task; Less people required to complete a task
—	Cost-benefit analysis	Cost of research/implementation vs. measured improvement (could be man hours, increased service life, etc.)
—	Life-cycle analysis (LCA)	# years extension vs. status quo
—	Life cycle cost analysis	# years extension vs status quo with initial costs and maintenance costs included
—	Improved environmental conditions	Reduction in CO_2 emissions
—	Lower initial cost	$ saved in construction; $ saved in design
Ohio	Cost savings	$ saved per unit (e.g., project, mile)
—	Time savings	# hours saved per unit (e.g., project, mile)
—	knowledge increase	Specific learned items from project
—	Leverage (e.g., demonstrating partnership/commitment/compliance)	
—	Process improvement	
Virginia	Improved safety	Number of lives saved; Reduction in crashes
—	Improved congestion/mobility	Improved travel time through congested corridors

State	Benefit categories	Measures
—	Longer lasting pavements and structures	Increased service life; Minimizing maintenance costs
—	Improved inspection/maintenance practices	
—	Strategic health monitoring to improve infrastructure assessment	
—	Improved decisions stemming from data analytics	

Question 4: If your organization has ever experienced any challenges/constraints to using the measures, please explain the challenges/constraints in the box below.

Out of 20 respondents, five state DOTs provided their challenges/constraints and are indicated on the map in Figure 12. Table 6 shows the inputs of the state DOTs responding to this question. The significant challenges/constraints identified, which included the lack of data for newly-introduced benefit measures or which require long-term monitoring; the lack of the resources to monitor long-term performance and collect the required data; and the reliability of the collected data.

Figure 12. Map of state DOTs that provided challenges

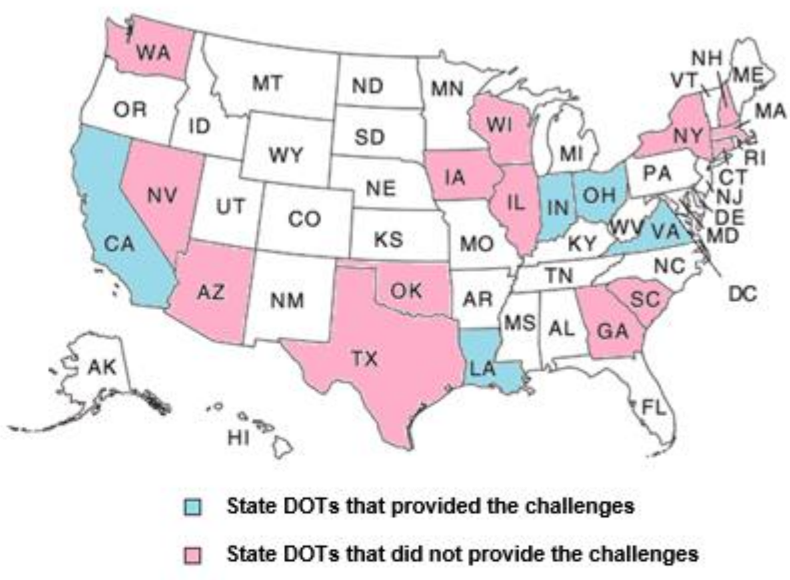


Table 6. Challenges/constraints to use the measures

State	Measures	Challenges/Constraints
California	Zero worker fatalities	—
	Reduce user Fatalities(F) and injury(I)	—
	Promote community health through active transportation	New area has lack of data
	Effectively manage transportation elements	—
	Efficiently deliver projects and service on time	—
	Improve quality of life in CA	New area has lack of data
	Reduce Environmental impacts	Lack of consistent methods - Green House gases
	Improve economic prosperity	New area has lack of data
	Improve travel time reliability	—
	Reduce peak period travel through ITS, strategies	New area has lack of data
	Improve integration and operation of system	New area has lack of data
	Promote positive work environment	—
	Increase customer satisfaction	—
	Improve communication	—
Indiana	Benefit/cost ratio	Monitoring the B/C in a long term
	Marginal Internal Rate of Return	Lack of data for the cost of implementation
	Severe crashes on state controlled roads	—
	Impacts of research to safety	—
	Travel time reliability	—
	Impacts of research to reduce congestions	—
	Impacts of research to quality of materials	Lack of resources to monitor the benefits in the long term
	Impact of research to time savings in testing and construction	Lack of resources to monitor the benefits in the long term
Louisiana	Reduced travel time	—
	Reduced congestion	—
	Reduction in crashes	—
	Reduction in lives lost	Difficult to get all crash data consistently
	Improved life cycle cost	Very difficult to account for all factors objectively
	# years increased	# years can be difficult to estimate, especially if it is on the 100 year timeframe
	Reduced man hours to perform a task	—
	Less people required to complete a task	—

State	Measures	Challenges/Constraints
	Cost of research/implementation vs. measured improvement	—
	# years extension vs. status quo	# years can be difficult to estimate, especially if it is on the 100 year timeframe
	# years extension vs status quo with initial costs and maintenance costs included	# years can be difficult to estimate, especially if it is on the 100 year timeframe
	Reduction in CO_2 emissions	—
	$ saved in construction	—
	$ saved in design	—
Ohio	$ saved per unit (e.g., project, mile)	Personnel uncertain of estimating savings rate or number of units
	# hours saved per unit (e.g., project, mile)	Personnel uncertain of estimating savings rate or number of units
	Specific learned items from project	Lack of consistent methods
Virginia	Number of lives saved	—
	Reduction in crashes	Incomplete crash data
	Improved travel time through congested corridors	—
	Increased service life	—
	Minimizing maintenance costs	Capturing all maintenance costs accurately

Research Categories and Subcategories

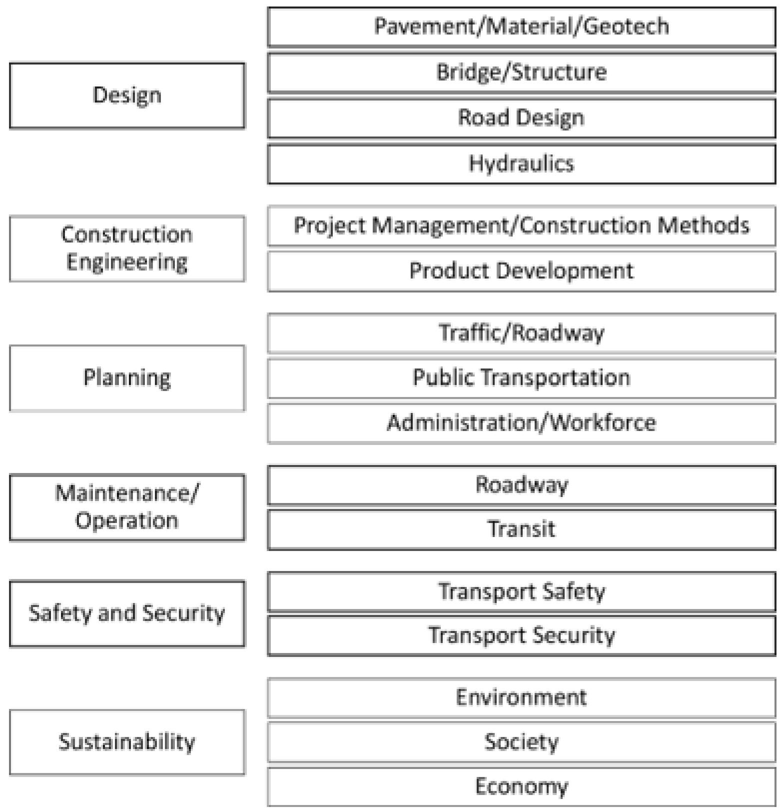
Based on the information collected in the literature and discovery search, the research areas in the nonhierarchical structure were identified. Then, the project categorization method proposed by Archibald (2013) was used to define the mutually exclusive higher-level categories. This method consisted of two components. First, the purpose of the project categorization: Archibald defined two main strategic purposes: (a) project selection - determining which potential projects are to be funded and executed; and (b) prioritization of selected projects - determining the relative importance of selected projects to assist in allocating scarce resources. Second, project attributes (criteria) selection - refers to project characteristics, such as application area, geography, and complexity. Crawford et al. (2005) concluded that “all organizations that have large numbers of projects must categorize them, although the categories are not always immediately visible.” Also, they stated that “The categorization of projects is beneficial and useful to organizations, but it needs to be practical and not theoretically oriented.” In this study, it was apparent that it was important to define the goal of this research project, which was to determine the value of transportation research results. Therefore, the research team made every effort to identify criteria for this research that aligned with its goal.

Furthermore, it was critical to defining criteria that leads to research categories with less overlap, which covers most of the research projects sponsored by the state DOTs. Based on the knowledge obtained from the literature review, the survey data analysis results, the purposes of state DOT research programs, and the partnerships with state universities for the research programs, the research team identified three different criteria: 1) state DOTs' responsibilities (Type A), 2) civil engineering discipline areas (Type B), and 3) impact assessment elements (Type C). Once the research categories based on these three types were established, the subcategories of each of the research categories were determined to increase the level of detail. Also, the coverage rates for the three types were investigated by comparing the suggested research categories with the research categories used by state DOTs.

State DOTs Responsibilities (Type A)

The primary goal of state DOTs is to provide safe, reliable transportation systems to improve the quality of life of local residents and communities. The safety and reliability of transportation systems should be secured during their entire lifetimes from planning through operation and maintenance. In addition, it is becoming more critical as transportation systems are sustainable for the environment and the economy for future generations, which adds more responsibilities to the public agencies responsible for transportation systems. To fulfill these responsibilities effectively and efficiently, state DOTs operate research programs that develop research to find solutions to overcome current and future challenges to build safe, reliable, and sustainable transportation systems. Therefore, the state DOTs' responsibilities include design, planning, construction, operation, maintenance, safety, and sustainability. To develop the subcategories for each of the candidate research categories based on the state DOTs' responsibilities, the properties of the categories were further investigated. As a result, the identified research categories and subcategories based on Type A are shown in Figure 13.

Figure 13. Research categories and subcategories based on type A



Civil Engineering Discipline Areas (Type B)

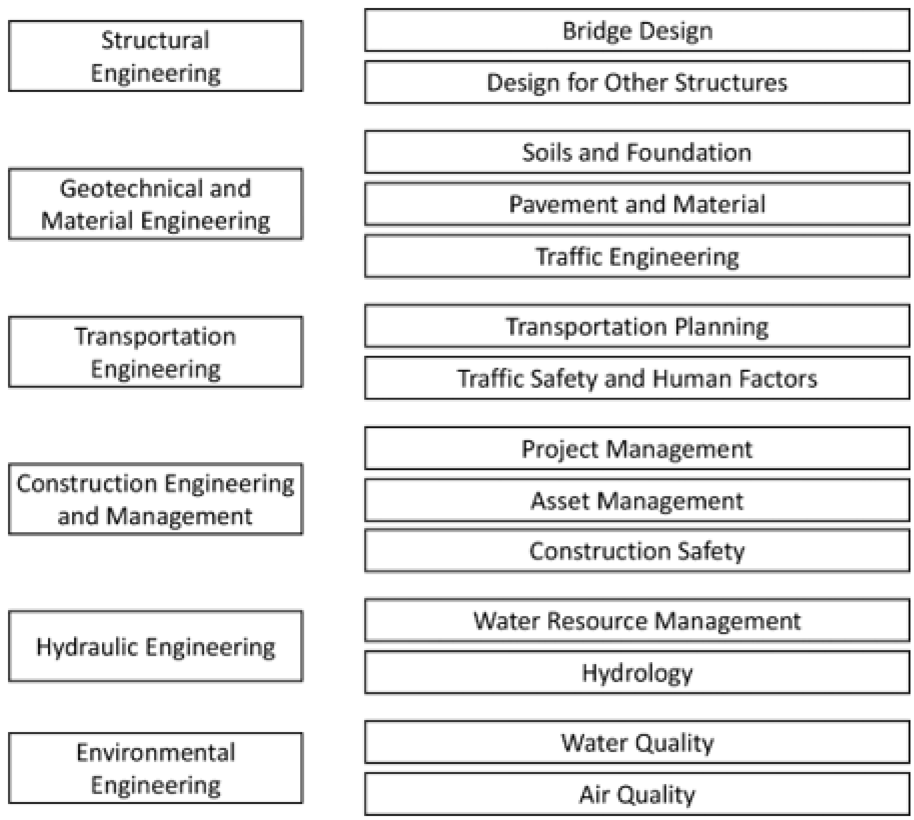
The development of the research categories based on Type B was based on the understanding that state DOTs contract state universities, especially the departments of civil engineering, to conduct their research. Therefore, the accepted civil engineering discipline areas were considered as the basis for the development of the Type B research categories. For this purpose, various civil engineering research programs at U.S. universities were investigated, which included structural engineering, geotechnical engineering, transportation engineering, construction engineering and management, hydraulic engineering, material engineering, and environmental engineering. The characteristics of each of the discipline areas were further investigated to develop the following research subcategories:

Structural Engineering: Design of bridges, buildings, and other types of structures using concrete, steel, wood, masonry, and composites. It should be noted that the main focus of most state DOTs is bridge structures.

- **Geotechnical Engineering:** Design of pavement, foundation, and earth retaining walls and the study of rock and soil mechanics to investigate subsurface and geologic conditions.
- **Transportation Engineering:** Application of technology, scientific principles, and integrated strategies focused on smart and sustainable development in planning, functional design, and operation and management of facilities for any mode of transportation for movement of people and goods.
- **Construction Engineering and Management:** Management of construction sites and processes focusing on project management, process modeling and simulation, service-life prediction and life-cycle costing, and information technologies.
- **Hydraulic Engineering:** Management of urban water supply, the design of urban storm-sewer systems, and flood forecasting.
- **Material Engineering:** Design, manufacture, and characterization of engineering materials for specific applications, focusing on asphaltic and concrete pavements, recycled construction materials, pavement evaluation corrosion within structures, nondestructive testing, and fracture and damage mechanics.
- **Environmental Engineering:** Treatment of chemical, biological, and thermal wastes, purification of water and air, and remediation of contaminated sites after waste disposal or accidental contamination.

Based on the identified discipline areas and their characteristics, the research categories and subcategories were developed as shown in Figure 14.

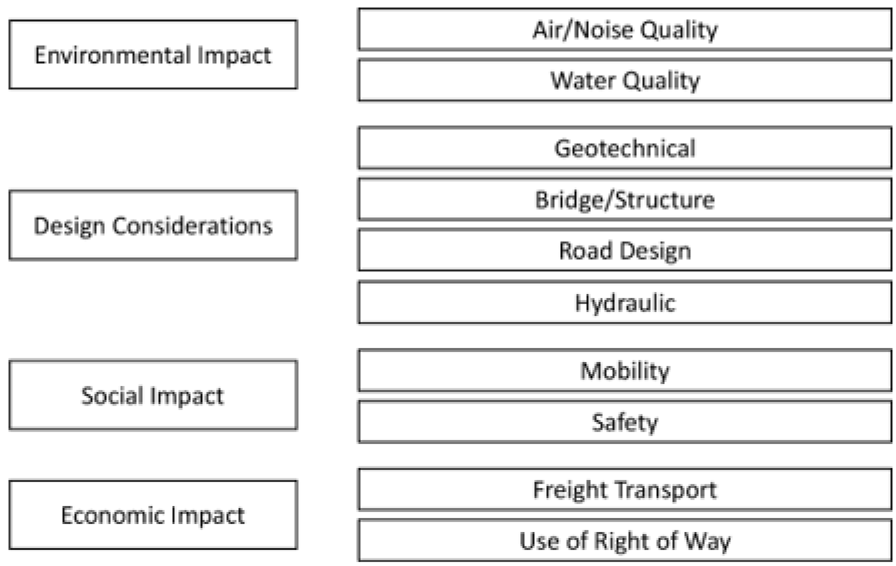
Figure 14. Research categories and subcategories based on type B



Impact Assessment Elements (Type C)

In general, transportation systems affect communities in a variety of ways. For example, they can help revitalize business districts, stimulate economic development, improve access to jobs, and reinforce growth management. The process to evaluate the effects of transportation systems on a community and its quality of life is called a "community impact assessment" (Kramer and Williams, 2000). The assessment measures the extent to which transportation systems address a variety of important topics, such as environmental impacts including: air/noise quality and water quality; social impacts which are categorized as mobility, safety, and design considerations; as well as economic impacts as transportation projects tend to affect businesses. Potential economic impacts on businesses include changes in business activities and land use due to the need for right of way. Furthermore, changes in economic activities may influence the demand for freight services. Since state DOTs solicit research topics within these areas, the impact assessment elements were considered as a basis for the development of the Type C research categories. Figure 15 presents the Type C research categories based on the impact assessment elements.

