

Synthesis of Best Practices for Determining Value of Transportation Research on Safety and Environmental Sustainability

Departments of Transportation (DOTs) sponsor research projects to enhance safety and environmental sustainability of transportation systems. Although these departments use a variety of methods to determine the value of research, there has not been a study to synthesize these methods and provide examples on how to use existing methods to determine value of research on safety and environmental sustainability. The overall objective of this paper is to synthesize existing methods, measures, and data sources for determining the value of transportation research on safety and environmental sustainability. Survey was used to identify existing methods, measures, and data sources for determining value of research on safety and environmental sustainability. Several examples were also collected through the survey. Results show that various methods have been utilized by transportation agencies to determine the value of research on safety and environmental sustainability. Methods used for determining value of safety research can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and benefit (dollar)/cost (dollar) analysis. Benefit (Dollar) analysis goes beyond benefit analysis by transferring the value of safety research in dollar values. The benefit analysis is conducted using various approaches: before-and-after study, statistical analysis, simulation analysis, assumption-based estimation, and field experiments. Methods used for determining value of research on environmental sustainability can be classified into two major categories: benefit analysis, and benefit (dollar) analysis. The benefit analysis is conducted using various approaches: lab experiments, before-and-after study, assumption-based estimation, and field experiments. Several measures and data sources that are used by transportation agencies to determine the value of research are also collected. This research provides a list of existing methods, measures, and data sources along with several examples that can be used by transportation agencies for determining value of research on safety and environmental sustainability.

Keywords: Transportation, Environmental Sustainability, Safety, Value of Research

Introduction

Transportation agencies sponsor various transportation research projects to improve safety and environmental sustainability of transportation systems. Although these departments use a variety of methods to determine the value of research, there has not been a study to synthesize these methods and provide examples on how to use existing methods to determine value of research on safety and environmental sustainability. There is a need to synthesize existing methods, measures, and data sources for demonstrating the value of research on safety and environmental sustainability. This research was a part of a more comprehensive research in which the authors found that methods and measures for determining value of research in the areas of sustainability and safety are underrepresented and it is worth highlighting them.

Departments of Transportation (DOTs) have published several documents regarding the determination of value of transportation research (Anderson 2010; Ardis 1988; Concas et al. 2002; Ellis et al. 2003; Tavakoli and Collyard 1991; Worel et al. 2008). For example, Ellis et al. (2003) developed a cost/benefit evaluation method for the Florida DOT to evaluate the benefits of the DOT research projects and measure the cumulative benefits of the department's total research program. They considered both qualitative and economic benefits in their evaluation method. In another significant study, Krugler et al. (2006) conducted a National Cooperative Highway Research Program (NCHRP) research and listed research-related performance measures (PMs) from surveys and literature. It was

found that top performance measures were lives saved, reduction in crashes, and construction, maintenance, and operations cost savings. Moreover, Transportation Research Board (TRB) publishes "Research Pays Off" documents demonstrating the benefits of research and the Value of Research Task Force of the American Association of State Highway and Transportation Officials (AASHTO) Research Advisory Committee (RAC) collects high value research projects from across the nation.

Although transportation agencies use a variety of methods to determine the value of research, there has not been a study to synthesize these methods and provide examples on how to use existing methods to determine value of research on safety and environmental sustainability. Hence, the industry suffers from the lack of awareness about a collection of implementable methods, measures, and data sources for determining the value of transportation research on safety and environmental sustainability. The overall objective of this paper is to synthesize existing methods, measures, and data sources for determining the value of research on safety and environmental sustainability. This research provides a list of existing methods, measures, and data sources along with several examples that can be used by transportation agencies for determining value of research on safety and environmental sustainability.

