Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SWUTC/15/600451-00008-1		

4. Title and Subtitle A DECISION SUPPORT TOOL FOR SELECTING TRAFFIC CONTROL DEVICES	5. Report Date July 2015
	6. Performing Organization Code
7. Author(s) James Robertson and H. Gene Hawkins, Jr.	8. Performing Organization Report No. Report 600451-00008-1
9. Performing Organization Name and Address Texas A&M Transportation Institute Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTRT12-G-UTC06
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas A&M Transportation Institute Texas A&M University System College Station, Texas 77843-3135	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program and general revenues from the State of Texas.

16. Abstract

The Federal Highway Administration (FHWA) and transportation profession continue updating and publishing the Manual on Uniform Traffic Control Devices (MUTCD). However, it is beyond the scope of the MUTCD to provide the breadth of knowledge necessary for evaluating traffic control devices (TCDs) as part of the larger transportation system. In this report, researchers use existing theory and a survey of transportation professionals to develop a decision support tool for use in selecting TCDs. To accomplish this, researchers first use a survey of transportation professionals to evaluate the relative importance of safety, mobility, environmental sustainability, and economic activity when selecting TCDs. This investigation leads researchers to conclude that the best solution meets local needs and desires, conforms to engineering principles and practice, and provides an engineering benefit. Additionally, this investigation finds that safety and mobility are the engineering benefits driving the selection of TCDs. Next, researchers use a portion of the same survey of transportation professionals to evaluate the importance of crashes, driver compliance, and mobility when ranking transportation alternatives. This investigation finds that compliance is a reasonable surrogate measure of safety in the absence of crash data. Additionally, within this evaluation, researchers identify performance measures for use in selecting traffic control devices. Finally, researchers use the relative importance of agency objectives evaluation and the identified performance measures to develop a decision support tool for use in selecting TCDs. Researchers demonstrate the use of this decision support tool with a case study.

17. Key Words	18. Distribution Statement
Traffic Control Devices, Decision Theory, Performance Management, Performance Measurement	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	169	

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

A DECISION SUPPORT TOOL

FOR SELECTING TRAFFIC CONTROL DEVICES

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SWUTC/15/600451-00008-1

Sponsored by

Southwest Region University Transportation Center
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July 2015

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ACKNOWLEDGEMENTS

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center, which is funded, in part, with general revenues from the State of Texas.

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, Dwight David Eisenhower Transportation Fellowship Program.

The authors would also like to thank Dr. Mark Burris, Dr. Jeff Hart, and Dr. Deborah Kerr for their service as committee members on James Robertson's dissertation committee.

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EXECUTIVE SUMMARY

Many transportation professionals have dedicated time, effort, and money towards the development of manuals for evaluating the mobility and safety of transportation systems. At this time, the profession has published five editions of the Highway Capacity Manual (HCM) and one edition of the Highway Safety Manual (HSM). A purpose of these manuals is to aid transportation professionals in making decisions in a consistent manner. Additionally, the Federal Highway Administration (FHWA) continues to update and publish the Manual on Uniform Traffic Control Devices (MUTCD). However, it is beyond the MUTCD's scope to provide the breadth of knowledge necessary for evaluating traffic control devices (TCDs) as part of the larger transportation system. In this dissertation, researchers use existing theory and a survey of transportation professionals to develop a decision support tool for use in selecting TCDs in a consistent manner.

To accomplish the research objectives, researchers first use a survey of transportation professionals to evaluate the relative importance of safety, mobility, environmental sustainability, and economic activity when an agency selects TCDs. Based upon this evaluation, researchers conclude that the best solution meets local needs and desires, conforms to engineering principles and practice, and provides an engineering benefit. Researchers find that safety and mobility are the engineering benefits driving the selection of TCDs.

Next, researchers use a portion of the same survey of transportation professionals to evaluate the importance of crashes, driver compliance, and mobility when ranking of transportation alternatives. Based upon this evaluation, researchers conclude that compliance is a reasonable surrogate measure of safety in the absence of crash data. From this investigation and existing theory, researchers propose performance for use in the developed of a decision support tool.

Finally, researchers use the importance of agency objectives evaluation and the identified performance measures to develop a decision support tool for use in selecting TCDs. Researchers demonstrates the use of the nine-step decision support tool using a case study that evaluates the use of an all-way stop versus an improved crosswalk versus no change.

NOMENCLATURE

MUTCD	Manual on Uniform Traffic Control Devices
TCD	Traffic Control Device
FHWA	Federal Highway Administration
NHTSA	National Highway Traffic Safety Administration
HSM	Highway Safety Manual
HCM	Highway Capacity Manual
LOS	Level of Service
EPA	United States Environmental Protection Agency
MOVES	Motor Vehicle Emissions Simulation
TREDIS	Transportation Economic Development Impact System
IRB	Internal Review Board
NCUTCD	National Committee on Uniform Traffic Control Devices
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
CRF	Crash Reduction Factor
CMF	Crash Modification Factor

CHAPTER I

INTRODUCTION

Since the dawning of the transportation profession, transportation professionals have spent part of their focus on improving mobility. This focus led practitioners and researchers to develop the *Highway Capacity Manual* (HCM). Now in its fifth rendition, the HCM contains widely accepted methods for quantifying automobile, bicycle, pedestrian, and transit mobility (TRB 2011). More recently, the transportation profession has pushed for methods to quantify the safety of transportation alternatives. As a result of this push, the American Association of State Highway and Transportation Officials (AASHTO) published the first edition of the *Highway Safety Manual* (HSM) (AASHTO 2010).

In addition to the HCM and HSM, the transportation profession has also spent a great deal of time, money, and effort developing and revising the *Manual on Uniform Traffic Control Devices* (MUTCD), which the Federal Highway Administration (FHWA) publishes through federal rule making. The MUTCD establishes standards, guidance, and options related to the selection, design, installation, operation, and maintenance of traffic control devices (TCDs) (FHWA 2009). While the MUTCD provides support statements for some devices, it is beyond the manual's scope to provide the depth of knowledge needed to evaluate TCDs as part of the larger transportation system. To evaluate TCDs as part of the larger transportation system, transportation professionals rely on engineering judgment and engineering studies. When using engineering judgment and engineering studies, transportation professionals apply knowledge contained within the MUTCD, HCM, HSM, and other research. While the transportation profession continues developing methods for evaluating TCDs, the profession has not yet developed a widely accepted method for use in selecting TCDs. This report is an attempt to move the transportation profession closer to publishing a *Manual on Selecting TCDs*.

In the existing literature, there are many factors transportation professionals may consider when selecting a TCD. These factors include cost (materials, instillation, operating, and maintenance), local needs and desires (perceived need and perceived effectiveness), and engineering benefits (reduced crashes, driver compliance, system efficiency, and system reliability). Additionally, TCD alternatives are limited to devices that comply with engineering principles and practice, which means complying with applicable statutes and regulations. For many TCDs, the MUTCD contains the applicable statutes and regulations. (ITE 2013)

While the existing literature identifies many factors to consider when selecting TCDs, the transportation profession has not yet organized these factors into a structured decision support tool. The organization of these factors into an accepted structure is complicated by agencies and decision makers not always knowing which factors are critical to a TCD decision. While many of the factors could justify the installation of a device, considering these factors in an unstructured manner may lead to the misuse and overuse of TCDs. Within the MUTCD, FHWA recognizes that the misuse and overuse of TCDs may degrade their effectiveness, which may decrease public safety. The purpose of this Report is to develop an initial version of a decision support tool that focuses on the most critical factors while providing the flexibility to consider the effects of other factors within the process.

To develop a decision support tool, researchers focus on applying the concepts of performance-based decision-making and cost-effectiveness analysis to the selection of TCDs. At this time, few research efforts have attempted to use these theories within the context of selecting TCDs. In general, performance-based decision-making is the use of goals, objectives, and performance measures to evaluate an alternative's ability to meet performance benchmarks. In cost-effectiveness analysis, decision-makers compare the benefits and disbenefits of a decision using a cost-effectiveness ratio, which is the cost of the alternative divided by the benefits, with the benefits quantified in terms of effectiveness. Within a cost-effectiveness analysis, lower cost per point effectiveness is better.