Figure 15. Research categories and subcategories based on type C



Estimation of Coverage Rates

Once research categories and subcategories have been developed based on the three different types, the coverage rates at the subcategory-level for each type were estimated by investigating how many numbers of the research categories used in any state DOT can be explained by the suggested research subcategories. As a result, the credibility of the suggested research categories can be tested by answering the following two questions: how distinct is each category from the other categories? Also, how inclusive is the hierarchical category structure for the maximum coverage of the research areas developed among the state DOTs? For the coverage rate, a simple formula was used as shown in equation (1), where CR: coverage rate, a: the number of the research categories of a state DOT covered by the proposed research subcategories, and b: the total number of the research categories of a state DOT:

$$CR = a \,/\, b \times 100(\%) \tag{1}$$

Figure 16 shows an example to estimate the coverage rate (CR) based on equation (1). The example considered the eight research categories used by ΔΔ DOT and the research categories/subcategories based on Type A. The comparison was made at the level of the Type A research subcategories. All research categories of the ΔΔ DOT except for "Special Studies" are linked to the research subcategories Type A. It indicates that the coverage rate of Type A for the ΔΔ DOT is 87.5% (= (7/8) × 100%). Similarly, the same procedures were conducted to estimate all state DOTs' coverage rates for Type A, B, and C research categories developed in this project. Figure 17 represents the coverage rates of the three different research category types for the state DOTs. Figure 18 compares the average coverage rates of the three different types, which shows that Type A has the highest coverage rate followed by Type B and Type C.

Figure 16. Example to estimate a coverage rate

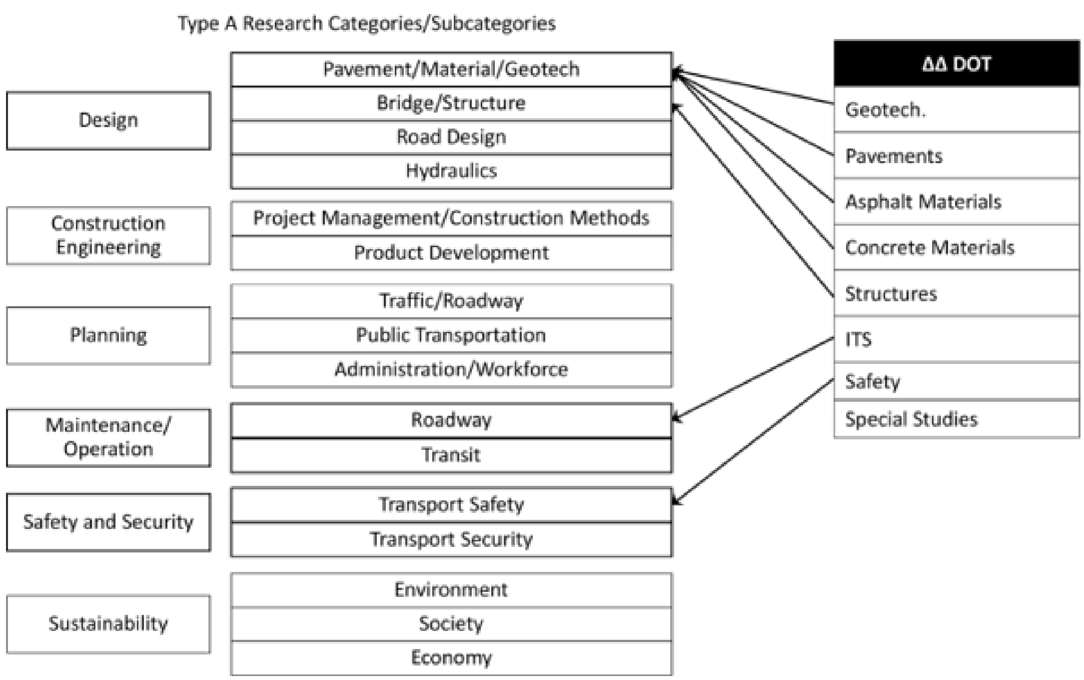


Figure 17. Coverage rates of type A, B, and C for all state DOTs

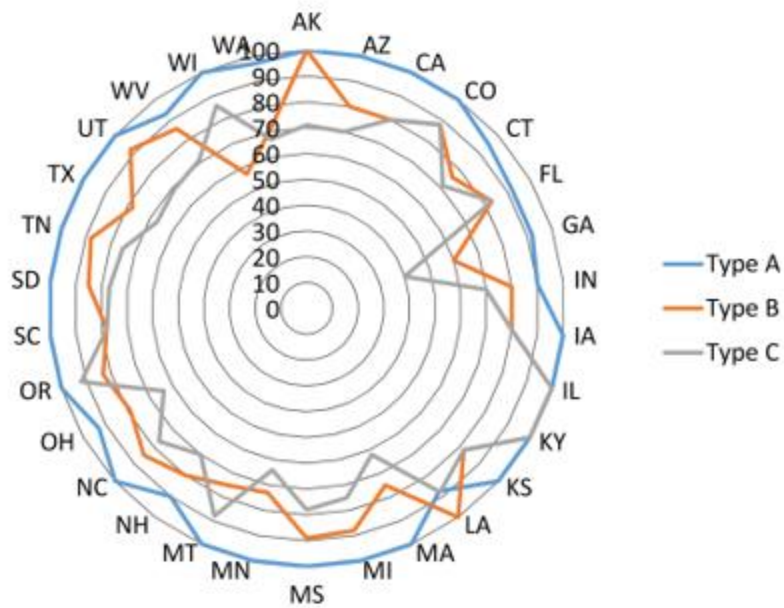
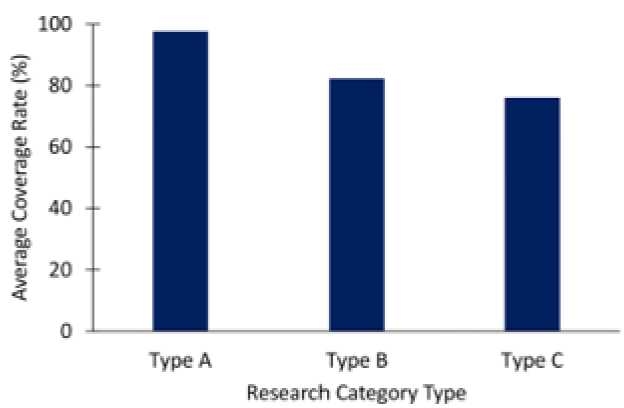


Figure 18. Average coverage rates of three different category types



Benefit Categories/Subcategories and Measures

To develop the benefit categories and subcategories, the information from the two data sources were utilized. The two data sources include the keywords captured from the state DOTs' mission statements and the benefit categories provided by the state DOTs' responses to Survey-2. The state DOTs' mission statements were available on their websites. Once the mission statements were retrieved, the keywords of the mission statements were identified through the thematic analysis. The captured keywords are summarized in Table 7. In addition, a data processing step was conducted for the keywords of the state DOTs who have already provided the benefit categories (see Table 4) in Survey-2.

Table 7. Benefit areas captured from state DOTs' mission statements

State	Result of Thematic Analysis
Alabama	Safety, Efficiency, Sound Environment, Economic and Social Development
Alaska	Quality of Life, Safety, Environmentally Sound, Reliability
Arizona	Safety, Workforce Development, Infrastructure Health, Innovation, Financial Resources
Arkansas	Safety, Efficiency, Customer Satisfaction, Social Enhancement, Economic Development, Environmental
California	Safety/Security, Infrastructure Preservation, Mobility, Economic Development, Technology/Innovation, Environmental
Colorado	Mobility and Accessibility, Environmental
Connecticut	Quality of Life, Safety, Environment
Delaware	Mobility and Accessibility, Safety, Environment, Partnership
Florida	Infrastructure Health, Safety, Economic Development, Organizational Excellence
Georgia	Safety, Environment, Economic Development, Partnership
Hawaii	Safety, Efficiency, Mobility and Accessibility, Economic Development, Quality of Life
Idaho	Safety, Mobility, Economic Developments, Innovation, Workforce Development
Kentucky	Safety, Efficiency, Environment, Quality of Life
Louisiana	Quality of Life, Economic Development
Maine	Safety, Economic Development
Maryland	Safety, Infrastructure Health, Quality of Life, Mobility and Accessibility, Project Delivery, Economic Development
Massachusetts	Safety, Reliability, Economic Development, Quality of Life
Michigan	Mobility, Efficiency, Partnership, Safety, Environment
Minnesota	Safety, Accessibility, Reliability, Efficiency,
Mississippi	Safety, Efficiency, Environment
Missouri	Safety, Infrastructure Health, Reliability, Economic Development
Montana	Quality of Life, Safety, Efficiency, Environment, Economic Development

State	Result of Thematic Analysis
Nebraska	Safety, Economic Development, Environment, Project Delivery, Infrastructure Health, Partnership, Workforce Development
Nevada	Safety, Innovation, Efficiency, Infrastructure Health
New Hampshire	Safety/Security, Customer Satisfaction, Mobility, Efficiency, Infrastructure Health, Partnership, Workforce Development
New Jersey	Quality of Life
New Mexico	Safety, Efficiency, Economic Development, Environment
New York	Safety, Mobility, Efficiency, Economic Development, Environment
North Carolina	Safety, Customer Satisfaction, Efficiency, Reliability, Economic Development
North Dakota	Safety, Mobility
Ohio	Efficiency, Mobility, Accessibility, Safety, Environment, Constructability, Cost Effectiveness
Oklahoma	Safety, Economic Development,
Oregon	Safety, Economic Development, Environment
Pennsylvania	Sustainability
Rhode Island	Safety, Efficiency, Environment, Mobility, Economic Development
South Carolina	Infrastructure Health
South Dakota	Safety, Efficiency
Tennessee	Safety, Reliability, Economic Development
Texas	Safety, Mobility
U.S. DOT	Mobility And Accessibility, Quality of Life
Utah	Safety, Infrastructure Health, Mobility
Vermont	Safety, Infrastructure Health, Environment, Customer Satisfaction, Workforce Development
Virginia	Safety, Mobility, Economic Development, Quality of Life
Washington	Safety, Reliability, Economic Development
West Virginia	Safety, Infrastructure Health, Economic Development, Environment
Wisconsin	Safety, Efficiency
Wyoming	Safety, Infrastructure Health, Efficiency, Environment

Figure 19. Proportions of keywords (Yoon and Dai 2017)

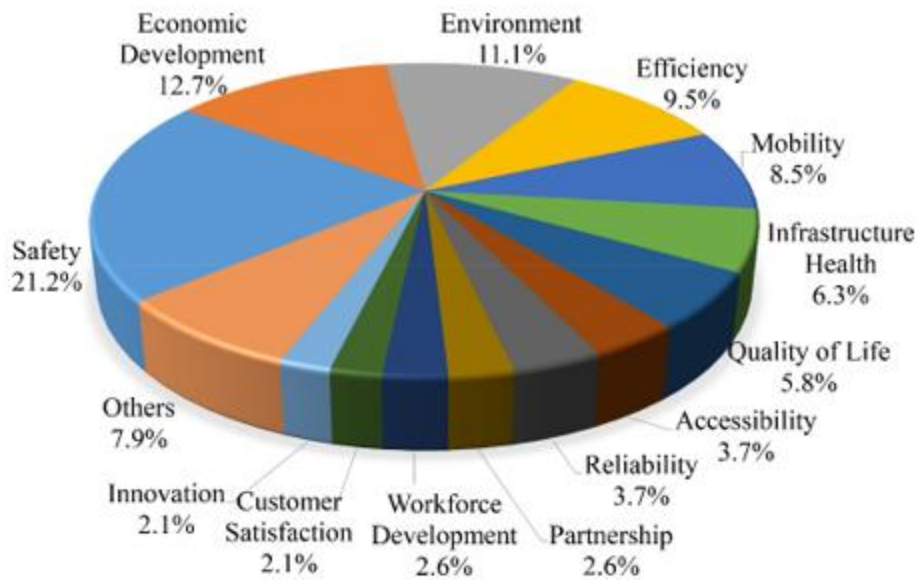
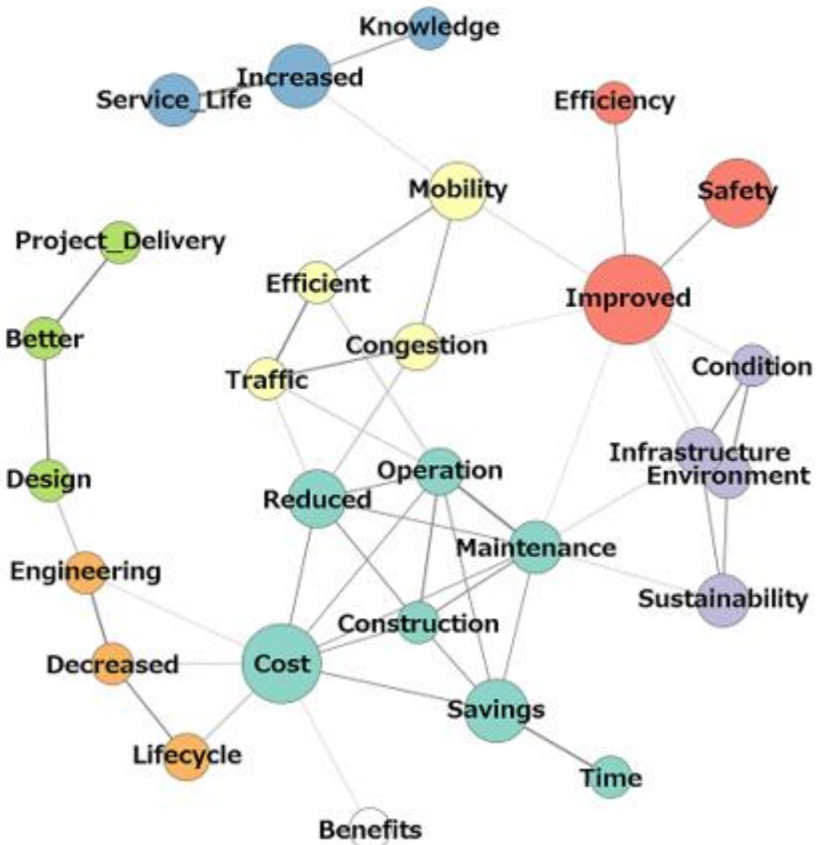


Figure 20. Co-occurrence network of the keywords (Yoon and Dai 2017)



The keywords were analyzed for two purposes: identification of the frequent keywords for the benefits and investigation of the keywords in co-occurrence for the benefit categories and subcategories. Figure 19 shows the proportions of keywords used through the analysis of missions statements and the benefit categories from Survey-2, where "Safety" has the highest frequency of 21.2%, and it was followed by "Economic Development" (12.7%), "Environment" (11.1%), and "Others" (7.9%) that includes: "Project Delivery", "Social Development", "Cost-Effectiveness", and so on. The community structures were utilized for the decomposed words in the co-occurrence network. The community structures organize the keywords in network nodes based on the strength of their connections in order to find the nodes within the same community (Newman and Girvan 2004). Figure 20 shows the result of the co-occurrence network analysis. In Figure 20, the larger circles represent a higher frequency of the word being used while the thicker lines represent a stronger co-occurrence. The dashed lines indicate an external connection between two words in different communities. The circle in a white background ("Benefits") in Figure 20 represents that the word is independent, as it does not belong to any other communities. Therefore, the co-occurrence network result can be interpreted to develop all feasible benefit categories and subcategories as listed in Table 8.