Research methodology

Survey was conducted to collect examples of determining the value of research on safety and environmental sustainability. The survey was distributed among representatives from 50 State DOTs, the District of Columbia, the Federal Highway Administration (FHWA), and the Transportation Research Board (TRB) via email. A copy of the survey was also distributed among contacts from the American Association of State Highway and Transportation Officials (AASHTO) Research Advisory Committee (RAC) via email. The survey included several questions regarding the determination of value of transportation research, such as "Have you ever quantified the impact of any research project in the specified areas?" Safety and environmental sustainability were among two specified areas.

Several examples for determining value of research were collected. Moreover, the Value of Research Task Force of the AASHTO Research Advisory Committee (RAC) compiles high value research projects from across the nation and publishes them annually. These documents that represent high value research projects from across the nation were reviewed and projects related to safety and environmental sustainability were preliminary selected for further analysis. Corresponding agencies of the selected projects were contacted via email. The corresponding agencies were asked to provide further details on the background calculations for determining the benefits of the research projects. The scope of our research is limited to the examples that we found using our survey and the related high value research projects. These examples were reviewed and their contents were analyzed rigorously. This rigorous analysis resulted in the identification of methods, measures, and data sources used in the examples. The total of 11 examples related to safety and 9 examples related to environmental sustainability are selected and rigorously analysed. The following two sections represent the methods, measures, and data sources to identify value of research on safety and environmental sustainability. These methods, measures and data sources are identified using the rigorous analysis of the examples.

Research results

Methods, Measures, and Data Sources for Determining Value of Safety Research

Methods for Determining Value of Research in Transportation Safety

Methods used for determining value of safety research can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and benefit (dollar)/cost (dollar) analysis. These methods were identified from the detailed analysis of several research projects in transportation safety. These research projects are discussed in the rest of this section. Figure 1 shows the classification of methods used for determining value of safety research in conjunction with research projects that have utilized these methods.

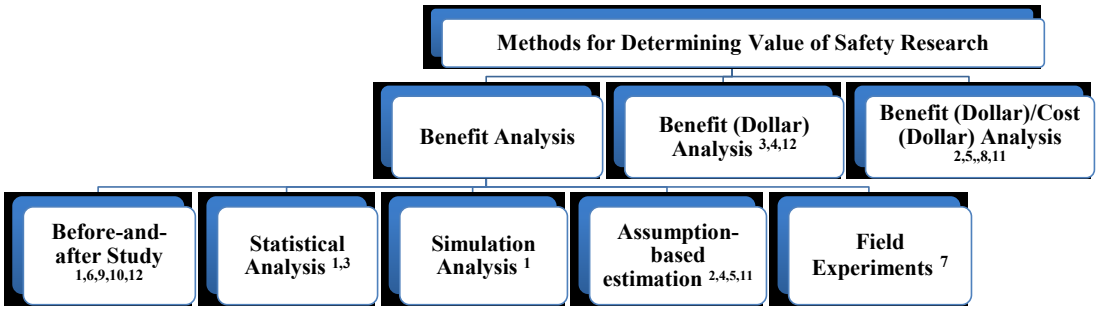

Figure 1: Classification of methods used for determining value of safety research.

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

Benefit analysis for determining value of safety research. Benefit analysis is a systematic approach for calculating value of safety research projects. Safety research projects aim to improve safety-related features of transportation systems. Benefit analysis determines the improvement in one or several safety-related features and uses this improvement as the basis to determine value of safety research in transportation. Benefit analysis can be conducted using one of the following five approaches as shown in Figure 1: before-and-after study, statistical analysis, simulation analysis, assumption-based estimation, and field experiments. These methods for benefit analysis were used by different transportation agencies to estimate the safety impact of high value research projects identified in our surveys:

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

Statistical Analysis refers to methods, such as regression analysis, that enables objective analysis of safety based on historical data. For example, in the Indiana Super 70 research project, the research aimed to estimate the safety effect of traffic management and enforcement countermeasures applied during the nine-month of construction. In

this project, logistic regression is used to estimate the impacts of individual safety countermeasures and other safety variables on number of crashes.