In addition to performance-based decision-making and cost-effectiveness analysis, behavioral economics provides insights into developing a decision support tool that avoids decision errors that result from decision-makers succumbing to the influence of heuristics and biases. Heuristics and biases are systematic and predictable processes that lead to decisions that do not conform to the assumptions of rational decision-making within the economics field. Often, heuristics and biases lead to suboptimal decisions.

Examples of heuristics that lead to decision errors are loss aversion and narrow framing. Loss aversion occurs when a decision maker overvalues what they have or are familiar with, which may result in them keeping an item or policy that they might otherwise be willing to sell or change (Heath & Heath 2013). In the transportation profession, an example of loss aversion is an agency not considering modern roundabouts as an intersection alternative, despite research that suggests modern roundabouts can result in fewer crashes and better mobility for some intersections. Narrow framing occurs when a decision maker frames the decision too narrowly and considers only one or fewer alternatives (Heath & Heath 2013). In the transportation profession, an example of narrow framing is the ad hoc selection of TCDs, which rarely considers more than one alternative. By applying behavioral economics research to the selection of TCDs, this report attempts to create a decision support tool that avoids some systematic and predictable decision errors.

PROBLEM STATEMENT

This report uses performance-based decision-making, cost-effectiveness analysis, and behavioral economics to develop a decision support tool for use in selecting TCDs. This report focuses on the selection of commonly used TCDs within an urban setting. While the decision support tool developed within this report provides recommendations, this tool is not a replacement for engineering judgment and engineering studies. The purpose of this research is to begin a conversation within the transportation profession that may ultimately result in the publication of a manual for transportation professionals to use when selecting TCDs. Researchers envisions a manual for TCD selection that has similar standing in the profession as the HCM and HSM.

RESEARCH OBJECTIVES AND RESEARCH QUESTIONS

This report creates a new framework for TCD analysis and decision-making that has its origins in existing theory and a survey of transportation professionals. To develop this framework, researchers accomplish three research objectives. The first research objective is to use a portion of a survey of transportation professionals to evaluate the relative importance of safety, mobility (mobility includes efficiency and reliability), environmental sustainability, and economic activity when selecting TCDs. The second research objective is to use a portion of a survey of transportation professionals to evaluate the relationship between crashes, driver compliance (measured as driver yielding), and mobility in the ranking of transportation improvement alternatives. The third research objective is to use the results of the survey of transportation professionals and existing theory to develop a decision support tool for use in selecting TCDs. To accomplish these research objectives, researchers use a single survey of transportation professionals that includes three parts.

To accomplish the first research objective, researchers use part one and part two of a survey of transportation professionals to evaluate the following research questions:

1. When selecting TCDs, should agencies consider safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
2. If considered in a decision support tool for selecting TCDs, what is the relative importance of safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
3. Does employer type, area of practice, professional licensure, experience, or geographic region influence the consideration of each agency objective?
4. Does employer type, area of practice, professional licensure, experience, or geographic region influence the relative importance of considered agency objectives?

Researchers evaluate these research questions within Chapter IV.

To accomplish the second research objective, researchers use part three of a survey of transportation professionals to evaluate the following research questions:

5. Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, level of service, percent free-flow speed, and average vehicle speed.
6. Which safety performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include injury crashes, property damage only crashes, and total crashes.
7. How does a single fatal crash effect the ranking of transportation improvement alternatives?
8. Can compliance act as a surrogate measure of safety when ranking transportation improvement alternatives?
9. Do transportation professionals place increased value on avoiding losses versus achieving gains when selecting between three transportation improvement alternatives?

The evaluates these research questions within Chapter V.

To accomplish the third research objective, researchers use existing theory the evaluation of agency objectives (research questions 1 thru 4), and the evaluation of performance measures (research questions 5 thru 9) to develop a decision support tool for use in selecting TCDs. Researchers document the decision support tool as a series of steps within Chapter VI. Additionally, researchers provide a set of example calculations in the form of a case study.

Key activities within this report are:

- A review of existing theory (Chapter II).
- The development of a survey of transportation professionals (Chapter III).
- The evaluation of survey data to determine agency objectives for use in selecting TCDs (Chapter IV).
- The evaluation of survey data to determine performance measures for use in selecting TCDs (Chapter V).
- The development of a decision support tool for selecting TCDs (Chapter VI).

Researchers summarize the findings and provides recommendations for future research efforts within Chapter VII.

CHAPTER II
BACKGROUND

This chapter contains background literature relevant to the decision support tool developed within this report. Specifically, this chapter provides a review of literature and background information related to the MUTCD, selecting TCDs, TCD cost, decision theory, and performance measures. Based upon this information, researchers developed research questions to evaluate using a survey of transportation professionals. Researchers provide a summary of these research questions at the end of this chapter.

MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

The MUTCD establishes standards, guidance, and options related to the selection, design, installation, operation, and maintenance of TCDs. A TCD is:

> *A sign, signal, marking, or other device used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, private road open to public travel, pedestrian facility, or shared-use path by authority of a public agency or official having jurisdiction, or, in the case of a private road open to public travel, by authority of the private owner or private official having jurisdiction. (FHWA 2009)*

The MUTCD is the result of federal rule making. States are required to adopt the federal version of the MUTCD or to adopt a state version that is in substantial compliance with the federal version of the MUTCD. At this time, all states have adopted the 2009 MUTCD or their own version of the 2009 MUTCD. (FHWA 2009).

Within the MUTCD, standard statements are the strongest statement and indicate something an agency shall do; guidance statements are the second strongest statement and indicate something an agency should do; and option statements indicate something agencies may do. For example, agencies have the option of using a stop sign at certain intersections; however, if they use a stop sign, there are standards and guidance statements related to the size of the sign, the size of the letters on the sign, and the location of the sign.

A reason FHWA continues to develop and update the MUTCD is to create uniformity and consistency within the transportation system (FHWA 2009). While there is a great deal of focus on the uniformity and consistency of TCDs in their design, installation, operation, and maintenance, it is also important to implement TCDs in a consistent manner. In general, consistency in the implementation of TCDs involves treating similar situations in a similar manner. This report focuses on developing consistency in the decision to use TCDs.

SELECTING TRAFFIC CONTROL DEVICES

Often, professional engineers are responsible for selecting TCDs using engineering judgment or engineering study; engineering study requires the engineer to document their decision and engineering judgment does not require documentation (FHWA 2009). However, the MUTCD does not specify how much experience a professional engineer needs prior to engaging in the selection of TCDs. And, professional engineers with limited TCD experience may find benefit in having a decision support tool for use in selecting TCDs. For this reason, previous research efforts began developing decision support tools based upon utility models and the analytic hierarchy process (Ayala and Hawkins 2008, McNeal 2010, McNeal & Hawkins 2011).

In 2008, Ayala and Hawkins applied an analytic hierarchy process to the selection of warning signs; an important contribution of their work was an attempt to determine the factors associated with selecting TCDs. Building upon the work of Ayala and Hawkins, McNeal and Hawkins (2011) applied a modified analytic hierarchy process model to the selection of TCDs. In their effort, they modified the analytic hierarchy process model to work within a utility model. An important contribution of the work by McNeal and Hawkins is the classification of TCD factors into the categories of need, impact, influence, and cost. Despite these advancements in the understanding of the factors transportation professionals use when selecting TCDs, there is still a need to develop a decision support tool that applies to all TCDs; a purpose of this report is to develop this decision support tool.

COST OF TRAFFIC CONTROL DEVICES

Factors that may limit an agency's ability to deploy TCDs is the cost of the device and the extent of the agency's budget. There are many costs associated with TCDs. Some of these costs occur because of the desire to create uniformity and consistency in the design, installation, operation, and maintenance of TCDs. For example, the design of a TCD effects the cost of purchasing a device, the cost of operating a device, the cost of deploying a device in the field, and the cost of operating a device after deploying it.

While the cost of designing, installing, and operating a device are often included in a decision to select a TCD, there is also a need to consider the cost for maintaining a TCD within this decision. Additionally, with the development and inclusion of maintenance requirements within the MUTCD, these costs are likely to increase and may influence an agency's ability to add devices to their transportation system (Carlson, Higgins, & Re 2011). This suggests a decision support tool for selecting TCDs should consider the cost of maintaining a device in addition to the cost of installing and operating a TCD. The decision support tool developed within this report includes the cost of maintaining a TCD in addition to the cost of installing and operating a TCD.