Table 8. Feasible benefit categories and subcategories

Benefit Categories	Benefit Subcategories
Improved Safety and Security	
Improved Mobility and Accessibility	Reduced Congestion
	Increased Speed
	Improved Travel Time
	Travel Time Reliability
	Reduced Travel Cost
	Improved accessibility to facilities and services
Improved Infrastructure	Capacity and availability
	Asset condition
	Remaining Life/Structural Capacity
	Increased Lifecycle
Improved Environment	Vehicle Emissions
	Length or Extent of Air Quality Problem
	Water Quality, Wetlands, Aquatic Life
	Energy Impacts
	Noise Impacts
Improved Technology/Innovation	
Workforce Development	
Expedited Project Delivery	
Increased Knowledge	
Improved Quality of Life	
Customer Satisfaction	

The determination of research values depends highly on the ability to evaluate the impact of research outcomes through benefit measures. Mission statements generally describe goals that organizations try to accomplish. They are also used to assist in establishing strategic initiatives and monitoring organizational performance for successful businesses. Therefore, to obtain and develop benefit measures, the mission statements of the 50 state DOTs in the nation also was carefully examined. As a result, the possible benefit measures corresponding to the benefit categories and subcategories in Table 8 were captured as listed in Table 9.

Table 9. Benefit measures corresponding to benefit categories/subcategories

Benefit Category	Benefit Subcategory	Measures
Improved Safety and Security		- Number of crashes by type, location type, and so forth - # lives saved - Dollar savings due to reduction in crashes - Number (or rate per capita or number of travelers) of crimes at rest areas, bus stops, highways, and so forth by type or severity - Value of losses from theft per capita, person-trip, shipment value, ton - Reduction in number of incidents in construction sites
Improved Mobility and Accessibility	Reduced Congestion	- Level of service (LOS)—measure of congestion from A–F based on volume-to capacity ratio (facility-specific measure) - Number of intersections congested (e.g., with LOS E or F) during peak hours - Travel time under congested conditions - Lane-mile duration index (number of congested lane-miles times the duration of congestion)
	Improved Speed	- Average speed for given roadway segment or origin-destination pair
	Improved Travel Time	- Average travel time (by mode or cross modes) for a given origin-destination pair or trip type - Travel time from freight intermodal facilities to highway facilities
	Travel Time Reliability	- Percent on-time shipments (by commodity or mode)
	Travel Cost	- Trip cost by mode for origin-destination pairs - Dollar losses due to freight delays - Dollar savings
	Accessibility to Facilities and Services	- Percent of urban population with convenient access to public transit (e.g., living within a quarter mile of a transit stop with a non-rush-hour service frequency of 15 minutes or less) - Access time to passenger or intermodal facilities
Improved Infrastructure	Capacity and Availability	- Intermodal terminal capacity
	Asset Condition	- Average health index (0–100 scale) - Percent structurally deficient (SD) - Number of steel bridges with section loss in a member
	Remaining Life/Structural Capacity	- Percent asset quantity out of service due to deteriorated condition - Reduction in distance (or time) between failures for transit vehicles - Age of fleet by vehicle type or remaining useful life for vehicles
	Increased Lifecycle	- Dollar savings due to use of durable materials
Improved Environmental	Reduced Vehicle Emissions	- Vehicular emissions by type—NOx, VOC, CO_2, CO, ozone, fine particulate matter (PM2.5) —can be limited to nonattainment areas and identified by source (e.g., passenger versus freight)

Benefit Category	Benefit Subcategory	Measures
	Length or Extent of Air Quality Problem	- Number of days that pollution standard index is in the unhealthful range
Improved Environmental	Water Quality, Wetlands, Aquatic Life, Farmlands	- Acres of wetlands replaced or protected for every acre affected by highway projects - Level of fish habitat reduction as a result of new construction - The amount of water leaving or discharging from the system - Changes in open space, gardens, parks, farmlands and wildlife habitat (#acres)
	Energy Impacts	- Percent of vehicles using alternative fuels - Average fuel consumption
	Noise Impacts	- Dollar savings - Number of residences or percent of population exposed to highway noise exceeding established standards (or greater than X decibels) - Number of noise receptor sites above threshold
New Technology/ Innovation		- Percent of contracts (or contract value) completed on-time - Percent of contracts (or contract value) completed on-budget - Reduction in emission
Workforce Development		- Rating the effectiveness of the workforce training program
Expedited Project Delivery		- Percent of contracts (or contract value) completed on-time - Percent of contracts (or contract value) completed on-budget - Number of contractor partnerships - Reduced installation time (# days, #hrs., etc.)
Increased Knowledge		- Rating the project based on the following criteria: a. This project expands the DOT knowledge base. b. This project expands the State knowledge base. c. This project expands the National knowledge base. d. This project lays the foundation for future research. - Number of research projects/products improving the body of knowledge in a specific area(s)) or decision-making processes. - Number of sponsored students
Improved Quality of Life		- Rating the project based on the following criteria: a. This project will increase the psychological comfort of users. b. This project will produce an aesthetic improvement. c. This project will improve transportation accessibility d. This project will improve the environment. - Number of research projects/products improving or protecting the natural environment
Customer Satisfaction		- Dollar savings by offering free services to customers - Customer satisfaction rating

The benefit categories in Table 8 were further divided into the relevant benefit subcategories for the measures. As the last step, the measures assigned to each of the benefit categories and subcategories then were mapped to the research categories and subcategories based on Type A which was finally selected by the research TAC. The mapping table is presented in Appendix C. Some of the data types in the mapping table are numbered as they can be interpreted based on the associated research categories and subcategories (see Appendix F).

Gap Analysis

The gap analysis was conducted for the research categories and subcategories based on Type A, which was finally selected for this research. Therefore, as the first step, a comparison table that included the research categories and subcategories based on Type A and the benefit measures associated with the research subcategories was created. Also, the comparison table shows the research subcategories of the state DOTs which have developed quantification procedures. Then, each of the benefit measures was justified by whether there was at least one state DOT having a developed quantification process for the measure in the second step. Finally, the research subcategories considered for the comparison were identified as belonging to one of the three groups as follows:

- Well-established research subcategories for the benefit measures with more than 80% quantification procedures
- Incomplete research subcategories for the benefit measures with the quantification procedures between 80% and 33%
- Under-developed research subcategories for the benefit measures with less than 33% quantification procedures

The data from 7 state DOTs in the STC (e.g., FL, GA, LA, MS, NC, VA, and WV) were available for the gap analysis. Table 10 is a list of the complete, incomplete, and under-developed research subcategories as a result of the gap analysis. The detailed analysis results are shown in Appendix D. For example, the research category "Pavement/Material/Geotech," has four measures such as remaining life, reduction of life-cycle cost, monetary savings, and volume of information sharing. All of the benefit measures except for the last one have the quantification procedures, which indicates 75% so that the research subcategory was identified as incomplete. On the other hand, the research subcategory "Road Design" was grouped into a well-established one as the quantification procedures for 4 of 5 benefit measures were developed by any state DOT.

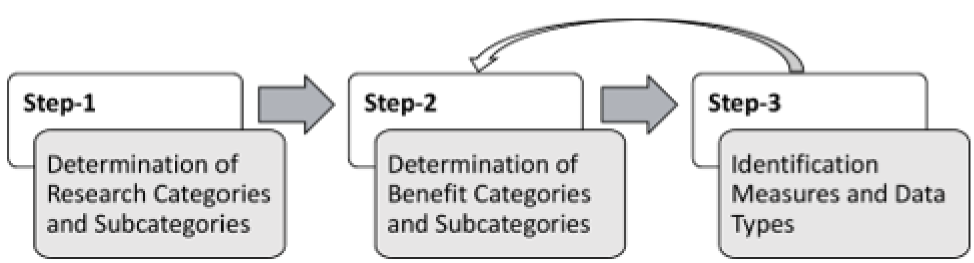
Table 10. A List of complete, incomplete, and under-developed research subcategories

Well-Established	Incomplete	Under-Developed
- Road Design - Hydraulics - Project Management/ Construction Methods - Roadway - Transit - Transport Safety - Environment	- Pavement/Material/Geotech - Bridge/Structure - Product Development - Traffic/Roadway - Public Transportation - Economy	- Administration/Workforce - Transport Security - Society

Utilization of the Mapping Table

The purpose of this chapter is to guide transportation agencies as they navigate the mapping table to effectively identify the relevant data type(s) needed to quantify the value of completed research. This chapter consists of subchapters that explain how to identify the research categories (RCs) and research subcategories (RSCs), the measures going through the benefit categories and subcategories, and the data type(s). Figure 21 illustrates the steps to utilize the mapping table. The successive three steps also include the feedback loop between Step-2 and Step-3, which is prepared to reevaluate the benefit categories and subcategories for alternative data types. That is, by moving forward on the mapping table, transportation agencies can identify the single or multiple data type(s) commonly associated with the benefit category and subcategory. However, although the benefit category and subcategory may be clearly determined, there may not be a single data type to measure the value of the completed research in question for the following possible reasons: 1) the attribute of the information used to determine the benefit category and subcategory is qualitative, and 2) the data type relevant to the benefit category and subcategory is not available to the transportation agency. This situation requires going back to Step-2 and measuring the research using alternative data type(s) in a different benefit category and subcategory. The steps to explore the mapping table are discussed in the last subchapter considering an actual recently completed research project.

Figure 21. Steps to utilize the mapping table



Research Categories and Subcategories

Most state DOTs classify and develop their research programs based on the generally known transportation research areas (e.g., structures, pavements, asphalt materials, etc.). The RCs and RSCs in this guidebook were developed considering the maximum inclusion of the research areas in use by the state DOTs of the STC. Table 11 shows the RCs and RSCs associated with the research areas of the STC states, which enables the agencies to quickly identify the appropriate RC/RSC in order to evaluate the value of research upon completion using Table 11. Occasionally, the "perfect" RC and RSC cannot be found in Table 11 as the coverage rating of the mapping table is 95%. For these occasions, the agency first must clarify the specific objectives and parameters of the research (e.g., scopes and outcomes expected) because good background information and in-depth knowledge of the research ultimately helps to identify the "best" suitable RC and RSC. It is noted that a single research project could have multiple (e.g., two or three) "feasible" RCs and RSCs depending on the nature of the objectives and expected outcomes of the research. Appendix E presents the general definitions of the RSCs under the associated RCs to assist agencies in selecting the best or most feasible categories when it is not possible to identify the perfect RC/RSC in the mapping table.

Table 11. Research areas by STC

Research Category	Research Subcategory	Research Areas of the STC States
Design	Pavements/Material/Geotech	Geotechnical | Pavement coating | Asphalt materials | Soils
	Bridge/Structure	Beam design | Span lengths | Load studies
	Road	Curve studies | Interstate modeling
	Hydraulics	Drainage
Construction Planning	Project Management/ Construction Methods	Project scheduling | Resource leveling | Resource allocation
	Product Development	Project progress plans
Planning	Traffic/Roadway	Intermodal planning | Freight transportation
	Public Transportation	Geographic Information System (GIS)
	Administration/Workforce	Policy development | Financial analysis | Business operation
Maintenance/ Operation	Roadway	Intelligence Transportation System (ITS) | Mobility | Legality | Civil rights | Maintenance
	Transit	Vehical maintenance | Transit route studies
Safety and Security	Transport Safety	Crash data analysis | Non - user impacts
	Transport Security	Quick response mobility | security

Research Category	Research Subcategory	Research Areas of the STC States
Sustainability	Environment	Environmental management | Environmental analysis | Air quality Energy

Data Type(s) through the Intermediate Steps

The main purpose for identifying the benefit category (BC) and the benefit subcategory (BSC) is to help agencies with the transition from the RC/RSC to the measures and subsequently the data type in the mapping table. Once the correct RC/RSC are chosen, the subsequent step is to move on to the columns for the BC and BSC in the mapping table. Each column provides minimal information, mainly key words that can be found in the objectives and expected outcomes (or deliverables) of any research project. The Measures column in the mapping table contains valuable information to help determine the appropriate data type(s) needed. The Definition column further elaborates on the meaning and definition of the measures in the Measures column. The major factor in determining the correct RC/RSC is based on the objectives of the project. If a project aims to achieve certain objectives, then it would be wise to choose a RC/RSC that has a data type that is available.

The RSC largely relates to the general objective of the project and its final goal. For example, if a project is within the Design category and is focused on the design of a bridge, then the appropriate RSC would be Bridge/Structure (see Figure 22). The next transition is from a RSC to a BC. This transition focuses on the benefit provided if the main objective is accomplished. Using the same above example, a bridge can be constructed for various reasons; and once again, based on the project objectives, an agency can choose a RSC to a BC. This transition focuses on the benefit provided if the main objective is accomplished. Using the same above example, a bridge can be constructed for various reasons; and once again, based on the project objectives, an agency can choose either “improved infrastructure” or “increased knowledge” on the mapping table. After the BC is determined, the next transition is to the BSC, which examines the ways to quantify the benefit category that was chosen. The BSC can be broken down into categories such as lifecycle, economic, and knowledge. These choices are largely up to the agency depending on their need. Assuming the largest factor the agency wants to consider is the life of the product, they would be encouraged to choose the economic option in BSC. Moving on from the BSC to the Measures is selfexplanatory and straightforward as all the measures are accompanied by definitions (Appendix G) to assist in the decision-making process. Finally, the agency identifies the data type(s) needed to determine the value of the completed research. Note that the agency can use either single or multiple data type(s) considering the data availability, data accessibility, and any other needs.

Example: Navigating the Mapping Table

The example research project used to illustrate how to navigate the mapping table is "Categorization of Erosion Control Matting for Slope Applications," which was conducted by the Georgia DOT (GDOT). The research was developed to address how to control the negative impacts that can result from high sediment loads in natural waterways, focusing on different types of erosion control products that are available and the best performers. Before the research began, GDOT had one category of erosion control products and all the products were assumed to be interchangeable in their performance. The ensuing research detailed the different considerations that would affect the performance of erosion control devices, all of which primarily dealt with the steepness of the slope to which the device would be applied. The next consideration was the time required for new vegetation to regrow after a construction project was completed. The final consideration on which the project focused was the lifespan of the erosion control device based on the device's material. This research was a follow up to a previous research conducted by GDOT that reviewed the erosion control products used in slopes.

Figure 22. Capture of the Mapping Table for the Design

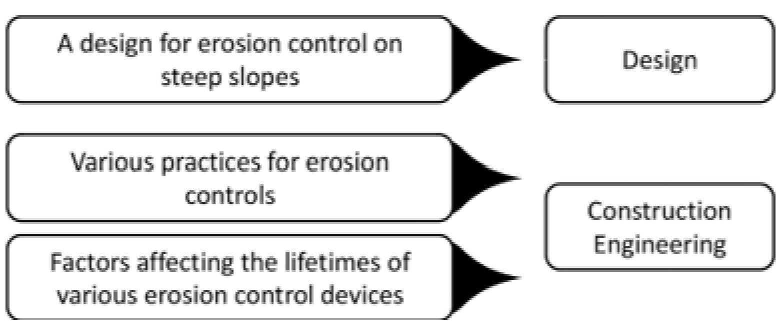
RC	RSC	BC	BSC	Measures	Data Type
Design	Pavement and materials	Improved Infrastructure	Lifecycle	Remaining Life	Percent of Design Life Achieved (1)
			Economic	Reduction of life-cycle cost	Data of life-cycle cost
				Monetary savings	Material cost per sq. yrd, lane mile, pavement lifetime
		Increased knowledge	Knowledge	Volume of information sharing	Number of citations, downloads, etc.
	Bridge/Structure	Improved Infrastructure	Lifecycle	Remaining Life	Percent of Design Life Achieved (1)
				Average health index	Data of all current element value and all initial elment value (2)
			Economic	Reduction of life-cycle cost	Data of life-cycle cost
				Monetary saving	Data of historical installing time; cost of installation per min/hour/day
		Increased knowledge	Knowledge	Volume of information sharing	Number of citations, downloads, etc.
	Road Design	Improved Accessibility/Mobility	Capacity	Accessibility to essential destinations	Reduction in daily travel time; reduction in travel time of goods to essential markets (region wide); attract greater number of enterprises in key indutries with enhanced accessibility to high-capacity highways or rail facilities.
		Improved Infrastructure	Lifecycle	Remaining Life	Percent of Design Life Achieved (1)
			Economic	Financial Measures	Infrastructure maintenance cost (3)
		Improved Safety/Security	Prevention Activity	Road networks that are predictable and recognizable to users	Existence of a system that adjusts speeds based on the presence of alternative modes and context
		Increased knowledge	Knowledge	Volume of information sharing	Number of citations, downloads, etc.
	Hydraulics	Improved Environment	Water Resources/Flood Protection	The amount of water discharged from the system	Data of amount of water discharge
		Increased knowledge	Knowledge	Volume of information sharing	Number of citations, downloads, etc.

Based on the previous research, various types of materials were examined to determine the behavior of the material under different conditions.