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

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

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

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

Benefit (Dollar)/Cost (Dollar) Analysis for Determining Value of Safety Research. Benefit (Dollar)/Cost (Dollar) analysis (B/C analysis) goes beyond benefit analysis and calculates and compares safety benefits and costs in terms of dollar values. For example, in the North Carolina research project entitled "Placement of Detection Loops on High Speed Approaches to Traffic Signals" and published in 2010, benefit (Dollar)/cost (Dollar) analysis is used to assess cost effectiveness of alternatives to evaluate various systems. An estimated percent reduction (a marginal 10 percent reduction) of crashes is assumed due to installation of technologies. Crash data for years 2006, 2007 and 2008 were collected from the North Carolina Department of Transportation and the average number of crashes is used for calculating benefits. The equivalent unit crash cost is extracted for each county from the North Carolina Department of Transportation Traffic Engineering and Safety Systems branch website. This cost was considered as the project benefit in terms of dollars and compared with the cost of installation of various systems, such as Detector-Control System (D-CS) and NQ4 system, which make this safety improvement possible.

Measures for Determining Value of Safety Research

Various measures have been used by different transportation agencies for determining value of safety research. These measures can be classified into three major categories that address different aspects of transportation safety: "crashes and injuries", "cost saving" and "others" as shown in Figure 2. "Crashes or injuries" measures are used to

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

Data Sources for Determining Value of Safety Research

Various data sources have been used to evaluate safety in different research projects. The identified data sources for determining the value of safety research are presented in Figure 3. "Crashes and injuries" data sources were used to present the value of safety research in terms of reduction in crashes and/or injuries. "Cost savings" data sources were used to calculate dollar of avoided crashes and injuries. The last category of data sources, called "Others," includes all the other sources of data that were used in the methods for determining value of safety research.