DECISION THEORY

While the work by Ayala and Hawkins (2008) and McNeal and Hawkins (2011) applied systems engineering concepts to the selection of TCDs, there are other areas of decision theory that deserve consideration and application to the selection of TCDs. Decision theorists are commonly concerned with rational decision-making and the evaluation of rational decision-marking within the context of their area of focus (Bermudez 2009). To do so, decision theorists define two types of decision theory; descriptive decision theory (how decision makers are making decisions) and normative decision theory (how to make logical decisions). This report is an attempt to use descriptive decision theory (through a survey of transportation professionals) to produce a normative decision theory model for selecting TCDs. Within normative and descriptive decision theory, this report applies the concepts of behavioral economics, performance-based decision-making, and effectiveness-cost analysis to the selection of TCDs. Effectiveness-cost analysis is a form of benefit-cost analysis with the benefits measured in terms of effectiveness rather than dollars; within this report, effectiveness is a measure of an alternatives ability to meet agency objectives, performance measures, and benchmarks.

Behavioral Economics

Behavioral economics is a subset of decision theory that occurs at the intersection of economic theory and psychological theory; it provides an alternative to rational decision-making (Ariely 2008; Ariely 2010). Behavioral economics began with the development of prospect theory (Kahneman & Tversky 1979; Tversky & Kahneman 2002). Prospect theory is a method for modifying utility theory to model decisions in a manner that allows for an overemphasis of losses verses gains. In general, research has found that humans often view negative outcomes as being two to four times worse than positive outcomes of equivalent magnitude (Kahneman 2011).

In its modern form, behavioral economics recognizes that decision makers are subject to heuristics and biases, which may result in decision errors or decisions that are less than optimal (Heath & Heath 2013). A value of behavioral economics is that it provides insights into steps decision-makers can take to avoid decision errors (Heath & Heath 2013). Some common biases that may lead to decision errors are (Kahneman 2011, Heath & Heath 2013):

- Narrow framing – unduly limiting the options considered.
- Confirmation bias – seeking information that confirms initial assumptions.
- Short-term emotion – undue influence by emotions that fade with time.
- Overconfidence – too much faith in personal predictions.

A potential method for avoiding narrow framing is to use a decision process that considers multiple reasonable alternatives simultaneously (Heath & Heath 2013). Reasonable alternatives are alternatives that a decision-maker would seriously consider using; considering unreasonable alternatives is unlikely to improve decision outcomes. Considering multiple alternatives simultaneously helps decision-makers overcome narrow framing by forcing the decision-maker to expand their set of options before making a decision. Research suggests decision outcomes improve when decision makers consider more than one alternative (Nutt 1993). The decision support tool presented in this report encourages the evaluation of multiple reasonable alternatives to avoid narrow framing.

A potential method for avoiding confirmation bias is to use a decision process that considers benefits and disbenefits for multiple reasonable alternatives simultaneously (Heath & Heath 2013). Considering the benefits and disbenefits of reasonable alternatives simultaneously aids the decision-maker in avoiding confirmation bias by considering the negative effects of each alternative in addition to the positive effects. Additionally, by using a process that considers multiple reasonable alternatives, a decision-maker is unlikely to focus on seeking information that confirms the decision-maker's initial assumptions. The decision support tool developed within this report considers benefits and disbenefits for multiple reasonable alternatives simultaneously.

A potential method for avoiding short-term emotion bias is to use a decision process that evaluates alternatives based upon core priorities (Heath & Heath 2013). For transportation agencies, an example of core priorities are the objectives the agency is trying to accomplish. Performance-based decision-making, described later, is a potential means for setting core priorities and making decisions using the established core priorities. The decision support tool developed within this report uses performance-based decision-making to establish core priorities and guide the selection of TCDs.

A potential method for avoiding overconfidence is to monitor the outcome of decisions and to modify decisions that fail to demonstrate the expected benefits (Heath & Heath 2013). By monitoring the outcome of a decision, an agency is better able to determine if the decision process in place is leading to the desired outcomes. Additionally, if the agency is monitoring the outcomes of a decision, they are better able to correct decision errors and modify the decision process to avoid similar errors in the future. Part of performance-based decision-making is the ongoing evaluation of the agencies decisions and the decisions ability to produce the desired outcomes (Hatry 2006). The decision support tool presented in this report is capable of providing data for a transportation agency's overarching performance management program.

As an initial effort to explore bias within transportation decision-making, researchers use a portion of the survey of transportation professionals to investigate the following research question:

- Do transportation professionals place increased value on avoiding losses versus achieving gains when selecting between three transportation alternatives?

Researchers explore this bias, known as loss aversion bias, because it is a form of short-term emotion bias demonstrated within prospect theory (Heath & Heath 2013).

Performance-Based Decision-Making

Performance-based decision-making is the use of goals, objectives, performance measures, and benchmarks to make informed decisions (Hatry 2006). In general, objectives are the results an agency is trying to achieve, performance measures are how an agency measures their ability to meet their objectives, and benchmarks are how an agency knows they are doing well enough in achieving a specific objective (Hatry 2006). For example, if an agency's objective is to increase safety while maintaining a certain level of mobility, the appropriate TCD is one that decreases crashes with minimal effects on vehicle delay. Table 1 shows an example of a performance-based evaluation. Within Table 1 is a set of seven agency objectives along with the associated performance measures, benchmarks, and present conditions. The last two columns show the estimated values given a traffic signal versus an all-way stop; the values suggest an all-way stop is the better because it meets all of the benchmarks at a lower cost.

Table 1. Example of Performance-Based Decision-Making.

Objective	Performance Measure	Benchmark	Present Conditions	Traffic Signal	All-Way Stop
Safety	Crashes	5 crashes/year	10 crashes/year	3 crashes/year	5 crashes/year
Automobile Mobility	Automobile LOS	LOS D	LOS B	LOS C	LOS D
Bicycle Mobility	Bicycle LOS	LOS D	LOS E	LOS C	LOS D
Pedestrian Mobility	Pedestrian LOS	LOS C	LOS E	LOS C	LOS C
Environmental	CO_2 Emissions	≤ 5 percent increase	1 million lb/year	2 percent increase	3 percent increase
Construction Costs	Dollars	-	-	$250,000	$50,000
Maintenance Costs	Dollars	-	-	$20,000/year	$5,000/year

A primary reason for using performance-based decision-making is to aid decision makers in making decisions that accomplish agency objectives. While different agencies may have different agency objectives, this report investigates how the following agency objectives influence the selection of TCDs:

- Provide a safe transportation system for all users.
- Provide a reliable and efficient transportation system for all users.
- Provide an environmentally sustainable transportation system for all users.
- Support economic activity.

This report focuses on these four agency objectives because transportation professionals commonly state aspects of these four objectives as factors consider in selection of TCDs and the evaluation transportation alternatives (McNeal & Hawkins 2011; Ayala & Hawkins 2008; Zietsman et al. 2011).

While these four objectives may play a role in the selection of transportation alternatives, the need to evaluate each of them and their relative importance in the selection of TCDs is not well established. Therefore, this report uses a portion of the survey of transportation professionals to investigate the following research questions:

- When selecting TCDs, should agencies evaluate safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
- If included in a decision support tool for selecting TCDs, what is the relative importance of safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
- Does employer type, area of practice, professional licensure, experience, or geographic region influence the consideration of each agency objective?
- Does employer type, area of practice, professional licensure, experience, or geographic region influence the relative importance of included agency objectives?