Step-1: Determination of RC and RSC

Step-1 begins by determining the research area for which GDOT developed this research so that the RC and RSC that match the research area can be identified from Table 11. The agency then moves to the subsequent steps of determining the information for the BC, BSC, Measures, and Data Type columns in the mapping table. If the research area is not included in the mapping table, the information for this step likely would be in the objectives and expected outcomes of their research in its final report. The report states that the research was developed to find the following: 1) a design for erosion control on steep slopes, 2) various practices that contractors can perform in regard to erosion control, and 3) factors that affect the lifetimes of various erosion control devices. From this information collected from the report, two main RCs (Design and Construction Engineering) from the first two objectives were clearly recognized. However, the third objective was somewhat vague for determining a relevant RC. In this situation, the best way to find a RC is to refer to all possible RSCs in the mapping table and the general definitions of them provided in Appendix E. Construction Engineering includes Project Management/Construction Methods as a RSC which is defined as "….advanced construction materials, equipment, technologies, and instruments…". Therefore, the RC considered for the last objective is Construction Engineering. Figure 23 describes the three RCs for this research.

Figure 23. Determination of research categories



Using the RCs as a starting point, the report was further examined for more details about the objectives and expected outcomes of the research to identify the RSC for each RC determined. This action was made for the first two RCs as the last RC already indicated the associated RSC. The report states that the steepness of slopes relates to the hydraulic stress of the soil, which identified Hydraulics as the RSC for Design. The report also emphasizes the way that the contractors implementing erosion control are managed as an influence on the quality of the practices, which indicated Project Management/Construction Methods as a RSC. Figure 24 is a partial capture of the mapping table to show the RCs and RSCs determined for the example research. Figure 24 includes the columns for BC and BSC intentionally to show how the RCs and RSCs are connected to the relevant BCs and BSCs in the next step.

Figure 24. RCs and RSCs determined for the example research

RC	RSC	BC	BSC	Measure
Design	Pavement and Materials	Improved Infrastructure	Lifecycle	Remaining Life
			Economic	Reduction of life-cycle c
				Monetary savings
		Increased knowledge	Knowledge	Volume of information s
	Bridge/Structure	Improved Infrastructure	Lifecycle	Remaining Life
				Average health index
			Economic	Reduction of life-cycle c
				Monetary saving
		Increased knowledge	Knowledge	Volume of information s
	Road Design	Improved Accessibility/Mobility	Capacity	Accessibility to essential
		Improved Infrastructure	Lifecycle	Remaining Life
			Economic	Financial Measures
		Improved Safety/Security	Prevention Activity	Road networks that are recognizable to users
		Increased knowledge	Knowledge	Volume of information s
	Hydraulics	Improved Environment	Water Resources/Flood Protection	The amount of water dis the system
		Increased knowledge	Knowledge	Volume of information s
Construction Engineering	Project Management/ Construction Methods	Improved Project/Program Delivery	Economic	Regionally produced con materials
				Construction costs are w budget
			Accomplishment: Effectiveness, Efficiency, Quality	Impact of construction a system efficiency
				Project Efficiency
				Delivery Rate
		Improved Safety/Security	Prevention Activity	Crash risk in work zone
				Improved work zone tra activities
		Improved Environment	Customer Satisfaction/Quality of Life	User satisfacation towar decisions which impact t
			Air Quality/Emissions	Reduction of constructio generates emissions

Step-2: Determination of BC and BSC

The determination of the BCs and BSCs for this project also utilized the information in the report focusing on the research objectives and expected outcomes. The research was developed to control the negative impacts on natural waterways from high sediment loads by applying different types of enhanced-lifespan erosion control devices. Also, one of the research deliverables includes the identification of the factors affecting the performance of contractors on various erosion control practices. The research objectives and expected outcomes indicated that the BCs and BSCs for this example research were: Improved Environment and Water Resources/Flood Protection as the BC and BSC for Design – Hydraulics; as well as Improved Project/Program Delivery and Accomplishment: Effectiveness, Efficiency, Quality as the BC and BSC for Construction Engineering – Project Management/Construction Methods (see Figure 24).

Step-3: Identification of Measure and Data Type

From the BCs and BSCs determined, the measures and data types for this research were identified from the mapping table. The first data type was “Data of amount of water discharge” for Improved Environment-Water Resources/Flood Protection in Design – Hydraulics as shown in Figure 25. The data type identified was supported by the report of this research, which states that a negative side effect of poor erosion control can cause inadequate vegetation growth as a result of the water discharged through the erosion control device. The report includes a table with the various amounts of water discharged under different conditions.

Figure 25. Measure and data type for erosion control

RSC	BC	BSC	Measure
...	...	...	recognizable to users
Hydraulics	Increased knowledge	Knowledge	Volume of information s
	Improved Environment	Water Resources/Flood Protection	The amount of water dis the system
	Increased knowledge	Knowledge	Volume of information s

BSC	Measures	Data Type
...	...	...
Knowledge	Volume of information sharing	Number of citations, downloads, etc.
Water Resources/Flood Protection	The amount of water discharged from the system	Data of amount of water discharge
Knowledge	Volume of information sharing	Number of citations, downloads, etc.

Figure 26. Data types under project efficiency measure

BSC	Measure	Data Type
Accomplishment: Effectiveness, Efficiency, Quality	Impact of construction activities on system efficiency	Travel time delay for commuters due to construction activities
	Project Efficiency	Duration of construction; Life-cycle cost
	Delivery Rate	Percent of construction projects completed on schedule/on budget

To identify the data type to measure the erosion control practices of contractors, the possible data types of the three measures under the BSC—Accomplishment: Effectiveness, Efficiency, Quality—were recognized as shown in Figure 26.

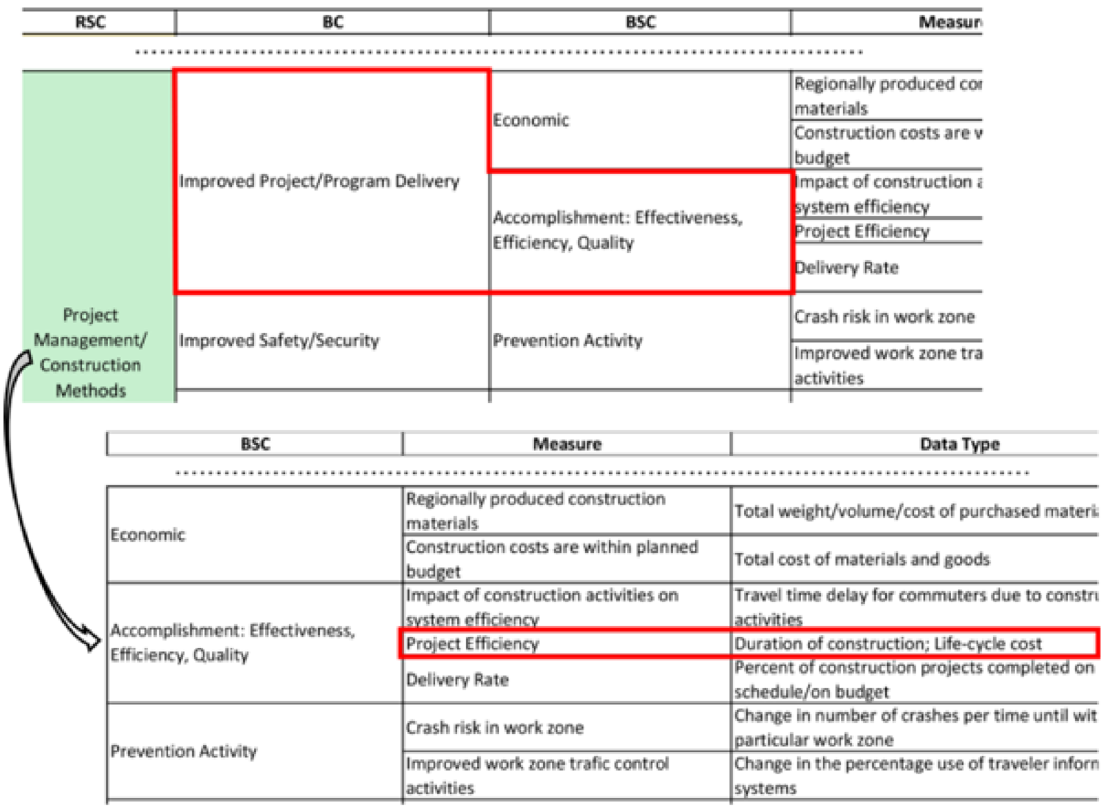
Figure 27. Measure and data type for contractors' performance on erosion control practices

RSC	BC	BSC	Measure
Project Management/ Construction Methods	Improved Safety/Security	Prevention Activity	Crash risk in work zone
			Improved work zone traf activities
	Improved Environment	Customer Satisfaction/Quality of Life	User satisfaction towarc decisions which impact tl
		Air Quality/Emissions	Reduction of constructio generates emissions
		Land Use	Habitat restoration and l
		Noise	Impacts

BSC	Measure	Data Type
Prevention Activity	Crash risk in work zone	Change in number of crashes per time until within a particular work zone
	Improved work zone trafic control activities	Change in the percentage use of traveler information systems
Customer Satisfaction/Quality of Life	User satisfaction towards construction decisions which impact the enviornment	Percentage of customers satisfacation (5)
Air Quality/Emissions	Reduction of construction activities that generates emissions	Engine hours of operation/emission rates/idling hours pe day
Land Use	Habitat restoration and landscaping	Ratio of restored and maintained area to disturbed area
Noise	Impacts	Number of noise receptor sites above established standards (6)

However, none of these data types were appropriate to directly quantify the performance of the contractors on the erosion control practices because the attributes of the information are qualitative. Therefore, it was necessary to investigate other possible data types in different BCs and BSCs, but in the same RC and RSC initially determined utilizing the report of the research to find a suitable data type. The enhanced performance by the contractors can minimize water pollution in natural waterways. As a result, it concluded that the performance quality of the contractors could be measured by the alternative data type, “Ratio of restored and maintained area to disturbed area in Improved Environment as a BC and Land Use” as a BSC as shown in Figure 27. The third data type to measure the enhanced-lifespan erosion control devices was “Life-cycle cost” for the measure Project Efficiency, as shown in Figure 28. The Project Efficiency measure in the mapping table suggests two possible data types: “Duration of construction” and “Life-cycle cost.” The latter data type can reasonably to be considered as a measure for erosion control devices.

Figure 28. Measure and data type for enhanced-lifespan erosion control devices



RSC	BC	BSC	Measur
Project Management/ Construction Methods	Improved Project/Program Delivery	Economic	Regionally produced co materials
			Construction costs are v budget
		Accomplishment: Effectiveness, Efficiency, Quality	Impact of construction a system efficiency
			Project Efficiency
			Delivery Rate
	Improved Safety/Security	Prevention Activity	Crash risk in work zone
			Improved work zone tra activities

BSC	Measure	Data Type
Economic	Regionally produced construction materials	Total weight/volume/cost of purchased materi
	Construction costs are within planned budget	Total cost of materials and goods
Accomplishment: Effectiveness, Efficiency, Quality	Impact of construction activities on system efficiency	Travel time delay for commuters due to constr activities
	Project Efficiency	Duration of construction; Life-cycle cost
	Delivery Rate	Percent of construction projects completed on schedule/on budget
Prevention Activity	Crash risk in work zone	Change in number of crashes per time until wit particular work zone
	Improved work zone trafic control activities	Change in the percentage use of traveler inforn systems

Evaluation Method to Determine Research Value

The research value measurement process basically assumes that: 1) the outcome of a completed research can be obtained by measuring its immediate (< 2 years) or short-term (2–5 years) performance based on the data type identified from the mapping table; 2) a state DOT manages the historical outcome data, which is a dataset of the past research using the same data type as the current research to be evaluated; and 3) a state DOT has a target value for the data type. A target value is a long-term goal set by a state DOT to ultimately achieve a benefit measure for the data type. However, it is not always the case that the state DOT can collect historical data and set a target value because the data type of research may not be identifiable or available. In particular, target values cannot be determined for the data types pursuing maximum or minimum, such as maximizing cost savings or minimizing life-cycle costs. It is also very challenging for the state DOTs to provide an objective evaluation to qualitative research. Considering the state-of-the-practice and challenges in determining the value of completed research, Table 12 represents all possible theoretical combinations which the state DOTs encounter in terms of the existence of an outcome estimated, target value, and historical data.

Table 12. All possible combinations of target value, outcome, and historical data

Comb.	Target Value	Outcome	Historical Data
1	O	O	O
2	O	O	X
3	O	X	O
4	O	X	X
5	X	O	O
6	X	O	X
7	X	X	O
8	X	X	X

In Table 12, Comb.-1 is the best condition to determine the value of completed research while Comb.-8 is the worst. Comb.-3 and -7 might not be possible in practical terms because it is more reasonable to assume that outcomes should be available if historical data exist, which is a set of research outcomes accumulated. Comb.-2 and -6 might look impossible because there should be historical data when the outcomes of completed research are estimated. However, these cases could happen one time when the state DOTs have just started to estimate and collect outcomes, which eventually will be moved to

Comb.-1 or -5. Comb.-4, which indicates that the state DOTs have set a target value to determine the research value for a certain measure, but have no capabilities to collect the data type for the measure currently. Therefore, this chapter provides information about the state DOTs to use the measurement method and alternative approach for the research under the following different condition:

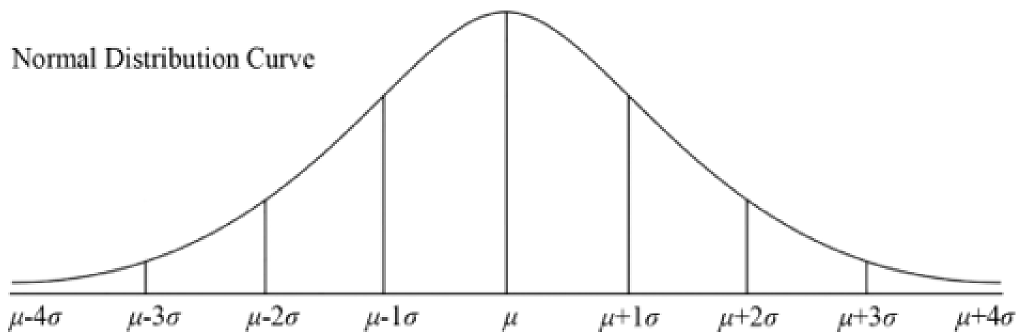
- Case-1: research with a target value, an outcome measured, and historical data
- Case-2: research with a target value and an outcome measured, but no historical data
- Case-3: research with a target value, but no outcome measured and no historical data
- Case-4: research with an outcome measured and historical data, but no target value
- Case-5: research with an outcome measured, but no target value and no historical data
- Case-6: research with no target value, outcome measured, and historical data

The measurement method is a very straightforward and simple equation as shown in equation (2). The equation is called Progress towards Target (PtT) in this guidebook as it evaluates the progress of research outcomes to achieve the target value in percentage.

$$PtT = Outcome/(Target\ Value) \times 100(\%) \qquad (2)$$

The PtT equation primarily can be applied to quantify the value of the research in any case, although it requires a subjective judgment for the cases with no outcome measured (e.g., Case-3 and -6). However, using an alternative approach based on the statistical confidence level can provide some extent of scientific basis to the subjective judgment of transportation agencies. The cases with no target values should not be an issue when a target value is always represented as 100% in a percentage. Also, a target value can be newly set up or updated regularly when there is historical data available using the concept of a Z-score (also called standard score). This becomes possible because a set of data points that were collected in the past or will be collected in the future for the data type is generally assumed to follow a normal distribution curve with a mean (μ) and standard deviation (σ) of the dataset as shown in Figure 29.