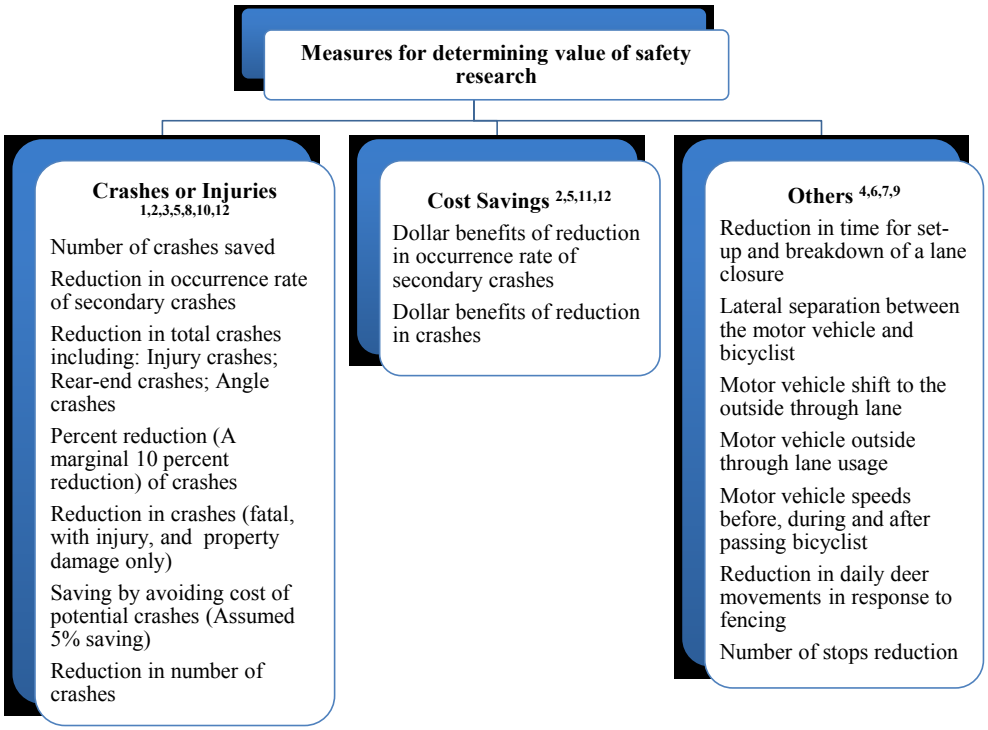

Figure 2: Measures for determining value of safety research

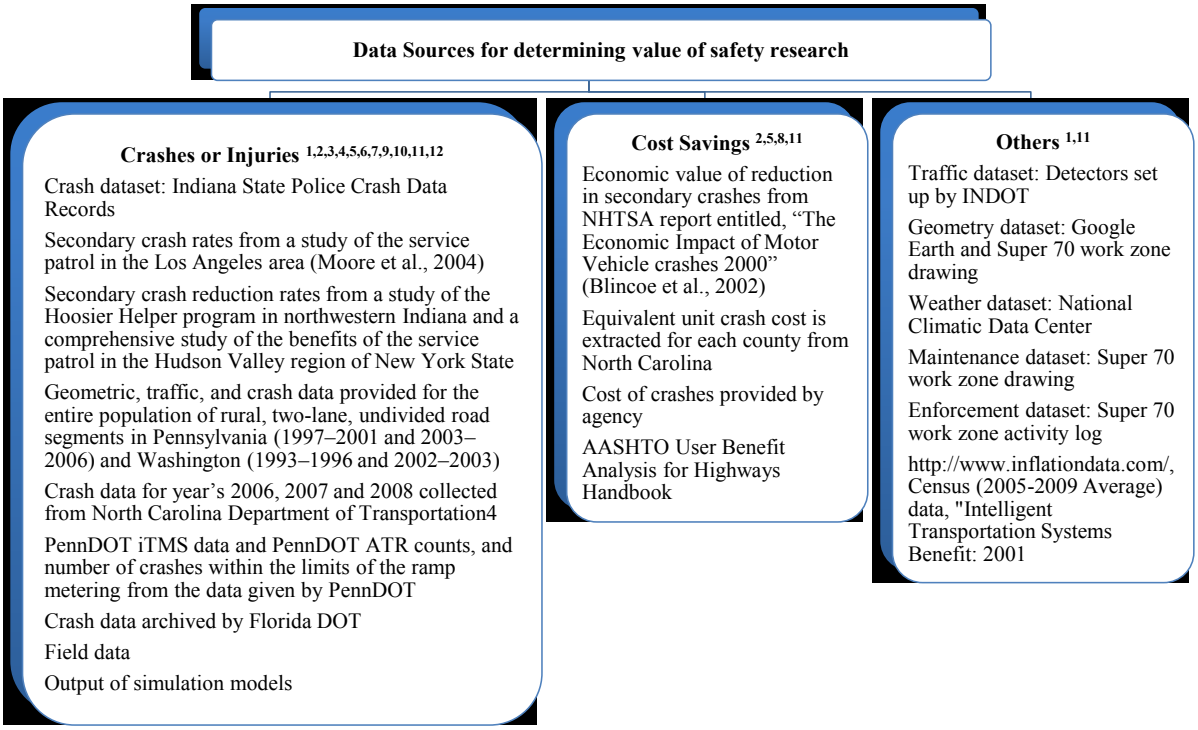

Figure 3: Data Sources for determining value of safety research

Methods, Measures, and Data Sources for Determining Value of Research on Environmental Sustainability

Methods for Determining Value of Research on Environmental Sustainability

The identified methods for determining value of research about environmental sustainability can be classified into two major categories: benefit analysis and benefit (dollar) analysis. These methods were identified from the detailed analysis of several research projects in environmental sustainability. Figure 4 shows the classification of methods used for determining value of environmental sustainability in conjunction with research projects that have utilized these methods.