Cost Effectiveness Analysis

Cost-effectiveness analysis is a form of cost-benefit analysis with each alternative's benefits or disbenefits quantified in terms of effectiveness rather than dollars (Phillips 2009). Cost-effectiveness is useful in evaluating alternatives where the benefits are difficult to quantify in terms of dollars. Mathematically, the following equations are a method for calculating a cost-effectiveness ratio:

$CER_k = Cost_k / Effectivness_k$ Equation 2-1

$Effectiveness_k = Effect(+)_k – Effect(–)_k$ Equation 2-2

$Effect(+)_k = \Sigma i,j$ [Obj_Wi × PM_Wij × Imp_{jk}] Equation 2-3

$Effect(–)_k = \Sigma i,j$ [Obj_Wi × PM_Wij × $Loss_{jk}$] Equation 2-4

$Cost_k = Intall\_Cost_k + Op\_Cost_k + Maint\_Cost_k$ Equation 2-5

where:

CER_k	= Cost-effectiveness ratio for alternative k (lower cost-effectiveness ratios are better).
$Effectiveness_k$	= Ability of alterative k to meet agency goals and objectives.
$Effect(+)_k$	= Positive portion of effectiveness caused by positive outcomes.
$Effect(–)_k$	= Negative portion of effectiveness caused by negative outcomes.
$Cost_k$	= Estimated cost of alternative k in dollars.
$Install\_Cost_k$	= Estimated instillation costs associated with alternative k.
Op_Cost_k	= Estimated operating costs associated with alternative k.
$Maint\_Cost_k$	= Estimated maintenance cost associated with alternative k.
Σi,j	= Summation over all objectives and measures.
Obj_Wi	= Weight for objective i.
PM_Wij	= Weight for performance measure j associated with objective i.
Imp_{jk}	= Estimated improvement in measure j from alternative k.
$Loss_{jk}$	= Estimated loss in measure j from alternative k.

Within this report, researchers quantify the variable values for use within a cost-effectiveness analysis of TCDs.

PERFORMANCE MEASURES

Performance measures are a method for quantifying an agency's ability to achieve its objectives (Hatry 2006). Performance benchmarks are a method for determining which performance measures the agency is doing well and which performance measures need improvement (Hatry 2006). When used together, agency objectives, performance measures, and benchmarks allow an agency to make informed, performance-based decisions. Despite the benefit of information provided by having more performance measures, there is value in limiting the number of performance measures a decision-maker uses to guide their decisions.

Selecting Performance Measures

A potential error in performance-based decision-making is the use of too many performance measures. Within this report, researchers will refer to the use of too many performance measures as performance measure overload. This terminology comes from the concept of choice overload (Iyengar 2010; Heath & Heath 2013). Choice overload is the phenomena where consumers presented with too many options for a particular product are less likely to purchase that type of product; in these cases, it is theorized that the cost of evaluating the alternatives is too high, which results in the consumer refuses to make a choice (Iyengar 2010). Conversely, consumers presented with fewer alternatives are more likely to purchase one of the products; it is theorized that this might occur because the cost of evaluating the alternatives is lower (Iyengar 2010).

Research suggests that consumers experience choice overload when presented with between 10 and 20 options; however, this number varies depending on the type of product (Iyengar 2010; Heath & Heath 2013). When developing a performance-based decision-making system, the preferred number performance measures is around 10 with a maximum of 15 (Hatry 2006). Often, performance-based decision-support tools with more than 15 performance measures become burdensome to use and maintain. In order to avoid performance measure overload, this report seeks to limit the number of performance measures within the developed decision support tool to 15 or fewer.

A method for reducing the number of measures within a performance-based decision support tool is to minimize the number of performance measures that provide similar information (Hatry 2006). For example, if a decision support tool for selecting intersection traffic control included both delay per automobile and automobile level of service (LOS) as performance measures, it would be best to remove one of the measures from the tool. A reason for this is that delay per automobile is how automobile LOS is determined at intersections. The next four sections of this chapter documents potential performance measures for safety, mobility, environmental sustainability, and economic activity.

Safety Performance Measures

The National Highway Traffic Safety Administration (NHTSA) suggests ten safety performance measures for state departments of transportation (NHTSA 2008). The ten performance measures are fatal crashes, fatal crashes per vehicle mile traveled, fatal crashes per capita, injury crashes, injury crashes per vehicle mile traveled, injury crashes per capita, observed safety belt use, alcohol related fatal crashes, alcohol related fatal crashes per vehicle mile traveled, percent of all fatal crashes that involve alcohol. Based upon the concept of performance measure overload, it would be difficult for a decision-maker to make timely and effective decisions if they were considering all of the performance measures suggested by the NHTSA.
Of the performance measures recommended by the NHTSA, crashes are becoming the common performance measure within the transportation profession. A reason for the transportation professions focus on crashes is the publishing of the HSM and the ongoing research that will be used to develop future editions of the HSM (AASHTO 2010). In general, it is desirable to have 36 months of crash history (Chrysler et al. 2011). In situations where the data are not available

or the data show there are few crashes, transportation professionals may use compliance as a surrogate measure of safety (Chrysler et al. 2011, Fitzpatrick et al. 2014).

In general, low compliance levels may indicate aspects of the roadway environment that are violating driver expectancy. Violations of driver expectancy occur when drivers come upon a situation that they were not expecting, which may result in crashes. An example of a roadway feature that may violate driver expectancy is a curve that driver cannot see that results in a driver taking the curve at a rate of speed that may cause them to leave the roadway surface. Based upon these engineering practices, it could be useful for a decision support tool for selecting TCDs to use both crashes and compliance as measures of safety.

To investigate the use of safety performance measures when making transportation decisions, this report investigates the following research questions:

- Which safety performance measures have a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include injury crashes, property damage only crashes, and total crashes.
- How does a single fatal crash effect the ranking of transportation improvement alternatives?
- Can compliance act as a surrogate measure of safety when ranking transportation improvement alternatives?

Mobility (Efficiency and Reliability) Performance Measures

A historic authority on measuring mobility on urban streets is the *HCM*; the most recent version is the *HCM 2010* (TRB 2011). The *HCM* quantifies transportation system performance in terms of LOS, which is a measure of quality of service. Performance measures that can be estimated using methods from the HCM are:

- LOS (automobile, bicycle, pedestrian, and transit modes).
- Average delay (automobile, pedestrian).
- Percent free-flow speed (automobile).
- Stops per mile (automobile).

LOS is a grading system that goes from A to F and is similar to the grading system used within schools with A being the best and F being the worst; LOS is a method for quantifying transportation user perceived quality of service. In most jurisdictions, transportation systems are design to operate at LOS D or better. At intersections, the HCM methodology often determines LOS based upon the average delay experienced by users. Along urban street segments, the HCM methodology for automobiles determines LOS based upon percent free-flow speed; percent free-flow speed is the difference between the posted speed limit and the average travel speed along the roadway segment. Additionally, stops per mile is an alternative method for quantifying automobile quality of service on urban street segments; research documented in National Cooperative Research Program (NCHRP) Research Report 616 found that stops per mile could be a better predictor of perceived quality of service than percent free-flow speed (Dowling et al. 2008).

Presently, the *HCM* does not provide methods for measuring and estimating transportation system reliability. In general, transportation system reliability represents the temporal uncertainty experienced by transportation system users (Carrion & Levinson 2012). Some measures of transportation system reliability are (Schrank, Eisele, & Lomax 2012):

- 95^{th} percentile travel time.
- 80^{th} percentile travel time.
- Planning Time Index.

Ninety-fifth percentile travel time is the worse travel time a roadway user would experience in 19 out of 20 trips. Eightieth percentile travel time is the worse travel time a roadway user would experience in 16 out of 20 trips. Planning time index is the difference between the 95^{th} percentile travel time and the average travel time divided by the average travel time. A planning time index of 2.00 means that for a 20-minute trip in light traffic, a traveler should plan for a trip of 40 minutes during peak periods.

Of the measures of reliability, 95^{th} percentile travel time and planning time index are suggested for quantify transportation system user experience and 80^{th} percentile travel time is suggested for use by transportation agencies when making decisions. A reason for using 80^{th} percentile travel time to make decisions is that 95^{th} percentile travel time often describes delay caused by crashes or other random and infrequent events; however, 80^{th} percentile travel time is often a function of the roadway infrastructure rather than random events. Therefore, transportation agencies should use 80^{th} percentile travel time because changes in transportation infrastructure have an opportunity to improve 80^{th} percentile travel time even though the same change may not have an effect on 95^{th} percentile travel time. (SCOPM 2012)

Due to limits on survey participant time and patience, the survey of transportation professionals focuses on efficiency performance measures rather than reliability performance measures. Specifically, this report investigates the following research question:

- Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, LOS, percent free-flow speed, and average vehicle speed.