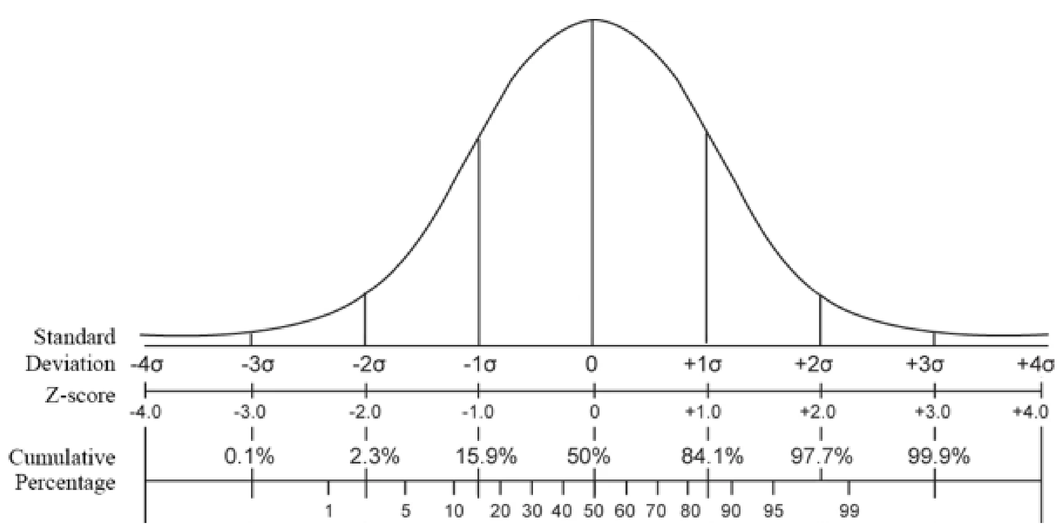
Figure 29. Normal distribution curve of data points



The normal distribution is converted to a standard normal distribution at which the mean is 0 and the standard deviation is 1, using the Z-score equation (3), where x is the outcome of a completed project to be evaluated for its value, μ is a mean, and σ is a standard deviation. In the standard normal distribution, the Z-score is represented as the number of standard deviations from the mean as shown in Figure 30.

$$Z = (x - \mu)/\sigma \tag{3}$$

Figure 30. Standard normal distribution showing Z-scores



Examples of the Possible Cases

To show how the measurement method in equation (1) and the alternative approach are used for the six cases, a hypothetical example is presented in the following subchapters. The hypothetical example revolves around an ongoing effort performed by a state DOT to improve the average health index of various single span bridges across the state. It is assumed that a research project was conducted to develop a new preservation material for concrete overlays to extend their lifetimes and was completed in 2013. The RC chosen for the research is Design, which leads to a RSC of Bridge/Structure in the mapping table. The BC and BSC associated to the RC and RSC are Improved Infrastructure and Lifecycle. Assuming the impact of the example research completed in 2013 on the average health index would start presenting after five years, the data required to measure the value of the research is the average health index of the bridge network in year 2018.

Case-1: Research with a Target Value, Outcome, and Historical Data

The DOT is in a perfect position to measure the value of complete research. Figure 31 shows the historical data of the average health index going back to 2004. The average and standard deviations are the statistics of the historical data from 2004 to 2018. It is assumed that the DOT has an established target value to achieve the average health index of 90 percent on all their single span bridges in 2004. The PtT as the value of the outcome of the example research completed is 95.0% (= (76⁄80) × 100%) using equation (2).

Figure 31. Historical data of average health index, research outcome, and target value

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Avg. Health Index	61	62	59	64	63	65	66	64	66	68	70	72	73	75	76

Avg. (μ)	66.9
Sted. (σ)	5.22
Target V	80.0

Since the target value was established in 2004 considering the average health indices at that time, the state DOT may decide to revise the target value to address the average health index trends in recent years. As a target value is the goal of the state DOT represented as 100%, it can be done very easily by employing the concept of the Z-score and the cumulative percentage in a standard normal distribution as shown in Figure 30. That is, the Z-score of a target value is +4 standard deviation when the standard deviations between -4 and +4 are used. As long as the historical data is available, the statistics for the average and standard deviation can be obtained. By rearranging equation (2) for x, the new target value that can be suggested to the state DOT is 87.8 (= (4×5.22) + 66.9). Therefore, the state DOT can rationally revise the target value considering the value suggested and apply the revised one to compute the PtT of complete research outcomes from 2019.

Case-2: Research with a Target Value and Outcome, but no Historical Data

The research in Case-2 considers that everything is kept constant as in Case-1 except for the historical data and a different target value of 90 as shown in Figure 32. The different target value is intended to show various PtT results. As there are no historical data, the average and standard deviations are not available. The state DOT started collecting the average health index of single-span bridges in 2018 to measure the five-year impact after the example research was completed in 2013. The average health index collected was 76 for the target value of 90 set in 2018. The PtT for the outcome of this research is 84.4% (= (76⁄90) × 100%) from equation (2). The research in Case-2 eventually moves to Case-1 as the outcomes are accumulated in the following years.

Figure 32. Research outcome and target value, but no historical data

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Avg. Health Index	61	62	59	64	63	65	66	64	66	68	70	72	73	75	76

Avg. (μ)	N/A
Sted. (σ)	N/A
Target V	90.0

Case-3: Research with a Target Value, but No Outcome and Historical Data

The research in Case-3 is encountered under the condition that the state DOT has no capability to monitor or control the data type identified from the mapping table to determine the research value. In this case, the only way to handle this situation is to use a subjective inference for the research outcome based on the confidence level. The confidence level in statistics is equivalent to the cumulative percentage in Figure 30. In this guidebook, the confidence level can be interpreted as how certain the transportation agency is about the performance of the research towards a target value or how well the transportation agency satisfies the research pace. That is, if the research was conducted at an average pace, the confidence level may be assumed as 50% in terms of a cumulative percentage on the standard normal distribution curve, so that the PtT is 50% (= ((50%)⁄(100%)×100%)). If the research proceeded at a better pace than expected, the confidence level could be assumed to be higher than 50%.

Table 13. Tentative confidence levels for research performance or pace

Research Performance or Pace	Confidence Level (CL)
Very Good	80% ≤ CL
Good	60% ≤ CL < 80%
Fair	40% ≤ CL < 60%
Poor	20% ≤ CL < 40%
Very Poor	CL < 20%

To help the agency's engineering judgment to determine the confidence level of a research performance or pace, Table 13 is presented on a temporary basis until the state DOT is capable of collecting the data type required for research outcome to move to Case-2 and finally Case-1. For example, if the agency considers any research performance or pace as a "Good," the confidence level could be any percentage in the range. Normally, the agency could simply choose the average of the range, which is 70% for this example. However, a lower level could be considered, such as 60% or 65%, if the agency is not confident in that range.

For the hypothetical example with a target value of 90 only as shown in Figure 33, the state DOT is "fairly" but very "confident" that the average health index of the single-span bridges has been improving recently, based on the visual inspection since they applied the new preservation material as a result of the example resarch. Therefore, the agency considers 60% as the confidence level of the reserch outcome for the target value of 90, which is equivalent to 100% in a confidence level so that the PtT is 60.0% (= ((60%)⁄(100%)) × 100%).

Figure 33. Target value, but no research outcome and historical data

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Avg. Health Index	61	62	59	64	63	65	66	64	66	68	70	72	73	75	N/A

Avg. (μ)	N/A
Sted. (σ)	N/A
Target V	90.0

Case-4: Research with an Outcome Measured and Historical Data, but No Target Value

In this case, the state DOT has no target value set up to determine the value of complete research. Without the target value, it is impossible to use the PtT equation so a target value must be developed. As mentioned earlier, a new target value can be developed using the Z-score and cumulative percentage in Figure 30, having statistics of the historical data. In Figure 34, the average and standard deviation of the historical data are 66.9 and 5.22, respectively. The Z-score of a target value is always +4 standard deviation in a standard normal distribution between -4 and +4. Using equation (2), the target value that can be suggested to the state DOT is 87.8 (= (4×5.22) + 66.9). When the target value is determined at 88.0, the PtT is 86.4% (= (76.0⁄88.0) × 100%). It should be noted that the target value is tentative based on the historical data, which implies that the state DOT revises the target value at the time when the outcome of any research meets or exceeds the target value.

Figure 34. Research outcome and historical data, but no target value

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Avg. Health Index	61	62	59	64	63	65	66	64	66	68	70	72	73	75	76

Avg. (μ)	66.9
Sted. (σ)	5.22
Target V	N/A

Case-5: Research with an Outcome Measured, but No Historical Data and Target Value

The research using a data type that the state DOT has just started collecting and monitoring or the research with data types that have no upper or lower boundaries (e.g., maximizing cost savings or minimizing annualized maintenance cost) falls into Case-5. For the research in the former condition, the best approach for a state DOT is to set up a new target value so that the outcome measured can be applied to the PtT equation in [equation (1)]. However, if the state DOT is not in a position to do so, the most plausible way to determine the value of the complete research relies on subjective engineering judgment based on the confidence level suggested in Table 13. Similarly, the research in the latter condition takes the outcome into account for the concept of the confidence level. Figure 35 is a hypothetical example for Case-5. As the data type of this example is an average health index, the tentative target value could be established at 90 out of 100 so that the PtT is 84.4% (= (76.0 ⁄ (90.0) × 100%)). If determining the target value of the research is ambiguous, the state DOT evaluates the performance or pace of the research based on the confidence levels in Table 13. The confidence level selected becomes the PtT as the target value is 100%.

Figure 35. Research outcome, but no historical data and target value

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Avg. Health Index	61	62	59	64	63	65	66	64	66	68	70	72	73	75	76

Avg. (μ)	N/A
Sted. (σ)	N/A
Target V	N/A

Case-6: Research with No Outcome Measured, Historical Data, and Target Value

The research in Case-6 is most challenging to the state DOT as there is no way to determine the value of the research in an objective manner but instead relies on a subjective judgment. Some studies suggested methods such as a survey and a focus group. A focus group is a type of group decision in a small group to minimize the subjectivity of the decision-making process. However, the state DOT might not be able to conduct such methods and is looking for a simple approach, such as Table 13, which is still subjective but mitigates the subjectivity issue to some extent. Figure 36 shows an example for Case-6. The state DOT evaluates the performance or pace of the research completed towards a target of 100% using the tentative confidence levels in Table 13. The confidence level to be selected is a PtT value.

Figure 36. No research outcome, historical data, and target value

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Avg. Health Index	61	62	59	64	63	65	66	64	66	68	70	72	73	75	N/A

Avg. (μ)	N/A
Sted. (σ)	N/A
Target V	N/A

Various Discrete Rating Systems

The values of the completed research outcomes in any of the cases are measured in terms of percentages based on the PtT equation. These percentages can be classified into a few different types of ratings or grades. Table 14 shows examples for the five-point rating or grade for different scores in percentages. As shown in Table 15, a descriptive scale based on percentages also can be considered. DOTs can select any form of measurement scale that is suitable. However, it is recommended that the scale be consistent throughout all state DOTs for uniformity purposes.

Table 14. Five-point ratings or grades for different scores

Rating	% Score			Grade
5	85%	90-100	93-100	A
4	70%	80-89	92-85	B
3	50%	70-79	77-84	C
2	30%	60-69	70-76	D
1	< 30%	0-59	≤ 69	F

Table 15. Descriptive scales based on percentages

PERCENTAGE	DESCRIPTION
90-100	Exceptional
80-89	Excellent
70-79	Good
60-69	Satisfactory
50-59	Barely acceptable
0-49	Unacceptable

The PtT values of any given completed research projects, considering all the various research categories/subcategories, can be combined to form one integrated value. These values can be used to evaluate the effectiveness of the agency's entire research program. The two basic approaches to combine these different PtT values generally are the arithmetic mean and the weighted mean. The arithmetic mean approach considers all the equal weights of the PtT values regardless of the RCs/RSCs for the completed research. The weighted mean approach provides different weights for the PtT values based on the relative importance of the RCs/RSCs in the agency's research program. The transportation agency can assign different weights at the level of RC, RSC, or both. To demonstrate the processes for the weighted mean approach in three conditions such as weights assigned to RCs, RSCs, or both, pseudo data for the PtT values and weights were created. Table 16 is presented, if a state DOT has multiple complete research projects in the different RSCs evaluated in Year 2018.

Table 16. Research evaluated for PtTs in year 2018

RC	RSC	Research Completed	PtT (%)
Design (D)	Pavement/Material/Geotech (D-1)	D-1 1	95
		D-1 2	58
	Bridge/Structure (D-2)	D-2 1	48
		D-2 2	72
	Road Design (D-3)	D-3 1	88
		D-3 2	69
	Hydraulics (D-4)	D-4 1	81
Construction Engineering (CE)	Project Management/ Construction Methods (CE-1)	CE-1 1	63
		CE-1 2	66
		CE-1 3	82
		CE-1 4	89
	Product Development (CE-2)	None	-
Planning (P)	Traffic/Roadway (P-1)	P-1 1	52
		P-1 2	42
	Public Transportation (P-2)	P-2 1	81
		P-2 2	87
	Administration/Workforce (P-3)	None	-
Maintenance/ Operation (MO)	Roadway (MO-1)	MO-1 1	86
		MO-1 2	58
		MO-1 3	96
		MO-1 4	70
		MO-1 5	46
	Transit (MO-2)	MO-2 1	54
Safety and Security (SS)	Transport Safety (SS-1)	SS-1 1	79
		SS-1 2	89
	Transport Security (SS-2)	None	-

RC	RSC	Research Completed	PtT (%)
Sustainability (S)	Environment (S-1)	S-1 1	67
		S-1 2	82
		S-1 3	93
	Society (S-2)	S-2 1	79
		S-2 2	55
	Economy (S-3)	None	-

Table 17 shows the weights assigned to the RCs, which implies that the RSCs under each RC have an equal weight. Therefore, the integrated PtT value was computed as 75.6% as presented in Table 18. The mean PtT of the research for each RC in Table 18 is the arithmetic mean of the PtT values of the complete research falling into the same RC. The weighted PtT value for each RC in Table 18 is a product of the RC weight and the mean PtT of research.

Table 17. Weights for the RCs

RC	RC Weight (%)	RSC
Design	15	Pavement Material/Geotech
		Bridge/Structure
		Road Design
		Hydraulics
Construction Engineering	10	Project Management/ Construction Methods
		Product Development
Planning	10	Traffic/Roadway
		Public Transportation
		Administration/Workforce
Maintenance/ Operation	15	Roadway
		Transit
Safety and Security	30	Transport Safety
		Transport Security
Sustainability	20	Environment
		Society
		Economy

Table 18. Weighted PtT values for RCs

RC	RC Weight (%)	Mean PtT at RC (%)	Weighted PtT Value (%)
Design	15	73.0	11.0
Construction Engineering	10	75.0	7.5
Planning	10	65.5	6.6
Maintenance/Operation	15	68.3	10.3
Safety and Security	30	84.0	25.2
Sustainability	20	75.2	15.0
Total	100		75.6

Table 19 presents the different weights assigned to RSCs, assuming an equal weight for the RCs. The sum of the RSC weights in each RC is equal to 1. In Table 16, some of the RSCs, such as Production Development, Administration/Workforce, Transport Security, and Economy, were assumed to have no research evaluated for PtT in 2018. The RSC weights in

Table 19 therefore were adjusted for the RSCs with the evaluated research as shown in Table 20. The weights can be adjusted by distributing the weight of a RSC with no research evaluated for the year over the rest of the RSCs based on their initial portions in the same RC. For example, the weights of Environment and Society in Sustainability are equally 30% so that the weight of Economy is equally distributed to these two RSCs, raising their weights to 50% (= 30%+(40%)⁄2). Accordingly, the weighted PtT values at the RSC level of RSC were calculated by multiplying the mean PtT at the RSC by the adjusted RSC weights. The sum of the weighted PtT values of the RSCs for each RC is the weighted mean PtT value for the RC. This concludes that the overall PtT value for the research program of the state DOT is 72.6%, which is an arithmetic mean of the weighted mean PtT values of the RSCs as shown in Table 20.