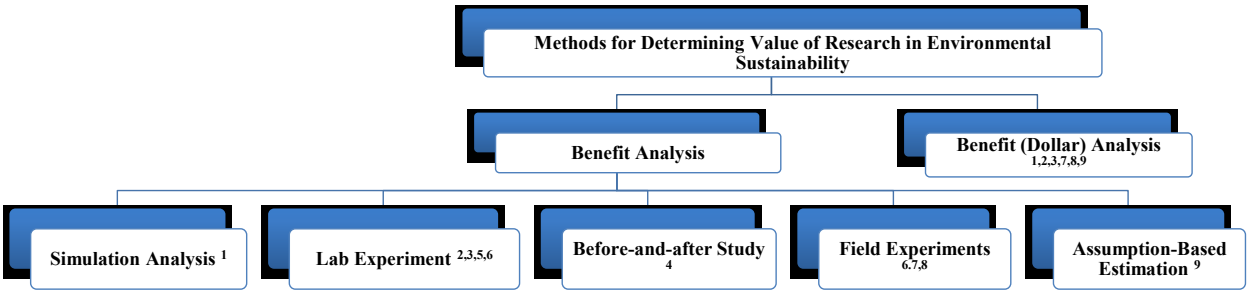

Figure 4: Classification of the methods for determining value of research on Environmental Sustainability

1. "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" Sponsored by Alabama DOT
2. "Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions" Sponsored by Florida DOT
3. "Evaluation of Ternary Cementitous Combinations" Sponsored by Louisiana DOT
4. "Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri" Sponsored by Missouri DOT
5. "Retrofitting Culverts and Fish Passage-Phase II" Sponsored by Utah DOT

6. "Recycling of Salt-Contaminated Stormwater Runoff for Brine Production" by Virginia DOT
7. "An assessment of the Virginia Department of Transportation's Animal Carcass Disposal Practices and Guidance for the Selection of Alternative Carcass-Management Options" by Virginia DOT
8. "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule" Sponsored by Missouri DOT
9. "A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit"

Benefit Analysis for Determining Value of Research on Environmental Sustainability. Benefit analysis is used to calcualte the value of research on environmental sustainability. Benefit analysis for determining value of research on environmental sustainability can be conducted using one of the following five approaches as shown in Figure 4: simulation analysis, lab experiment, before-and-after study, field study, and assumption-based estimation. These methods for benefit analysis were used by different transportation agencies to estimate the environmental impact of high value research projects identified in our survey.

Simulation is used to determine value of research on environmental sustainability. For instance, simulation software is used for calculating mobility measures and emission outputs in the research project entitled "An Evaluation of the Benefits of the Alabama Service and Assistance Patrol" sponsored by the Alabama DOT. Lab Experiment is used to test environmental sustainability impacts of transportation research project under controlled conditions. For example, in the research project sponsored by the Florida DOT, entitled "Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions" 46 tests were conducted at the University of Central Florida to examine how the amount of phosphorus (which is undesirable adjacent to bodies of water) can be reduced.

Before-and-after Study is used to evaluate environmental impact of proposed systems. For example, in the research project entitled "Evaluation of an Adaptive Traffic Signal System" sponsored by the Missouri DOT, changes in vehicle emissions (estimated by the amount of released HC, CO, and NOx) were determined using a before-and-after study approach on Route 291 in Lee's Summit DOT. Results showed a decrease of 50 percent in vehicle emissions through using traffic signal system. Field Experiments refers to experiments that examine the impact of research in environmental sustainability in the real world. For example in the project sponsored by the Missouri DOT, entitled "Evaluation of Life Expectancy of LED Traffic Signals and Development of a Replacement Schedule", field experiments were used to evaluate LEDs in terms of energy savings. Field experiments were also used to evaluate the impact of the manufacturer, indicator type, color and directional view on the degradation of LED traffic signals, and to develop a comprehensive replacement plan for the LEDs based on the data collected. Assumption-based Estimation refers to the calculation of benefits through assumption-based estimations for key improvement in environmental sustainability features. The sources of assumptions can be experience, engineering judgment, and/or the literature. For example, in a project sponsored by Connecticut DOT, entitled "A Study of Bus Propulsion Technologies Applicable in Connecticut and Demonstration and Evaluation of Hybrid Diesel-Electric Transit", emission rates were drawn from the literature and used to estimate environmental sustainability benefits.