Environmental Sustainability Performance Measures

In general, sustainability means meeting the needs of the present without compromising the ability to meet the needs of the future (Zietsman et al. 2011). Environmental sustainability is the application of this principle to environmental concerns. Traditionally, environmental sustainability efforts within transportation have focused on reducing unrenewable resource dependency (fossil fuels), reducing emissions caused by transportation system usage, reducing the environmental footprint of transportation system facilities, and replacing or restoring ecosystems disrupted by transportation system construction.

In addition to environmental issues, sustainability concepts have expanded to encompass other aspects of transportation system development (Zietsman et al. 2011). For example, Black (2000) offered five sustainability concerns within the transportation field; they are:

- Consumption of finite fossil fuel.
- Use of fuel creating local air-quality problems.

- Use of fuel contributing to global warming.
- The transportation system producing fatalities and injuries.
- The transportation system suffering from congestion in major urban areas.

While the concepts of sustainability now encompasses safety and mobility, this report focuses on the application of sustainability to environmental concerns.

Some performance measures associated with environmental sustainability are (Zietsman et al. 2011):

- Vehicle miles traveled.
- Vehicle emissions.
- Pedestrian, bicycle, and transit area coverage.

Vehicle miles traveled is the number of vehicles traveling down a roadway segment multiplied by the length of the roadway segment; a positive effect on environmental sustainability is a reduction in vehicle miles traveled. Vehicle emissions are the emissions produced by vehicles using the transportation system; the United States Environmental Protection Agency (EPA) Motor Vehicle Emissions Simulation (MOVES) model provides a method for estimating vehicle emissions produced by transportation systems (EPA 2014). A component of estimating vehicle emissions using the MOVES model is vehicle miles traveled.

The number of jobs or population within a certain distance of a facility is a method for quantifying pedestrian, bicycle, and transit area coverage. Specific measures are:

- Jobs or population within ¼ mile of transit.
- Jobs or population within ¼ mile of sidewalks.
- Jobs or population within ½ mile bicycle routes or bicycle lanes.

The transit and sidewalk measures use a distance of ¼ mile because many transit users and pedestrians are comfortable traveling ¼ mile to reach a facility. The bicycle measure uses a distance of ½ mile because many bicycle users are comfortable traveling ½ mile to reach bicycle facilities. (Zietsman et al. 2011)

This report investigates if the agency objective of "provide an environmentally sustainable transportation system for all users" should be part of the decision support tool for use in selecting TCDs. However, due to limitations on survey participant time and patience, this report does not investigate which performance measures would be best when measuring this objective. If this report were to find that the agency objective of environmental sustainability should be included in the decision support tool, researchers would use the information presented in this literature review to recommend potential performance measures. Then, future research efforts may investigate this relationship further as part of efforts to continue improving the process used when selecting TCDs.

Economic Activity Performance Measures

Transportation infrastructure is a fundamental feature of economic competitiveness between cities, states, and countries (Norboge 2012). The economic benefits of transportation projects typically come from (Weisbrod 2008):

- Reductions in travel time.
- Reductions in travel cost (including cost of crashes).
- Increased system reliability.
- Access to new markets (consumers, labor, or resources).
- Access to intermodal transfer connections.
- Increased travel route connectivity.

However, there is a need for research determining the quantifiable contribution from each of these improvements to economic activity (Black 2000). A step in the direction of quantifying the economic value of transportation investment is the Transportation Economic Development Impact System (TREDIS) framework (Weisbrod 2008). The TREDIS framework categorizes the benefits of transportation projects as effecting changes in the cost of doing business (cost shifts) and changes in access to new markets (market access shifts).

Potential performance measures for cost shifts are (Weisbrod 2008):

- Change in annual cost of business operation.
- Expansion of existing business sales.
- Expansion of existing business jobs.
- Expansion of existing business payroll.

While it would be difficult for cities, states, and countries to observe changes in the annual cost of business operations, a city, state, or country could observe expansions of existing businesses as changes in tax revenue, tax fillings, increases in population, or decreases in unemployment.

Potential performance measures for market access shifts are (Weisbrod 2008):

- Change in access to populations within 45 to 90 minutes.
- Growth of new business sales.
- Growth of new business jobs.
- Growth of new business payroll.

It is possible to quantify change in access to populations within 45 to 90 minutes based upon changes in travel time and changes in travel time reliability. As observed in the performance measures for cost shifts, it is possible for cities, states, and countries to track growth of new business as changes in tax revenue, tax fillings, increases in population, or decreases in unemployment.

In addition to providing economic benefit, not investing in transportation systems may have a negative effect on a city, state, or country economies (Norboge 2012). For example, Sweet (2014) found evidence that congestion of freeways in urban areas starts slowing job growth when average delay gets above 4.5 minutes during a one-way trip or the annual average daily traffic across the regional freeway network gets above 11,000 vehicles per lane per day.

This report investigates if the agency objective of “support economic activity” should be part of the decision support tool for use in selecting TCDs. However, due to limitations on survey participant time and patience, this report does not investigate which performance measures would best measure this objective. If this report were to find that the agency objective of “support economic activity” should be included in the decision support tool, researchers would use the information presented in this literature review to recommend potential performance measures. Then, future research efforts may investigate this relationship further as part of efforts to continue improving the process used when selecting TCDs.

Performance Benchmarks

A performance benchmark is how an agency knows they are doing well enough for a given performance measure (Hatry 2006). Performance benchmarks may vary between agencies based upon the community served by the agency. An example of a benchmark for a transportation agency is design LOS for transportation facilities near new developments, which engineers evaluate within traffic impact analyses. A design LOS is the LOS expected by an agency after adding traffic generated by a new development to the existing system traffic. If the LOS of the system drops below the design LOS after adding the new traffic to the exciting system, many agencies require the developer to cover part or all of the cost for new infrastructure to mitigate their developments impact on system performance. For example, in many jurisdictions the design LOS for signalized intersections is LOS C or LOS D. This means, in these jurisdictions, LOS C or LOS D is good enough.

CHAPTER SUMMARY AND RESEARCH QUESTIONS

This chapter contains a review of background literature that is relevant to the development of the decision support tool within this report. Based upon the literature, researchers developed research questions to address using a survey of transportation professionals. The research questions are:

1. When selecting TCDs, should agencies consider safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
2. If considered in a decision support tool for selecting TCDs, what is the relative importance of safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
3. Does employer type, area of practice, professional licensure, experience, or geographic region influence the consideration of each agency objective?
4. Does employer type, area of practice, professional licensure, experience, or geographic region influence the relative importance of considered agency objectives?
5. Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, level of service, percent free-flow speed, and average vehicle speed.
6. Which safety performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include injury crashes, property damage only crashes, and total crashes.
7. How does a single fatal crash effect the ranking of transportation improvement alternatives?
8. Can compliance act as a surrogate measure of safety when ranking transportation improvement alternatives?
9. Do transportation professionals place increased value on avoiding losses versus achieving gains when selecting between three transportation improvement alternatives?

In Chapter III, researchers document the development of a survey of transportation professionals to evaluate these research questions.

CHAPTER III

SURVEY OF TRANSPORTATION PROFESSIONALS

This chapter documents the creation of a survey of transportation professionals. The purpose of this survey is to evaluate the research questions listed at the end of the previous chapter. The evaluation of the research questions takes place in the following two chapters with the first chapter focusing on the agency objectives associated with selecting TCDs and the second chapter focusing on performance measures associated with selecting TCDs. The division of the analysis is associated with different portions of the survey of transportation professionals. The agency objectives analysis uses part one of the survey (demographic questions) and part two of the survey (relative importance of agency objectives) and the performance measures analysis uses part three of the survey (selection of transportation improvement alternatives).