Table 19. Weights for the RSCs

RC	RSC	RSC Weight (%)
Design	Pavement/Material/Geotech	20
	Bridge/Structure	30
	Road Design	30
	Hydraulics	20

RC	RSC	RSC Weight (%)
Construction Engineering	Project Management/ Construction Methods	60
	Product Development	40
Planning	Traffic/Roadway	40
	Public Transportation	40
	Administration/Workforce	20
Maintenance/Operation	Roadway	60
	Transit	40
Safety and Security	Transport Safety	50
	Transport Security	50
Sustainability	Environment	30
	Society	30
	Economy	40

Table 20. Weighed mean PtTs at the level of RSC

RC	RSC	Mean PtT of RSC (%)	Adj. RSC Weight (%)	Weighted PtT Value (%)	Mean PtT of RC (%)
Design	Pavement/Material/Geotech	76.5	20	15.3	73.1
	Bridge/Structure	60.0	30	18.0	
	Road Design	78.5	30	23.6	
	Hydraulics	81.0	20	16.2	
Construction Engineering	Project Management/ Construction Methods	75.0	100	75.0	75.0
	Production Development	—	—	—	
Planning	Traffic/Roadway	47.0	50	23.5	65.5
	Public Transportation	84.0	50	42.0	
	Administration/Workforce	—	—	—	
Maintenance/ Operation	Roadway	71.2	60	42.7	64.3
	Transit	54.0	40	21.6	
Safety and Security	Transport Safety	84.0	100	84.0	84.0
	Transport Security	—	—	—	
Sustainability	Environment	80.6	50	40.3	73.8
	Society	67.0	50	33.5	
	Economy	—	—	—	

For the last condition, the weights used in Table 18 and Table 20 were considered for the RCs and RSCs as summarized in Table 21. The adjusted weights for the RSCs with the research evaluated also were included in Table 21. As the PtT values of the complete research in Table 16 were used, the weighted PtT values of the RSCs and the mean PtT for RCs in Table 20 were utilized. The weighted PtT values for the RCs were calculated as the product of the RC weights and the mean PtT values of the RCs as shown in Table 22. The sum of these weighted PtT values is the weighted mean PtT value for the research program of the state DOT, which is 75.6%.

Table 21. Weights for both RCs and RSCs

RC	RC Weight (%)	RSC	RSC Weight (%)	Adj. RSC Weight (%)
Design	15	Pavement/Material/Geotech	20	20
		Bridge/Structure	30	30
		Road Design	30	30
		Hydraulics	20	20
Construction Engineering	10	Project Management/ Construction Methods	60	100
		Product Development	40	—
Planning	10	Traffic/Roadway	40	50
		Public Transportation	40	50
		Administration/Workforce	20	—
Maintenance/ Operation	15	Roadway	60	60
		Transit	40	40
Safety and Security	30	Transport Safety	50	100
		Transport Security	50	—
Sustainability	20	Environment	30	50
		Society	30	50
		Economy	40	—

Table 22. Weighted PtT values for the RC

RC	RC Weight (%)	Mean PtT of RC (%)	Weighted PtT Value (%)
Design	15	73.1	11.0
Construction Engineering	10	75.0	7.5
Planning	10	65.5	6.6
Maintenance/Operation	15	64.3	9.6
Safety and Security	30	84.0	25.2
Sustainability	20	73.8	14.8
Total	100		74.7

Conclusions and Recommendations

Public agencies at any level (e.g., federal, state, or local) spend large amounts of resources on operating research programs to develop research that is essential to improving transportation practices and policies that address current and future issues, as well as finally achieve their intended goals. Therefore, successfully monitoring and tracking the value of research is essential to promoting the process efficiency and quality of a research program. However, estimating the value of complete research is challenging due to the obstacles as follows: the difficulties in accurately describing intangible benefits and interpreting qualitative benefit; the nature of wide-ranging research outputs, which requires a variant form of techniques and measures for estimating the research values; and the scarcity of data about the measures chosen to estimate research values. In an attempt to mitigate the obstacles, this research was conducted to develop the mapping table and research value estimation method through the data collection and analysis.

The data utilized for this research were derived from a comprehensive literature review and two national surveys. The data were examined using thematic analysis and the clustering/coding approach to generate the mapping table which includes the columns for research categories, research subcategories, benefit categories, benefit subcategories, benefit measures, and data types. The mapping table allows transportation agencies to develop and recognize research and benefit categories/subcategories to identify associated benefit measures and data types. Consequently, the data types are quantified and integrated using the research value estimation method so that the value of complete research can be efficiently measured and rational decisions about future program development can be made.

The research deliverables (e.g., mapping table, guidebook, and final report) will enhance the capability of state DOTs to operate and manage their research programs efficiently and systematically. However, the use of the research findings can be further expanded by the future efforts and recommendations as follows:

- **Target values for benefit measures.** The evaluation method equation requires target values as an input to evaluate the performance of complete research outcomes. Therefore, it is strongly recommended that state DOTs conduct future work to develop systematic procedures to set up target values for each of the benefit measures in the mapping table.

- **Benefit measures not suitable to set up target values.** Although the target values are required to utilize the deliverables of this research best, it is not always the case that a state DOT can set up target values for all benefit measures because the associated data types may not be available and pursue maximum or minimum (e.g., maximizing cost savings or minimizing life-cycle costs). Therefore, the recommendations and future work to minimize the possible negative impacts of these data types on the evaluation reliability are:
    - To use a substitute research subcategory with a data type available for the state DOT on a temporary basis, while the state DOT makes a strategic plan to collect the originally-suggested data type as a permanent future solution.
    - To build historical data for the data types pursuing maximum or minimum so that a statistical method, such as the Z-score approach (see the guidebook for details), can be utilized.

- **Mapping table as an evolving document.** The mapping table was developed considering all current practices of the state DOTs referred to this research. As the current practices and policies could be revised or new practices and policies could be added to the existing research programs, the mapping table should be evaluated and updated on (if needed) a regular basis to accommodate these possible changes.

- **Research areas of completed projects not included in the mapping table.** Due to the diversity of the research areas within which research projects can be developed, the mapping table is not able to incorporate every research area. The mapping table has about a 95% coverage rate for all research areas being used in state DOTs. For the 5% of research areas that are not included, it is recommended that a state DOT first explore the objectives and expected outcomes of the projects and match them into the benefit categories, subcategories, and measures in the mapping table in order to the best-fit research categories and subcategories.

Acronyms, Abbreviations, and Symbols

Term	Description
ASAP	Alabama Service and Assistance Patrol
AADT	Average Annual Daily Traffic
AASHTO RAC	American Association of State Highway and Transportation Officials Research Advisory Committee
BCR	Benefit Cost Ratio
CMF	Crash Modification Factor
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CR	Coverage Rate
DOT	Department of Transportation
EDC	Every Day Counts
FHWA	Federal Highway Administration
FRP	Fiber-Reinforced Plastic
FY	Fiscal Year
IE	Implementation Effectiveness
ITS	Intelligent Transportation System
LCA	Life-Cycle Analysis
LOS	Level of Service
NASBO	National Association of State Budget Officers
NCHRP	National Cooperative Highway Research Program
NDT	Non-Destructive Test
NOx	Oxides of Nitrogen
OMB	Office of Management and Budget
PM	Particulate Matter
PtT	Progress towards Target
RPM	Research Performance
SD	Structurally Deficient
SHRP	Strategic Highway Research Program

Term	**Description**
SPFs	Safety Performance Functions
STC	Southeast Transportation Consortium
TAC	Technical Advisory Committee
VOC	Volatile Organic Compound

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Appendix

Note: Appendix A1–B2 are presented in a separate PDF document due to its size. To access these appendixes, please contact Dr. Yoojung Yoon at yoojung.yoon@mail.wvu.edu or 304.293.9937.

Appendix A1: Survey-1 Questionnaire
Appendix A2: Survey-1 Responses
Appendix B1: Survey-2 Questionnaire
Appendix B2: Survey-2 Responses

Appendix C

Mapping Table (1)

RC	RSC	BC	BSC	Measure	Data Type
Design (D)	Pavement/ Material/ Geotech (D-1)	Improved Infrastructure	Lifecycle	Remaining Life	Percent of design life achieved (1)
			Economic	Reduction of Life-Cycle Cost	Data of life-cycle cost
				Monetary Savings	Material cost per sq. yd, lane mile, pavement lifetime
		Increased Knowledge	Knowledge	Volume of Information Sharing	Number of citations, downloads, etc.
	Bridge/ Structure (D-2)	Improved Infrastructure	Lifecycle	Remaining Life	Percent of design life achieved (1)
				Average Health Index	Data of all current element value and all initial element value (2)
			Economic	Reduction of Life-Cycle Cost	Data of life-cycle cost
				Monetary Saving	Data of historical installing time; cost of installation per min/hour/day
		Increased Knowledge	Knowledge	Volume of Information Sharing	Number of citations, downloads, etc.
	Road Design (D-3)	Improved Accessibility/Mobility	Capacity	Accessibility to Essential Destinations	Reduction in daily travel time; Reduction in travel time of goods to essential markets (region wide); Attract greater number of enterprises in key industries with enhanced accessibility to high-capacity highways or rail facilities
		Improved Infrastructure	Lifecycle	Remaining Life	Percent of design life achieved (1)
			Economic	Financial Measures	Infrastructure maintenance cost (3)
		Improved Safety/Security	Prevention Activity	Road Networks Predictable and Recognizable to Users	Existence of a system that adjusts speeds based on the presence of alternative modes and context
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Hydraulics (D-4)	Improved Environment	Water Resources/ Flood Protection	The Amount of Water Discharged from the System	Data of amount of water discharge
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
Construction Engineering (CE)	Project Management/ Construction Methods (CE-1)	Improved Project/Program Delivery	Economic	Regionally Produced Construction Materials	Total weight/volume/cost of purchased materials
				Construction Costs within Planned Budget	Total cost of materials and goods

Mapping Table (2)

RC	RSC	BC	BSC	Measure	Data Type
Construction Engineering (CE)	Project Management/ Construction Methods (CE-1)	Improved Project/Program Delivery	Accomplishment: Effectiveness, Efficiency, Quality	Impact of Construction Activities on System Efficiency	Travel time delay for commuters due to construction activities
				Project Efficiency	Duration of construction (4)
				Delivery Rate	Percent of construction projects completed on schedule/on budget
		Improved Safety/Security	Prevention Activity	Crash Risk in Work Zone	Change in number of crashes per time until within a particular work zone
				Improved Work Zone Traffic Control Activities	Change in the percentage use of traveler information systems
		Improved Environment	Customer Satisfaction/Quality of Life	User Satisfaction towards Construction Decisions that Impact The Environment	Percentage of customers satisfaction (5)
			Air Quality/Emissions	Reduction of Activities generating Pollutant Emissions	Engine hours of operation; Emission rates; Idling hours per day
			Land Use	Habitat Restoration and Landscaping	Ratio of restored and maintained area to disturbed area
			Noise	Impacts	Number of noise receptor sites above established standards (6)
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Product Development (CE-2)	Improved Safety /Security	Prevention Activity	Accident Reduction Rate	Number of accidents in a certain time period
		Improved Project/ Program delivery	Economic	Monetary Savings	Total cost of project
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
Planning (P)	Traffic/ Roadway (P-1)	Improved Accessibility/Mobility	Economic	Accessibility to Jobs	Change in number of jobs within reasonable travel time (by mode) for region's population
			Customer Satisfaction /Quality of Life	Quality of Life	Customer perception of satisfaction with commute time; Lost time due to congestion
			Capacity	Total Freeway Lane-Miles	Per capita; Per measure of regional business volume; Per VMT; Per square mile

Mapping Table (3)

RC	RSC	BC	BSC	Measure	Data Type
Planning (P)	Traffic/ Roadway (P-1)	Improved Environment	Air Quality/Emissions	Reduction of Activities generating Pollutant Emissions	Change in trips; VMT; Percent of non-drivers; Tons of emissions per day
			Economic	Cost Efficiency	Average cost per trip; Average cost per ton-mile
			Noise	Users Affected	Number of residences or percent of population exposed to noise/air/light pollution exceeding established standards
			Customer Satisfaction /Quality of Life	Customer Perception towards Transportation Decisions that Impact the Environment	Percentage of customers satisfaction
		Improved Safety/Security	Economic	Cost Per Accident	Average accident cost per trip
			Prevention Activity	Number of Safety Aspects Considered Early in Project Planning	Percentage of project implementing predictive methods
			Emergency Response	Incident Response	Average response time for emergency services
			Customer Satisfaction /Quality of Life	Customer Perception of Safety While on Roadway Systems	Percentage customer satisfaction
		Improved Project /Program Delivery	Economic	Schedule and Budget Adherence	Percentage projects completed on time and on budget
			Customer Satisfaction /Quality of Life	Customer Perception towards Emergency Response Time	Percentage of customer satisfaction
			Accomplishment: Effectiveness, Efficiency, Quality	Customer Impact	Vehicle miles of detour due to projects; Hours of delay due to projects
				Efficiency	Percent of capital costs spent; Percent cost of preliminary engineering rework
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Public Transportation (P-2)	Improved Accessibility/Mobility	Capacity	Service Accessibility	Percent of population with convenient access to public transit
			Economic	Cost Efficiency	Total transit operating expenditures per transit-mile
			Customer Satisfaction /Quality of Life	Customer Ratings towards Transit Reliability, Congestion, Cost, Time, etc.	Percentage of customer satisfaction

Mapping Table (4)

RC	RSC	BC	BSC	Measure	Data Type
Planning (P)	Public Transportation (P-2)	Improved Environment	Air Quality/Emissions	Use of Non-motorized Modes	Change in planned miles/transit routes/pedestrian facilities/population within reasonable distance of transit
			Economic	Demand for Single-Occupancy Vehicle Travel	Change in the number or cost of multimodal options
			Noise	User Affected	Identify number of noise receptor sites above threshold (6)
			Customer Satisfaction /Quality of Life	Customer Perception towards Public Transportation Decisions Which Impact the Environment	Percentage of customer satisfaction
		Improved Safety/Security	Economic	Cost of Incidents	Average accidents cost per intermodal movement
			Prevention Activity	Condition of Transit Systems	Number of safety related improvements
			Emergency Response	Incident Response	Response time to incidents
			Customer Satisfaction /Quality of Life	Customer Perception towards Safety in Public Transportation Systems	Percentage of customers satisfied (5)
		Improved Project /Program Delivery	Economic	Schedule and Budget Adherence	Percentage projects completed on time and on budget
			Customer Satisfaction /Quality of Life	Customer Perception of Emergency Response Time	Percentage of customer satisfaction (5)
			Accomplishment: Effectiveness, Efficiency, Quality	Efficiency	Percent of capital costs spent; Percent cost of preliminary engineering rework
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Administration/ Workforce (P-3)	Improved Administration/Workforce	Industry Demand	Number of Entries Into Workforce	Number of planned and actual entry level; Total number of employees over time
			Education Supply	Education	Percentage passing each stage of screening
			Economic	Financial Measures	Administrative costs as percent of total program
			Improved Efficiency /Effectiveness	Efficiency	Total amount of time saved measured in hours
		Increased knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.

Mapping Table (5)

RC	RSC	BC	BSC	Measure	Data Type
Maintenance/ Operation (MO)	Roadway (MO-1)	Improved Infrastructure	Economic	Financial Measures	Infrastructure maintenance cost
			System Preservation	Preservation Activities	Maintenance hours
		Improved Accessibility/Mobility	Economic	Financial Measures	Public cost for transportation system
			Customer Satisfaction /Quality of Life	Customer Perception of Facility Operations and Availability	Percentage of customer satisfaction (5)
			Capacity	Availability	Number of hours of road closure
		Improved Environment	Air Quality/Emissions	Fuel Efficiency	Average fuel consumption per VMT
			Economic	Financial Measures	Tons of pollution (or vehicle emissions) generated per day
			Noise	Impacts	Number of noise receptor sites above threshold (6)
			Customer Satisfaction /Quality of Life	Customer Perception of Operational Impacts on Environment	Percentage of customer satisfaction (5)
		Improved Safety/Security	Economic	Financial Measures	Number of fatalities; Reduced congestion
			Prevention Activity	General Prevention	Number of annual incidents
			Emergency Response	Incident Recovery	Incident clearance time
			Customer Satisfaction /Quality of Life	Customer Perception of Operational Safety	Percentage of customer satisfaction (5)
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Transit (MO-2)	Improved Infrastructure	Economic	Financial Measures	Infrastructure maintenance cost
			System Preservation	Preservation Activities	Maintenance hours
		Improved Accessibility/Mobility	Economic	Financial Measures	Public cost for transportation system
			Customer Satisfaction /Quality of Life	Customer Perception of Facility Operations and Availability	Percentage of customer satisfaction (5)
			Capacity	Availability	Number of hours of system/route closure
		Improved Environment	Air Quality/Emissions	Reduction of Activities generating Pollutant Emissions	Tons of emissions per day
			Economic	Financial Measures	Delays measured in time; Occurrence of incidents
			Noise	Impacts	Number of noise receptor sites above threshold

Mapping Table (6)

RC	RSC	BC	BSC	Measure	Data Type
Maintenance/ Operation (MO)	Transit (MO-2)	Improved Environment	Customer Satisfaction /Quality of Life	Customer Perception of Operational Impacts on Environment	Percentage of customer satisfaction (5)
		Improved Safety/Security	Economic	Financial Measures	Delays measured in time; Occurrence of incidents
			Prevention Activity	Security Improvements	Percent of facilities with specific security features (cameras, lighting, guards, etc.)
			Emergency Response	Incident Recovery	Incident clearance time
			Customer Satisfaction /Quality of Life	Customer Perception of Operational Safety	Percentage of customer satisfaction (5)
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
Safety and Security (SS)	Transport Safety (SS-1)	Improved Safety	Customer Satisfaction /Quality of Life	Customer Perception of Safety While on Roadway Systems	percentage customer satisfaction (5)
				Customer Perception of Safety While on Public Transportation Systems	percentage customer satisfaction
			Economic	Financial Measures	Delays measured in time; Occurrence of incidents
			Prevention Activity	General Prevention	Number of roadway sections; Number of roadway
			Emergency Response	Funds Availability towards Incidents	Response time to incidents
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Transport Security (SS-2)	Improved Security	Customer Satisfaction /Quality of Life	Capacity of Transportation Systems to Recover Swiftly from Incidents	Change in capacity of parallel/redundant routes across all modes
			Economic	Financial Measures	Delays measured in time; Occurrence of incidents
			Prevention Activity	Security Improvements	Percent of facilities with specific security features (cameras, lighting, guards, etc.)
			Emergency Response	Incident Recovery	Incident clearance time
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.