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

Measures for Determining Value of Research on Environmental Sustainability

Various measures have been used by different transportation agencies for determining the value of research in this area. These measures can be classified into four major categories that address different aspects of transportation research in environmental sustainability: "Emissions," "Energy Consumption," "Cost Savings," and "others" as shown in Figure 5. "Emissions" measures are used to present the value of research in terms of reduction in emission outputs, such as HC, CO, NOx. "Energy Consumption" measures are used to present the value of research in terms of reduction in energy consumption. "Cost savings" measures refer to costs avoided by the reduction in emissions

and energy consumption. There are several measures categorized under "others." These measures, such as "Fish passages," characterize the value of research on this area in specific conditions.

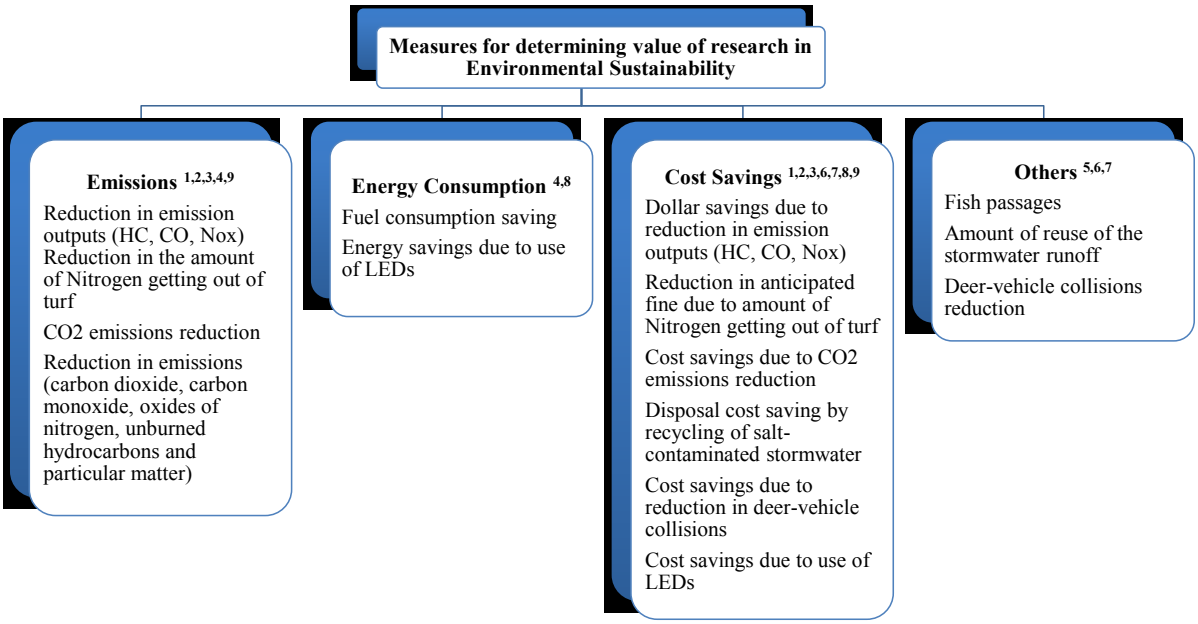

Figure 5: Measures for determining value of research in environmental sustainability

Data Sources for Determining Value of Research on Environmental Sustainability

Various data sources have been used to evaluate environmental sustainability in. The identified data sources for determining the value of environmental sustainability research are presented in Figure 6. "Emissions" data sources were used to present the value of research in terms of reduction in emission outputs, such as HC, CO, NOx. "Energy Consumption" data sources were used to present the value of research in terms of reduction in energy consumption. "Cost savings" data sources were used to calculate dollars equivalence of avoided emissions.