SURVEY OVERVIEW AND RECRUITMENT

To reach a geographically diverse audience, researchers developed an online survey using LimeSurvey Version 2.00+ Build 130526 (LimeSurvey 2013). The Texas A&M Transportation Institute hosted the survey on one of its webpages. The survey included three distinct parts. The first part asked for participant demographic information. The second part asked participants to allocate a total of 100 points to five objectives related to the selection of TCDs. The third part asked participants to rank three different projects based upon the provided mobility data, safety data, and project cost data

Prior to submitting the survey questions to the Texas A&M University Internal Review Board (IRB), researchers had transportation professionals with various backgrounds review and comment on the questions and how they were asked. After going through several iterations of survey questions, researchers received approval from the Texas A&M University IRB for the survey methods and questions used within this report. After entering the survey questions into LimeSurvey, researchers then pilot tested the electronic version of the survey with the same individuals that reviewed and commented on the questions prior to researchers submitting the questions to Texas A&M University IRB for approval. Data collected during the pilot tests were not included in this reports analysis. Additionally, researchers did not recruit transportation professionals that aided in question development as survey participants using personal emails; however, since the recruitment methods used a public forum that many of these individuals have access to, researchers cannot guarantee that these individuals did not take the survey.

Survey participants were recruited using the Institute of Transportation Engineers (ITE) All Members Form (an engineering community discussion list) and direct emails. There were two sets of direct emails; the first was from Dr. James Robertson (first author on this report) to his professional contacts; the other was from Dr. H. Gene Hawkins and Dr. Paul Carlson to their professional contacts. Dr. Hawkins is a coauthor on this report and Dr. Carlson is a researcher with the Texas A&M Transportation Institute. Many of Dr. Hawkins and Dr. Carlson's professional contacts are members of the National Committee on Uniform Traffic Control Devices (NCUTCD). Survey data collection began on August 2, 2013 at 12:01 am and concluded on August 18, 2013 at Midnight. The recruitment messages seen by ITE All Member

Forum members are provided in Appendix A, the direct email recruitment messages used the same format and contained the same information as the messages shown in Appendix A.

The distribution of complete and incomplete survey responses by recruitment method are provided in Table 2. Dr. Robertson sent a direct email to 112 personal professional contacts with a response rate of 32.1 percent and a dropout rate of 25.0 percent. The number of individuals viewing the ITE All Members Forum Post and the emails from Dr. Hawkins and Dr. Carlson is unknown; however, ITE has approximately 16,000 members and each member has access to the ITE All Members Forum. The data within Table 2 suggests that participants recruited via email were more likely to complete the survey than were participants recruited through the ITE All Members Forum posts. This difference is likely due to participants receiving the direct emails having personal relationships with Dr. Robertson, Dr. Hawkins, or Dr. Carlson.

Table 2. Distribution of Completed and Incomplete Surveys by Recruitment Method.

Recruitment Method	Completed Surveys	Incomplete Surveys	Total Participants	Dropout Rate
ITE All Members Forum (Posted by Dr. Robertson)	49	25	74	33.8 %
Direct Email (Dr. Robertson)	27	9	36	25.0 %
Direct Email (Dr. Hawkins & Dr. Carlson)	40	9	49	18.4 %
Total	116	43	159	27.0 %

The distribution of the incomplete surveys by stopping point are provided in Table 3. These data suggest that most participants stopped taking the survey before completing the questions in part three, which asked participants to select between three alternatives based upon the presented mobility data, safety data, and project cost data. The questions in part three were difficult to answer because they forced survey participants to make tough decisions with limited information and survey participants could not move forward in the survey without answering these questions. A difficult question that a survey participant could not skip could explain why 22 participants that made it to part three chose to drop out without completing the survey. In addition to the dropouts in part three of the survey, 14 participants (9 percent of the total that started taking the survey) dropped out before completing the demographic questions in part one; these dropouts were likely due to computer server issues that occurred when the survey first went live. These issues were resolved prior to the direct emails from Dr. Hawkins and Dr. Carlson.

Table 3. Number of Incomplete Surveys (Percent of Total) by Recruitment Method and Stopping Point.

Recruitment Method	Stopping Point		
	Part 1	Part 2	Part 3
ITE All Members Forum (Posted by Dr. Robertson)	9 (12 %)	4 (5 %)	12 (16 %)
Direct Email (Dr. Robertson)	5 (14 %)	1 (3 %)	3 (8 %)
Direct Email (Dr. Hawkins & Dr. Carlson)	0 (0 %)	2 (4 %)	7 (15 %)
Total	14 (9 %)	7 (4 %)	22 (14 %)

Part 1 = Participant stopped before completing the demographic questions.
Part 2 = Participant stopped before completing the relative importance of objectives question.
Part 3= Participant stopped before completing the ranking of transportation improvement alternatives questions.

SURVEY SECTIONS AND QUESTIONS

Within the one survey of transportation professionals, researchers asked each participant to answer 11 questions. The 11 questions were contained within the following survey sections:

- Welcome page (0 questions).
- Part one – demographic questions (5 questions).
- Part two – relative importance of agency objectives (1 question).
- Part three – selection of transportation improvement alternatives (4 questions).
- Final question – comments (1 question).
- Exit screen.

The remainder of this chapter documents the content of each of these sections, why researchers included each question, and why researchers chose the values or content within each question.

Welcome Page and Group Assignment

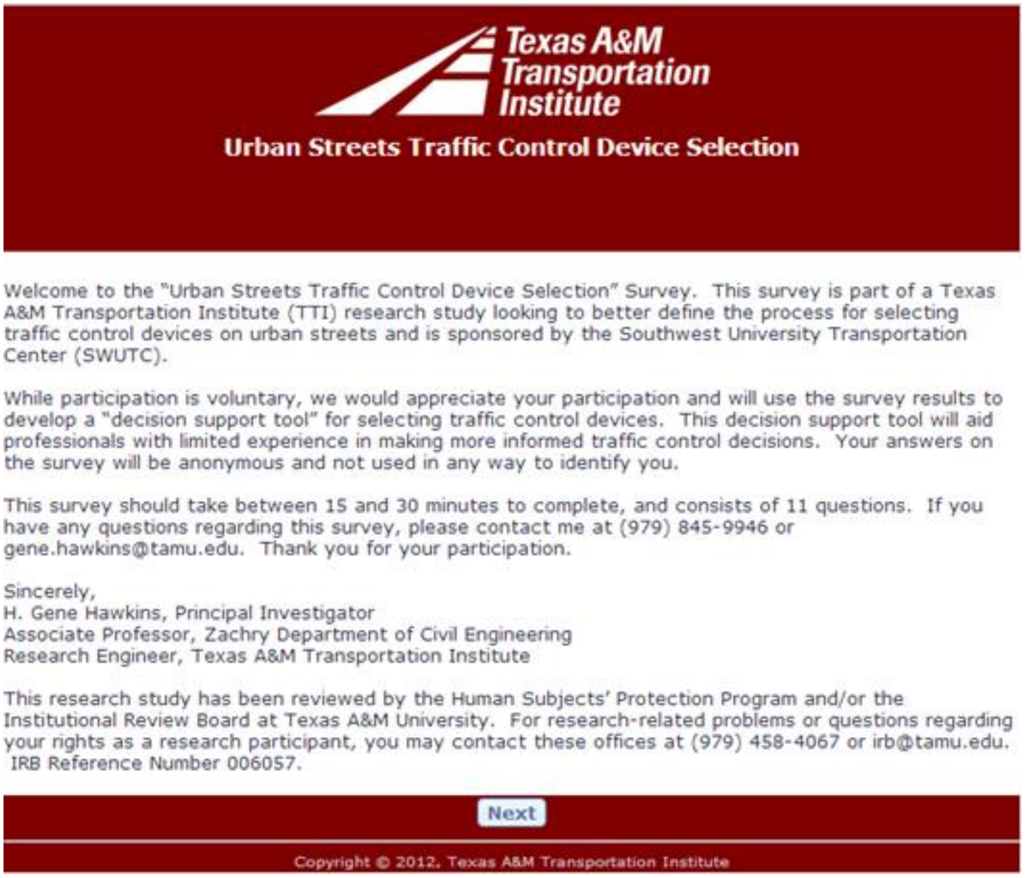
The webpage link within the recruitment email or ITE all member forum post took survey participants to a welcome page; a screen shot of the welcome page is shown in Figure 1. Once a survey participant clicked next, the survey program directed them to part one of the survey.

Part One – Demographic Questions

Part one of the survey asked participants for their demographic information. This report uses this information to investigate the research question:

3. Does employer type, area of practice, professional licensure, experience, or geographic region influence the consideration of each agency objective?
4. Does employer type, area of practice, professional licensure, experience, or geographic region influence the relative importance of considered agency objectives?