Mapping Table (7)

RC	RSC	BC	BSC	Measure	Data Type
Sustainability (S)	Environment (S-1)	Improved Environment	Customer Satisfaction /Quality of Life	Customer Perception of Satisfaction with Transportation Decisions Which Impact on Environment/Air Quality/ Water Quality/Noise Conditions	Percentage of customers satisfaction
			Air Quality/Emissions	Reduction of Activities generating Pollutant Emissions	Tons of emissions per day
			Water Resources /Flood Protection	Water Pollution; Ability to Minimize Impervious Surface Area	Per capita fuel consumption; Per capita impervious surface area
			Land Use	Open Space and Biodiversity Protection	Per capita land devoted to transport facilities
			Noise	Impacts	Number of noise receptor sites above threshold (6)
			Economic	Energy Costs	Per capita transport energy consumption; Per capita use of imported fuels
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Society (S-2)	Improved Accessibility/Mobility	Customer Satisfaction /Quality of Life	Transportation Systems to Accommodate All Users	Transport system diversity; Portion of destinations accessible by people with disabilities and low incomes
				Community Development	Quality of road and street environments
				Cultural Heritage Preservation	Responsiveness to traditional communities
		Improved Safety/Security	Customer Satisfaction Quality of Life	Risk of Accidents	Per capita traffic casualty (injury and death) rates; Traveler assault (crime) rates
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.
	Economy (S-3)	Improved Accessibility/Mobility	Customer Satisfaction /Quality of Life	Essential Services and Activities	Portion of low-income households that spend more than 20% of budgets on transport
			Economic	Pricing and Incentives /Maximize Accessibility	Per capita GDP/ Per capita congestion delay; Efficient prioritization of facilities

Mapping Table (8)

RC	RSC	BC	BSC	Measure	Data Type
Sustainability (S)	Economy (S-3)	Improved Project /Program Delivery	Economic	Operations and Asset Management Maximizes Cost Efficiency	Service delivery unit costs compared with peers
		Increased Knowledge	Knowledge	Volume Of Information Sharing	Number of citations, downloads, etc.

Appendix D

Gap Analysis Results (1)

RC	RSC	BC	Measure	LA	VA	GA	FL	MS	WV	NC
Design	Pavement/Material /Geotech	Improved Infrastructure	Remaining Life	Y	Y		Y		Y	Y
			Reduction of Life-Cycle Cost				Y		Y	Y
			Monetary Savings				Y		Y	Y
		Increased Knowledge	Volume of Information Sharing							
	Bridge/Structure	Improved Infrastructure	Remaining Life	Y	Y					
			Average Health Index	Y						
			Reduction of Life-Cycle Cost							
			Monetary Saving							
		Increased Knowledge	Volume of Information Sharing							
	Road Design	Improved Accessibility/Mobility	Accessibility to Essential Destinations	Y	Y	Y	Y		Y	Y
		Improved Infrastructure	Remaining Life	Y	Y		Y		Y	Y
			Financial Measures		Y		Y	Y	Y	Y
		Improved Safety/Security	Road Networks Predictable and Recognizable to Users	Y			Y	Y	Y	Y
		Increased Knowledge	Volume Of Information Sharing							
	Hydraulics	Improved Environment	The Amount of Water Discharged from the System	Y			Y		Y	Y
		Increased Knowledge	Volume Of Information Sharing							
Construction Engineering	Project Management/ Construction Methods	Improved Project/Program Delivery	Regionally Produced Construction Materials				Y			
			Construction Costs within Planned Budget				Y			
			Impact of Construction Activities on System Efficiency	Y	Y		Y			
			Project Efficiency	Y			Y			
			Delivery Rate	Y			Y			
		Improved Safety/Security	Crash Risk in Work Zone	Y	Y		Y	Y	Y	Y
			Improved Work Zone Traffic Control Activities	Y	Y		Y	Y	Y	Y
		Improved Environment	User Satisfaction towards Construction Decisions Which Impact the Environment	Y			Y		Y	Y
			Reduction of Activities generating Pollutant Emissions	Y			Y		Y	Y
			Habitat Restoration and Landscaping	Y			Y		Y	Y
			Impacts	Y			Y		Y	Y
		Increased Knowledge	Volume Of Information Sharing							
	Product Development	Improved Safety/Security	Accident Reduction Rate	Y	Y		Y	Y	Y	Y

Gap Analysis Results (2)

RC	RSC	BC	Measure	LA	VA	GA	FL	MS	WV	NC
Construction Engineering	Product Development	Improved Project/ Program delivery	Monetary Savings				Y			
		Increased Knowledge	Volume Of Information Sharing							
Planning	Traffic/Roadway	Improved Accessibility/Mobility	Accessibility to Jobs			Y				
			Quality of Life			Y				
			Total Freeway Lane-Miles	Y		Y				
		Improved Environment	Reduction of Activities generating Pollutant Emissions	Y			Y		Y	Y
			Cost Efficiency	Y			Y		Y	Y
			Users Affected	Y			Y		Y	Y
			Customer Perception towards Transportation Decisions Which Impact the Environment	Y			Y		Y	Y
		Improved Safety/Security	Cost Per Accident	Y	Y	Y	Y	Y	Y	Y
			Number of Safety Aspects Considered Early in Project Planning	Y	Y	Y	Y	Y	Y	Y
			Incident Response	Y		Y	Y	Y	Y	Y
			Customer Perception of Safety While on Roadway Systems	Y		Y	Y	Y	Y	Y
		Improved Project/Program Delivery	Schedule and Budget Adherence							
			Customer Perception towards Emergency Response Time							
			Customer Impact	Y	Y					
			Efficiency	Y						
		Increased Knowledge	Volume Of Information Sharing							
	Public Transportation	Improved Accessibility/Mobility	Service Accessibility	Y		Y				
			Cost Efficiency			Y				
			Customer Ratings towards Transit Reliability, Congestion, Cost, Time, etc.			Y				
		Improved Environment	Use of Non-motorized Modes	Y			Y		Y	Y
			Demand for Single-Occupancy Vehicle Travel	Y			Y		Y	Y
			User Affected	Y			Y		Y	Y
			Customer Perception towards Public Transportation Decisions Which Impact the Environment	Y			Y		Y	Y

Gap Analysis Results (3)

RC	RSC	BC	Measure	LA	VA	GA	FL	MS	WV	NC
Planning	Public Transportation	Improved Safety/Security	Cost of Incidents	Y	Y	Y	Y	Y	Y	Y
			Condition of Transit Systems	Y	Y	Y	Y	Y	Y	Y
			Incident Response	Y		Y	Y	Y	Y	Y
			Customer Perception towards Safety in Public Transportation Systems	Y		Y	Y	Y	Y	Y
		Improved Project/Program Delivery	Schedule and Budget Adherence							
			Customer Perception of Emergency Response Time							
			Efficiency	Y						
		Increased Knowledge	Volume Of Information Sharing							
	Administration/ Workforce	Improved Administration/Workforce	Number of Entries Into Workforce			Y				
			Education			Y				
			Financial Measures	Y		Y				
			Efficiency							
		Increased knowledge	Volume Of Information Sharing							
Maintenance/ Operation	Roadway	Improved Infrastructure	Financial Measures		Y		Y	Y	Y	
			Preservation Activities		Y		Y	Y	Y	
		Improved Accessibility/Mobility	Financial Measures			Y				
			Customer Perception of Facility Operations and Availability			Y				
			Availability	Y		Y				
		Improved Environment	Fuel Efficiency	Y			Y		Y	Y
			Financial Measures	Y			Y		Y	Y
			Impacts	Y			Y		Y	Y
			Customer Perception of Operational Impacts on Environment	Y			Y		Y	Y
		Improved Safety/Security	Financial Measures	Y	Y	Y	Y	Y	Y	Y
			General Prevention	Y	Y	Y	Y	Y	Y	Y
			Incident Recovery	Y		Y	Y	Y	Y	Y
			Customer Perception of Operational Safety	Y		Y	Y	Y	Y	Y
		Increased Knowledge	Volume Of Information Sharing							
	Transit	Improved Infrastructure	Financial Measures		Y		Y	Y	Y	
			Preservation Activities		Y		Y	Y	Y	

Gap Analysis Results (4)

RC	RSC	BC	Measure	LA	VA	GA	FL	MS	WV	NC
Maintenance/ Operation	Transit	Improved Accessibility/Mobility	Financial Measures			Y				
			Customer Perception of Facility Operations and Availability			Y				
			Availability	Y		Y				
		Improved Environment	Reduction of Activities generating Pollutant Emissions	Y			Y		Y	Y
			Financial Measures	Y	Y		Y		Y	Y
			Impacts	Y			Y		Y	Y
			Customer Perception of Operational Impacts on Environment	Y			Y		Y	Y
		Improved Safety/Security	Financial Measures	Y	Y	Y	Y	Y	Y	Y
			Security Improvements	Y		Y	Y	Y	Y	Y
			Incident Recovery	Y		Y	Y	Y	Y	Y
			Customer Perception of Operational Safety	Y		Y	Y	Y	Y	Y
		Increased Knowledge	Volume Of Information Sharing							
Safety and Security	Transport Safety	Improved Safety	Customer Perception of Safety While on Roadway Systems	Y		Y	Y	Y	Y	Y
			Customer Perception of Safety While on Public Transportation Systems	Y		Y	Y	Y	Y	Y
			Financial Measures	Y	Y	Y	Y	Y	Y	Y
			General Prevention	Y		Y	Y	Y	Y	Y
			Funds Availability towards Incidents	Y	Y	Y	Y	Y	Y	Y
		Increased Knowledge	Volume Of Information Sharing							
	Transport Security	Improved Security	Capacity of Transportation Systems to Recover Swiftly from Incidents							
			Financial Measures		Y					
			Security Improvements							
			Incident Recovery							
		Increased Knowledge	Volume Of Information Sharing							
Sustainability	Environment	Improved Environment	Customer Perception of Satisfaction with Transportation Decisions Which Impact the Environment/Air Quality/Water Quality/Noise Conditions	Y			Y		Y	Y

Gap Analysis Results (5)

RC	RSC	BC	Measure	LA	VA	GA	FL	MS	WV	NC
Sustainability	Environment	Improved Environment	Reduction of Activities generating Pollutant Emissions	Y			Y		Y	Y
			Water Pollution; Ability to Minimize Impervious Surface Area	Y			Y		Y	Y
			Open Space and Biodiversity Protection	Y			Y		Y	Y
			Impacts	Y			Y		Y	Y
			Energy Costs	Y			Y		Y	Y
		Increased Knowledge	Volume Of Information Sharing							
	Society	Improved Accessibility/Mobility	Transportation Systems to Accommodate All Users			Y				
			Community Development			Y				
			Cultural Heritage Preservation			Y				
		Improved Safety/Security	Risk of Accidents	Y	Y	Y	Y	Y	Y	Y
		Increased Knowledge	Volume Of Information Sharing							
	Economy	Improved Accessibility/Mobility	Essential Services and Activities	Y		Y				
			Pricing and Incentives/Maximize Accessibility			Y				
		Improved Project/Program Delivery	Operations and Asset Management Maximizes Cost Efficiency	Y						
		Increased Knowledge	Volume Of Information Sharing							

Appendix E

General Definitions of the Research Categories and Subcategories (1)

Research Category	Research Subcategory	General Definition
Design	Pavement/Material/ Geotech	- Pavement design for new roadways and the rehabilitation of existing roadways to optimize the level of service provided to road users. - Material design to meet the structural and functional demands of roadways. - Geotechnical issues in pavement and material design. - For example, pavement structure design; material testing; specification; mixture design and optimization for both traditional and innovative materials; characterization of subgrades and unbound base and subbase materials.
	Bridge/Structure	- Design for bridges and all other transportation structures such as railroads, parking facilities, docks, and bus stations.
	Road	- Geometric design of roads concerned with the positioning of the road physical elements to optimize the functionality of roads for efficiency and safety. - For example, designs for alignment, profile, and cross section.
	Hydraulics	- Hydraulic design to ensure that transportation structures (e.g., roadways, bridges, and railroads) have sufficient capabilities to control the movement of water and handle water-related impacts (e.g., erosion, collapse, and sediment).
Construction Engineering	Project Management/ Construction Methods	- Enhancement of the skills and knowledge of state DOT practitioners regarding project management and construction methods to successfully deliver complete transportation projects on-time and within-budget without sacrificing safety and quality. - For example, project data management; resource management; project delivery; partnering; effective governance and culture innovation; managing and reporting on the delivery status; advancement in existing construction technologies and materials; project cost, time, safety, and quality controls.
	Product Development	- Development of new technologies, materials, systems, and tools to enhance the efficiency and performance of transportation project planning, design, and construction.
Planning Planning	Traffic/Roadway	- Planning to enhance the safe and efficient movement of pedestrians, cyclists, vehicles, and goods on roadways - For example, traffic impact analysis; traffic data collection; traffic concurrency studies; trip generation studies; transportation due diligence; traffic operational analysis; corridor studies; traffic signal warrant studies.
	Public Transportation	- Development of public transportation systems such as buses, trains, subways, and other forms of transportation that charge set fares, run on fixed routes, and are available to the public. - Planning to optimize the quality of trips for public transportation users. - For example, strategic policy development; demand forecasting; operational and business-case analysis; network connectivity; route selection; urban-land-use issues.

General Definitions of the Research Categories and Subcategories (2)

Research Category	Research Subcategory	General Definition
Planning	Administration/ Workforce	- Administration planning to enhance the operations and services of an administrative infrastructure - Workforce planning to align the size, type, experience, knowledge, and skills of the agency's workforce with the needs and priorities to achieve its goal.
Maintenance/ Operation	Roadway	- Maintenance and operations of physical roadway systems to maintain a quality of serviceability. - This subcategory includes all physical facilities (e.g., bridges, tunnels, rest areas, and public areas) on the route of roadways.
	Transit	- Maintenance and operations of various public transit systems which include railways and mass transit systems.
Safety and Security	Transport Safety	- Protection of users from unintended structural and functional failures or errors of transportation systems.
	Transport Security	- Protection of users from deliberate or malicious attempts to disrupt or destroy transportation systems.
Sustainability	Environment	- Prolonged examination and preservation of the environment regarding factors such as water and air quality.
	Society	- Efforts to assure public equality, freedom and a healthy standard of living by developing transportation systems sustainably.
	Economy	- Development and enhancement of transportation systems in a way to reduce costs in economic sectors.