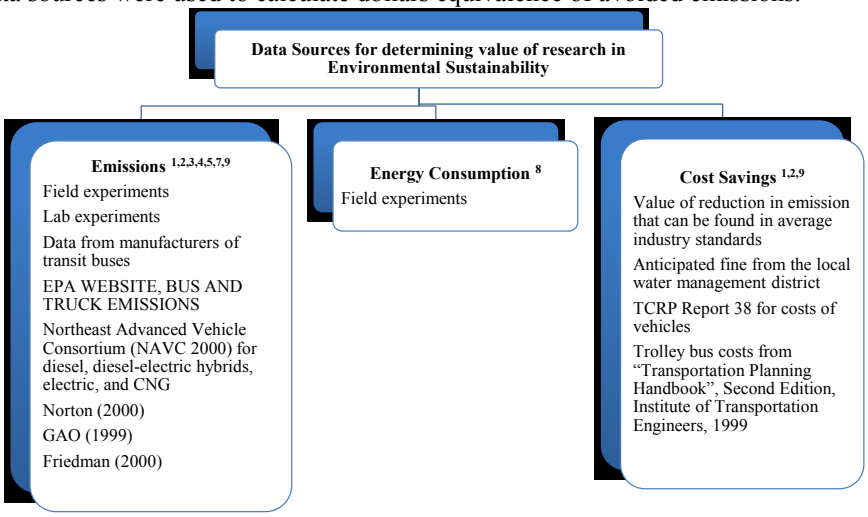

Figure 6: Data Sources for determining value of research in environmental sustainability

Conclusions

Various methods, measures, and data sources have been utilized to determine the value of research. Methods used for determining value of safety research can be classified into three major categories: benefit analysis, benefit (dollar) analysis, and benefit (dollar)/cost (dollar) analysis. This benefit analysis is conducted using various approaches: before-and-after study, statistical analysis, simulation analysis, assumption-based estimation, and field experiments. Methods used for determining value of research on environmental sustainability can be classified into two major categories: benefit analysis, and benefit (dollar) analysis. This benefit analysis is conducted using various approaches: lab experiments, before-and-after study, assumption-based estimation, and field experiments. Several measures and data sources that are used by transportation agencies to determine the value of research are also collected. This research provides a list of existing methods, measures, and data sources along with several examples that can be used for determining value of research. First, the existence of data sources should be assessed. Then, appropriate methods and measures can be selected from the list of available methods, considering the data availability. Provided example help select the method and measures.

References

Anderson, D.I. (2010). *Measuring the Benefits of Transportation Research in Utah*. Prepared for Utah Department of Transportation Research Division. Final Report, No. UT-10.01.

Ardis C.V. (1988). *Evaluation of ODOT Research and Development Implementation Effectiveness*, Final Report, Submitted to Ohio Department of Transportation, FHWA/OH-89/002, 1988.

Concas, S., Reich, S. L., and Yelds, A. T. (2002). *Valuing the Benefits of Transportation Research: A Matrix Approach. Final Report*. No. 2117-463L0, 2002.

Council, F., Zaloshnja, E., Miller, T., and Persaud, B. N. (2005). *Crash cost estimates by maximum police-reported injury severity within selected crash geometries*. No. FHWA-HRT-05-051.

Ellis Jr, R. D., Degner, J., O'Brien, W., and Peasley, G. (2003). *Review, Analyze and Develop Benefit Cost/return on Investment Equations. Guidelines and Variables*. No. UF Proj. 4910 45-04-835.

Tavakoli, A., and Collyard, C. S. (1991). *Benefit-cost analysis of transportation research projects*. Provided for Ohio DOT.

Krugler, Walden, M. N., Hoover, B., Lin, Y. Y. D., and Tucker, S. (2006). *Performance Measurement Tool Box and Reporting System for Research Programs and Projects*. NCHRP Project. 20-63.

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