The specific questions and response options are provided in Table 4; the page seen by participants is provided within Figure 2. Survey participants were not required to provide responses to demographic questions before proceeding to part two of the survey.



Texas A&M Transportation Institute

Urban Streets Traffic Control Device Selection

Welcome to the "Urban Streets Traffic Control Device Selection" Survey. This survey is part of a Texas A&M Transportation Institute (TTI) research study looking to better define the process for selecting traffic control devices on urban streets and is sponsored by the Southwest University Transportation Center (SWUTC).

While participation is voluntary, we would appreciate your participation and will use the survey results to develop a "decision support tool" for selecting traffic control devices. This decision support tool will aid professionals with limited experience in making more informed traffic control decisions. Your answers on the survey will be anonymous and not used in any way to identify you.

This survey should take between 15 and 30 minutes to complete, and consists of 11 questions. If you have any questions regarding this survey, please contact me at (979) 845-9946 or gene.hawkins@tamu.edu. Thank you for your participation.

Sincerely,
H. Gene Hawkins, Principal Investigator
Associate Professor, Zachry Department of Civil Engineering
Research Engineer, Texas A&M Transportation Institute

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you may contact these offices at (979) 458-4067 or irb@tamu.edu. IRB Reference Number 006057.

Next

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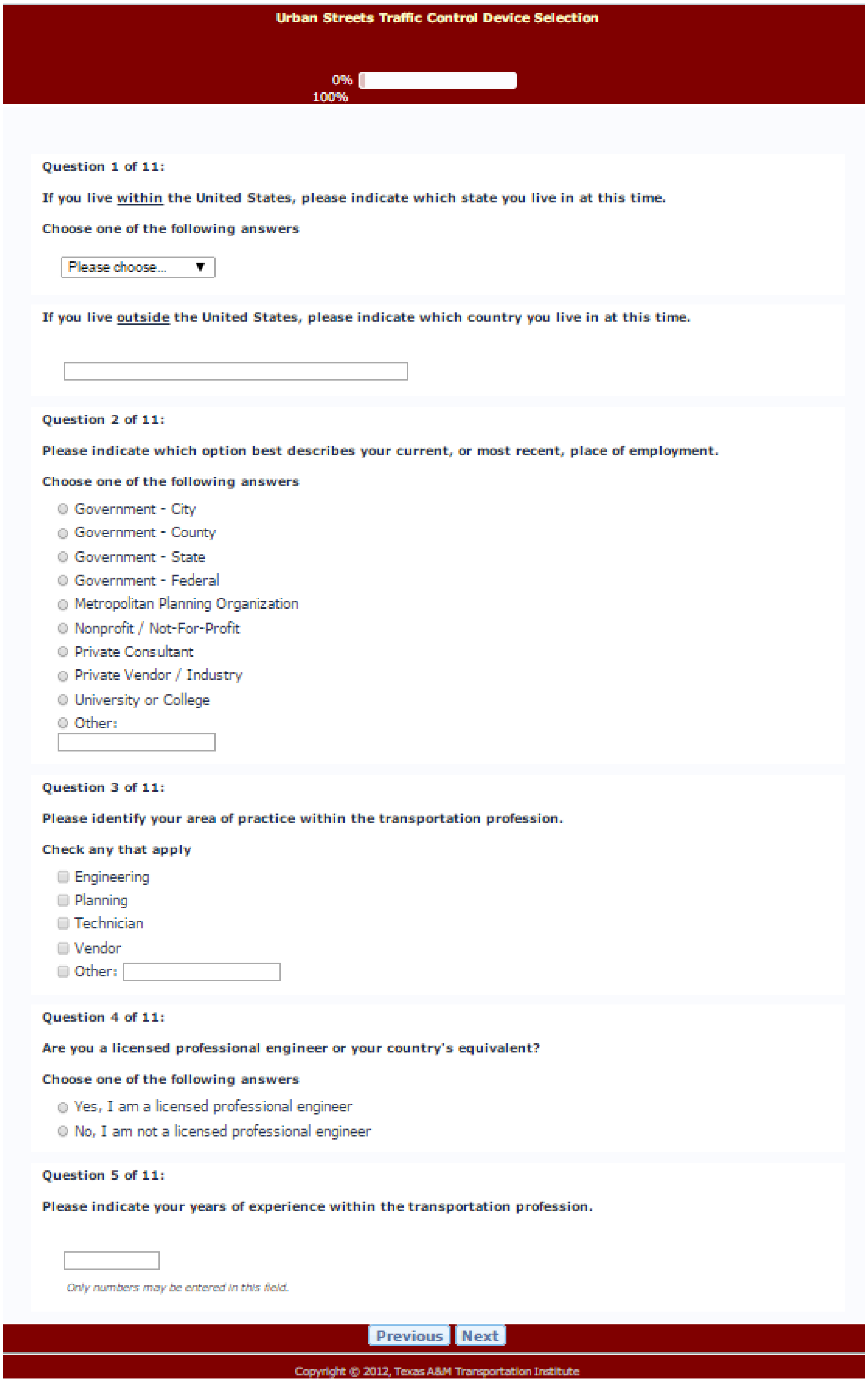
Figure 1. Survey Welcome Page.

Table 4. Demographic Questions and Response Options.

Question Number	Question	Response Options
1	If you live within the United States, please indicate which state you live in at this time. If you live outside the United States, please indicate which country you live in at this time.	Drop down menu for participants from within the United States. Text box for participants from outside the United States
2	Please indicate which option best describes your current, or most recent, place of employment.	Single response allowed: • Government – City • Government – County • Government – State • Government – Federal • Nonprofit / Not-For-Profit • Private Consultant • Private Vendor / Industry • University or College • Other: (text box)
3	Please identify your area of practice within the transportation engineering profession.	Multiple responses allowed: • Engineering. • Planning. • Technician. • Vendor. • Other: (text box).
4	Are you a licensed professional engineer or your country's equivalent?	Single response allowed: • Yes, I am a licensed professional engineer • No, I am not a license professional engineer.
5	Please indicate your years of experience within the transportation profession.	Open ended numeric response greater than zero.



Urban Streets Traffic Control Device Selection

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Question 1 of 11:

If you live within the United States, please indicate which state you live in at this time.

Choose one of the following answers

Please choose...

If you live outside the United States, please indicate which country you live in at this time.

Question 2 of 11:

Please indicate which option best describes your current, or most recent, place of employment.

Choose one of the following answers

- Government - City
- Government - County
- Government - State
- Government - Federal
- Metropolitan Planning Organization
- Nonprofit / Not-For-Profit
- Private Consultant
- Private Vendor / Industry
- University or College
- Other:

Question 3 of 11:

Please identify your area of practice within the transportation profession.

Check any that apply

- Engineering
- Planning
- Technician
- Vendor
- Other:

Question 4 of 11:

Are you a licensed professional engineer or your country's equivalent?

Choose one of the following answers

- Yes, I am a licensed professional engineer
- No, I am not a licensed professional engineer

Question 5 of 11:

Please indicate your years of experience within the transportation profession.

Only numbers may be entered in this field.

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Figure 2. Survey Demographic Questions.

Part Two – Relative Importance of Agency Objectives

Part two of the survey asked participants to indicate the relative importance of five agency objectives. In this report, researchers use this portion of the survey to investigate the following research questions:

1. When selecting TCDs, should agencies consider safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
2. If considered in a decision support tool for selecting TCDs, what is the relative importance of safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?

This portion of the survey contained one question, the specific question text was:

> *Within an urban setting, there are many reasons for selecting a traffic control device. Please allocate a total of 100 points among the following reasons for selecting a traffic control device, assigning more points to the reasons you consider more important.*
>
> *For example, if you consider only one reason to be important, assign all 100 points to that reason. However, if you find more than one reason to be important allocate the total of 100 points to each reason in proportion to its importance to you.*

The reasons participants could assign points to were:

- Provide a safe transportation system for all users.
- Provide a reliable and efficient transportation system for all users.
- Provide an environmentally sustainable transportation system for all users.
- Support economic activity.
- Meet other community expectations and preferences.

Researchers added the objective of "meet other community expectations and preferences" to the list of possibilities to cover reasons that would not fit into the four agency objectives identified in the background chapter of this report.