Appendix F

Different Applications of the Data Types Numbered (1)

Data Types Numbered	Applications
Percent of design life achieved (1)	- Percent asset quantity with fewer than 5 years remaining service life (RSL) - Average Remaining Service Life - Percent of design life achieved - Percent asset quantity forecast to achieve full design life - Average age or percent asset quantity greater than "n" years old (age can be a useful proxy for remaining life when data are limited) - Percent pavement miles with weight restrictions due to structural limitations - Percent assets eligible for replacement - Percent asset quantity out of service due to deteriorated condition
Data of all current element value and all initial element value (2)	- Average health index (0–100 scale) - Percent structurally deficient (SD) - Percent with sufficiency rating less than 50 - Percent of bridges that meet department standards - Number of posted or restricted bridges - Number of steel bridges with section loss in a member - Percent of bridges with deck, superstructure, and substructure NBI rating of 4 or below
Infrastructure maintenance cost (3)	- Cost/benefit of existing facility vs. new construction - Number and dollar value of projects that improve travel time on key routes - Average cost per lane-mile constructed - Cost per percentage point increase in lane miles rates fair or better on pavement condition - Percentage of increase in final amount paid for completed construction over original contract amount - Percent cost of re-work - Construction Productivity index (Cost of contract lettings, utilities, real estate acquisition, construction, change orders, and cost overruns DIVIDED BY staff costs, consultant contracts, and design construction change orders)
Duration of construction (4)	- Cost per lane-mile constructed - Administrative costs as percent of total program - Preliminary engineering (PE) and construction engineering (CE) costs as percent of construction costs - Design costs as percent of construction dollars let - Percent of highway capital costs spent on construction (contractor payments and direct on-site construction oversight) - Percent of cost of preliminary engineering rework - Duration of construction (by project type)
Percentage of customer satisfaction (5)	- Customer satisfaction with transportation decisions affecting the environment - Customer perception of air quality - Customer satisfaction rating for different maintenance elements - Customer rating of asset condition or agency preservation activities - Customer satisfaction rating - Customer ratings of trip time, reliability, congestion severity, travel cost, travel time, etc. - Customer satisfaction with snow and ice removal

Different Applications of the Data Types Numbered (2)

Data Types Numbers	Applications
Number of noise receptor sites above established standards (6)	- Number of residences or percent of population exposed to highway noise exceeding established standards (or greater than X decibels) - Number of noise receptor sites above threshold • Constraints on use due to noise (or water) - Percent of road network (including concrete sections) with quieter road surface by 2010

Appendix G

Definitions for Measures in the Mapping Table (1)

RC	RSC	BC	BSC	Measure	Definition
D	D-1	Improved Infrastructure	Lifecycle	Remaining Life	Condition and remaining life measures can be expressed as averages or distributions (e.g., percent of system length or VMT on roads in good, fair, and poor condition).
			Economic	Reduction of Life-Cycle Cost	Sum of all recurring and non-recurring costs over the full life span or a specified period of a good, service, structure, or system. Includes purchase price, installation cost, operating costs, maintenance and upgrade costs, and remaining (residual or salvage) value at the end of ownership or its useful life.
				Monetary Savings	Monetary savings due to use of durable materials
		Increased Knowledge	Knowledge	Volume of Information Sharing	
	D-2	Improved Infrastructure	Lifecycle	Remaining Life	Condition and remaining life measures can be expressed as averages or distributions (e.g., percent of system length or VMT on roads in good, fair, and poor condition).
				Average Health Index	Condition and remaining life measures can be expressed as averages or distributions (e.g., percent of system length or VMT on roads in good, fair, and poor condition).
			Economic	Reduction of Life-Cycle Cost	Sum of all recurring and non-recurring costs over the full life span or a specified period of a good, service, structure, or system. Includes purchase price, installation cost, operating costs, maintenance and upgrade costs, and remaining (residual or salvage) value at the end of ownership or its useful life.
				Monetary Saving	Monetary saving due to reduction of installing time
		Increased Knowledge	Knowledge	Volume of Information Sharing	
	D-3	Improved Accessibility/Mobility	Capacity	Accessibility to Essential Destinations	Change in travel time (by mode) to schools, health services, grocery stores, civic and public spaces, recreation
		Improved Infrastructure	Lifecycle	Remaining Life	Condition and remaining life measures can be expressed as averages or distributions (e.g., percent of system length or VMT on roads in good, fair, and poor condition).
			Economic	Financial Measures	Average cost per mile/ Average cost per trip /Vehicle operating cost reductions /Additional costs per trip (user fees) /Reduced costs per trip (subsidies)/ Use cost/ Person-mile (user cost)/ Insurance costs/ Value of fuel savings

Definitions for Measures in the Mapping Table (2)

RC	RSC	BC	BSC	Measure	Definition
D	D-3	Improved Safety/Security	Prevention Activity	Road Networks Predictable and Recognizable to Users	Existence of a functional class system of roadway; Existence of a system that adjusts speeds based on the hierarchy of roads.
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
	D-4	Improved Environment	Water Resources/Flood Protection	The Amount of Water Discharged from the System	Volumetric flow rate of water that is transported through a given cross-sectional area.
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
CE	CE-1	Improved Project/Program Delivery	Economic	Regionally Produced Construction Materials	Goods and materials should be purchased within a certain radius from the project
				Construction Costs within Planned Budget	Proportion of projects with construction costs within planned budget
			Accomplishment: Effectiveness, Efficiency, Quality	Impact of Construction Activities on System Efficiency	Change in multimodal LOS due to construction activities
				Project Efficiency	Design costs as percent of construction dollars/ Administrative costs as percent of total program/ Cost per lane-mile constructed
				Delivery Rate	Right of way plans completed on time/ Construction projects completed on schedule/ Construction projects completed on budget
		Improved Safety/Security	Prevention Activity	Crash Risk in Work Zone	Number of crashes as a portion of total time of work zones by functional class, county, and district/region
				Improved Work Zone Traffic Control Activities	Number of traffic control supervisors that are trained and on- site number of annual traveler safety complaints
		Improved Environment	Customer Satisfaction/Quality of Life	User Satisfaction towards Construction Decisions Which Impact the Environment	Refer to Appendix F
			Air Quality/Emissions	Reduction of Activities generating Pollutant Emissions	Tons of emissions generated per day due to construction

Definitions for Measures in the Mapping Table (3)

RC	RSC	BC	BSC	Measure	Definition
CE	CE-1	Improved Environment	Land Use	Habitat Restoration and Landscaping	Acres of wetlands replaced or protected for every acre affected by construction
			Noise	Impacts	Refer to Appendix F
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
	CE-2	Improved Safety/Security	Prevention Activity	Accident Reduction Rate	Rate of accidents
		Improved Project/ Program delivery	Economic	Monetary Savings	Equipment costs/labor costs/equipment lifecycle
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
P	P-1	Improved Accessibility/Mobility	Economic	Accessibility to Jobs	Direct jobs created
			Customer Satisfaction/Quality of Life	Quality of Life	Percent of population that perceives that its environment has become more 'livable' over the past year with regard to ability to access desired activities
			Capacity	Total Freeway Lane-Miles	Total freeway lane-miles in acceptable condition
		Improved Environment	Air Quality/Emissions	Reduction of Activities generating Pollutant Emissions	Change in percentage of commercial vehicles by EPA tier compliance
			Economic	Cost Efficiency	Ratio of oversize or overweight permit fees collected to dollar value of damage caused
			Noise	Users Affected	Refer to Appendix F
			Customer Satisfaction/Quality of Life	Customer Perception towards Transportation Decisions Which Impact the Environment	Refer to Appendix F
		Improved Safety/Security	Economic	Cost Per Accident	Accident rate, deaths, injury, property loss by type of corridor
			Prevention Activity	Number of Safety Aspects Considered Early in Project Planning	Projects where safety of a project was reviewed in each of the project development stages by a multidisciplinary review team
			Emergency Response	Incident Response	Response time to incidents
			Customer Satisfaction/Quality of Life	Customer Perception of Safety While on Roadway Systems	Refer to Appendix F

Definitions for Measures in the Mapping Table (4)

RC	RSC	BC	BSC	Measure	Definition
P	P-1	Improved Project/Program Delivery	Economic	Schedule and Budget Adherence	Contracts completed on time
			Customer Satisfaction/Quality of Life	Customer Perception towards Emergency Response Time	Refer to Appendix F
			Accomplishment: Effectiveness, Efficiency, Quality	Customer Impact	Lane-hours restricted due to construction
				Efficiency	Duration of project
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
	P-2	Improved Accessibility/Mobility	Capacity	Service Accessibility	Access time to intermodal facilities
			Economic	Cost Efficiency	Cost per passenger
			Customer Satisfaction/Quality of Life	Customer Ratings towards Transit Reliability, Congestion, Cost, Time, etc.	Refer to Appendix F
		Improved Environment	Air Quality/Emissions	Use of Non-motorized Modes	Route or service miles of transit routes, pedestrian facilities, designated bike facilities, population within 1 mile of transit, person-miles walk distance to transit stops, person-miles distance from building entrances to public pedestrian facilities (sidewalks, pedestrian ways), connectivity index (pedestrian facilities, bike facilities, transit) due to project
			Economic	Demand for Single-Occupancy Vehicle Travel	Make multimodal options cheaper and more accessible
			Noise	User Affected	Refer to Appendix F
			Customer Satisfaction/Quality of Life	Customer Perception towards Public Transportation Decisions Which Impact the Environment	Refer to Appendix F
		Improved Safety/Security	Economic	Cost of Incidents	Accident rate, deaths, injury, property loss by type of corridor
			Prevention Activity	Condition of Transit Systems	Miles of track not useable by certain traffic because of design or condition deficiencies
			Emergency Response	Incident Response	Response time to incidents

Definitions for Measures in the Mapping Table (5)

RC	RSC	BC	BSC	Measure	Definition
P	P-2	Improved Safety/Security	Customer Satisfaction/Quality of Life	Customer Perception towards Safety in Public Transportation Systems	Refer to Appendix F
		Improved Project/Program Delivery	Economic	Schedule and Budget Adherence	Contracts completed on time
			Customer Satisfaction/Quality of Life	Customer Perception of Emergency Response Time	Refer to Appendix F
			Accomplishment: Effectiveness, Efficiency, Quality	Efficiency	Duration of project
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
	P-3	Improved Administration/Workforce	Industry Demand	Number of Entries Into Workforce	Experienced hires
			Education Supply	Education	Number of students enrolled in related fields of study
			Economic	Financial Measures	Preliminary engineering (PE) and construction engineering (CE) costs as percent of construction costs
			Improved Efficiency/ Effectiveness	Efficiency	Effort in administrative work
		Increased knowledge	Knowledge	Volume Of Information Sharing	
MO	MO-1	Improved Infrastructure	Economic	Financial Measures	Average cost per mile/ Average cost per trip /Vehicle operating cost reductions /Additional costs per trip (user fees) /Reduced costs per trip (subsidies)/ Use cost/ Person-mile (user cost)/ Insurance costs/ Value of fuel savings
			System Preservation	Preservation Activities	Percentage of highway mainline pavement (or bridges) rated good or better
		Improved Accessibility/Mobility	Economic	Financial Measures	Total public expenditures on modal systems (freight vs. passenger)
			Customer Satisfaction/Quality of Life	Customer Perception of Facility Operations and Availability	Refer to Appendix F
			Capacity	Availability	Number of truck units, railroad cars, or containers that can be stored at intermodal facility

Definitions for Measures in the Mapping Table (6)

RC	RSC	BC	BSC	Measure	Definition
MO	MO-1	Improved Environment	Air Quality/Emissions	Fuel Efficiency	Gallons of wasted fuel
			Economic	Financial Measures	Economic Costs of pollution
			Noise	Impacts	Refer to Appendix F
			Customer Satisfaction/Quality of Life	Customer Perception of Operational Impacts on Environment	Refer to Appendix F
		Improved Safety/Security	Economic	Financial Measures	Economic costs of incidents
			Prevention Activity	General Prevention	Grade crossing collisions/ Level of redundancy for critical passenger and freight infrastructure/ Change in the capacity of parallel routes across all modes
			Emergency Response	Incident Recovery	Change in the number/ Value of projects as part of program designed to improve capacity of the transportation system to recover swiftly from incidents
			Customer Satisfaction/Quality of Life	Customer Perception of Operational Safety	Refer to Appendix F
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
	MO-2	Improved Infrastructure	Economic	Financial Measures	Average cost per mile/ Average cost per trip /Vehicle operating cost reductions /Additional costs per trip (user fees) /Reduced costs per trip (subsidies)/ Use cost/ Person-mile (user cost)/ Insurance costs/ Value of fuel savings
			System Preservation	Preservation Activities	Percentage of highway mainline pavement (or bridges) rated good or better
		Improved Accessibility/Mobility	Economic	Financial Measures	Total public expenditures on modal systems (freight vs. passenger)
			Customer Satisfaction/Quality of Life	Customer Perception of Facility Operations and Availability	Refer to Appendix F
			Capacity	Availability	Number of railroad cars, or busses that can be stored at intermodal facility
		Improved Environment	Air Quality/Emissions	Reduction of Activities generating Pollutants	Change in trips; VMT; percent non-driver
			Economic	Financial Measures	Economic costs of congestion
			Noise	Impacts	Refer to Appendix F

Definitions for Measures in the Mapping Table (7)

RC	RSC	BC	BSC	Measure	Definition
MO	MO-2	Improved Environment	Customer Satisfaction/Quality of Life	Customer Perception of Operational Impacts on Environment	Refer to Appendix F
		Improved Safety/Security	Economic	Financial Measures	Economic costs of transit incidents
			Prevention Activity	Security Improvements	Percent of facilities passing security tests
			Emergency Response	Incident Recovery	Change in the number/ Value of projects as part of program designed to improve capacity of the transportation system to recover swiftly from incidents
			Customer Satisfaction/ Quality of Life	Customer Perception of Operational Safety	Refer to Appendix F
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
SS	SS-1	Improved Safety	Customer Satisfaction/Quality of Life	Customer Perception of Safety While on Roadway Systems	Refer to Appendix F
				Customer Perception of Safety While on Public Transportation Systems	Refer to Appendix F
			Economic	Financial Measures	Economic costs of transit incidents
			Prevention Activity	General Prevention	Transit system stations not meeting safety standards/ Transit locations with identified hazards
			Emergency Response	Funds Availability towards Incidents	Relative change in capital and operational funding allocated to disaster/ Incident response and management
SS	SS-1	Increased Knowledge	Knowledge	Volume Of Information Sharing	
	SS-2	Improved Security	Customer Satisfaction/ Quality of Life	Capacity of Transportation Systems to Recover Swiftly from Incidents	Change in the number/value of projects as part of program designed to improve capacity of the transportation system to recover swiftly from incidents
			Economic	Financial Measures	Economic costs of transit incidents
			Prevention Activity	Security Improvements	Percent of facilities passing security tests
			Emergency Response	Incident Recovery	Change in the number/value of projects as part of program designed to improve capacity of the transportation system to recover swiftly from incidents
		Increased Knowledge	Knowledge	Volume Of Information Sharing	

Definitions for Measures in the Mapping Table (8)

RC	RSC	BC	BSC	Measure	Definition
S	S-1	Improved Environment	Customer Satisfaction/ Quality of Life	Customer Perception of Satisfaction with Transportation/ Air Quality/ Water Quality/ Noise Conditions	Refer to Appendix F
			Air Quality/Emissions	Reduction of Activities generating Pollutants	Change in trips; VMT; Percent non-driver
			Water Resources/ Flood Protection	Water Pollution; Ability to Minimize Impervious Surface Area	Management of used oil, leaks and stormwater
			Land Use	Open Space and Biodiversity Protection	Support for smart growth development/Policies to protect high value farmlands and habitat
			Noise	Impacts	Refer to Appendix F
			Economic	Energy Costs	Particularly petroleum imports
		Increased Knowledge	Knowledge	Volume of Information Sharing	
	S-2	Improved Accessibility/Mobility	Customer Satisfaction/Quality of Life	Transportation Systems to Accommodate All Users	Those with disabilities, low incomes, and other constraints.
				Community Development	Walkability and bikability
				Cultural Heritage Preservation	Preservation of cultural resources and traditions
		Improved Safety/Security	Customer Satisfaction/ Quality of Life	Risk of Accidents	Human exposure to harmful pollutants/Portion of travel by walking and cycling
		Increased Knowledge	Knowledge	Volume Of Information Sharing	
	S-3	Improved Accessibility/Mobility	Customer Satisfaction/ Quality of Life	Essential Services and Activities	Availability and quality of affordable modes (walking, cycling, ridesharing and public transport)
			Economic	Pricing and Incentives/ Maximize Accessibility	Portion of budgets devoted to transport/ Efficient pricing (road, parking, insurance, fuel, etc.)
		Improved Project/Program Delivery	Economic	Operations and Asset Management Maximizes Cost Efficiency	Performance audit results/ Service quality
		Increased Knowledge	Knowledge	Volume Of Information Sharing	

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