The survey presented these reasons to survey participants in a random order. To say it another way, sometimes survey participants saw the objectives in the order shown above and sometimes survey participants saw them in a randomly selected order different from the one shown above. The survey would not allow survey participants to proceed without answering this question; survey participants could return to previous pages if they desired to do so. Additionally, survey participants could provide comments regarding their response to this question. A screen shot of this portion of the survey is provided in Figure 3. Participant comments for this part of the survey are provided in Appendix B. Once a survey participant clicked next, they were taken to part three of the survey.

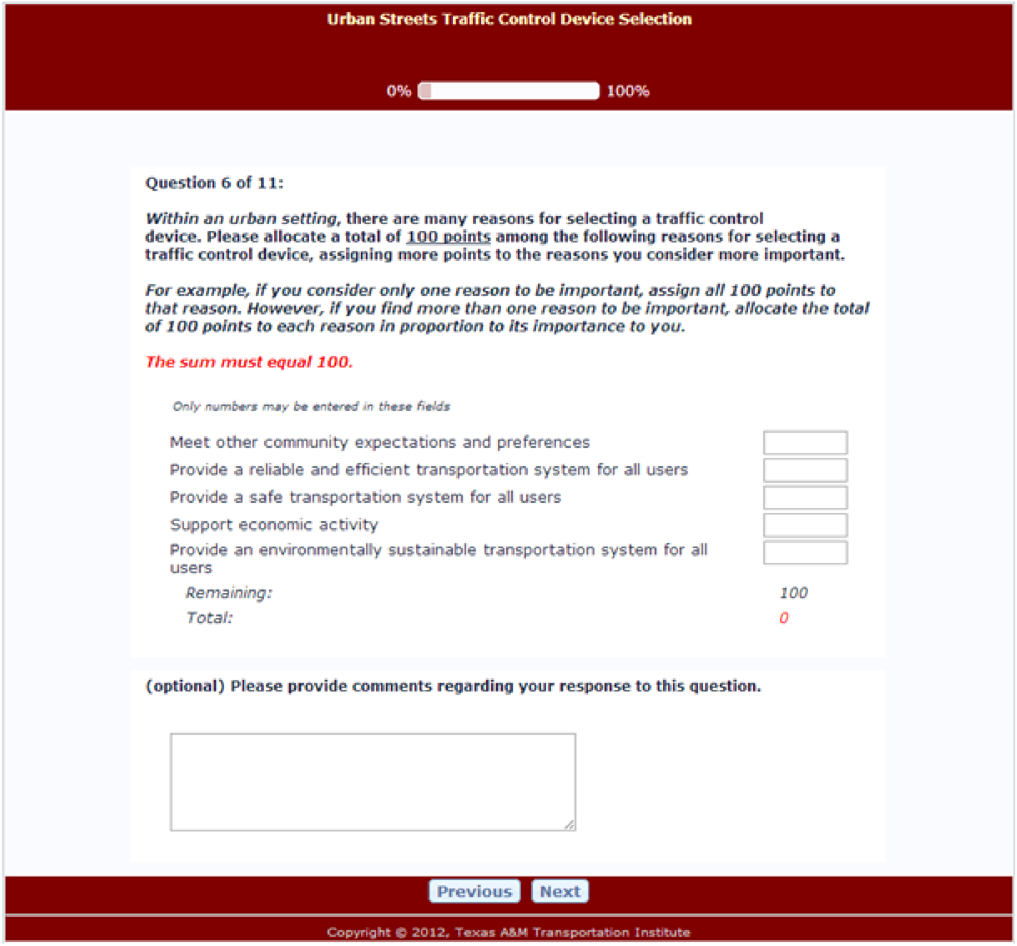


Figure 3. Question 6 – Relative Importance of Agency Objectives.

Part Three – Selection of Transportation Improvement Alternatives

Part three of the survey asked participants to select between three transportation improvement alternatives. Within this report, researchers use this part of the survey of transportation professionals to investigate the following research questions:

5. Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, level of service, percent free-flow speed, and average vehicle speed.
6. Which safety performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include injury crashes, property damage only crashes, and total crashes.
7. How does a single fatal crash effect the ranking of transportation improvement alternatives?
8. Can compliance act as a surrogate measure of safety when ranking transportation improvement alternatives?
9. Do transportation professionals place increased value on avoiding losses versus achieving gains when selecting between three transportation improvement alternatives?

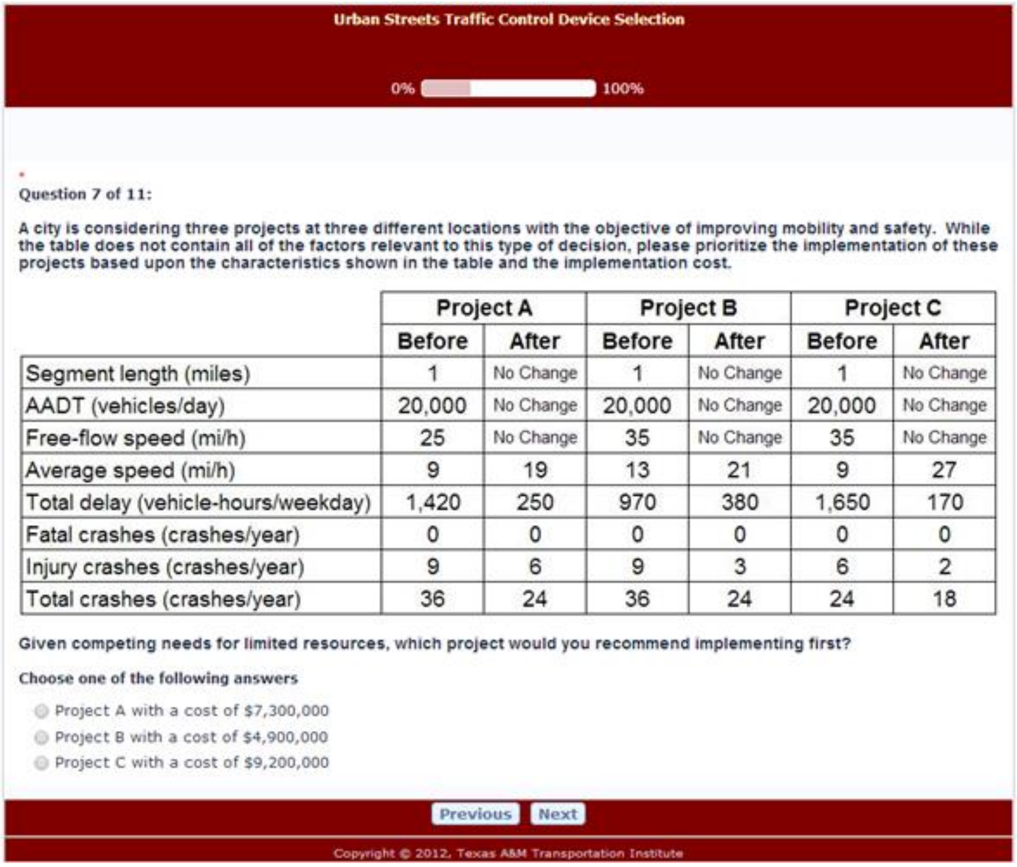
In order to address these four research questions within four questions per survey participant, researchers had LimeSurvey randomly assign each survey participant to one of six groups. For each group, question seven and question eight were similar, however, the style of question for question nine and question ten varied. The combinations of mobility, safety, and cost values for each question for each group are provided in Appendix C. The development of the content within Appendix C is described in a later section of this chapter; the contents of this section are to demonstrate how the scenarios in Appendix C were presented to each survey participant.

In general, these questions were difficult to answer and researchers designed these questions to force survey participants to make tough decisions with limited information. Additionally, participants could not continue the survey without responding to the questions in this part of the survey. This could be a reason why 22 survey participants that did not complete the survey (14 percent of the 159 that started taking the survey) and elected to stop answering questions when they reached part three. While participants could not move forward without responding, participants could return to previous screens in order to see or to change their answers if they desired to do so.

All Groups – Question 7 and Question 8

Researchers designed question seven and question eight to evaluate the relative importance of mobility and safety without looking at the influence of fatal crashes on the decision. This means the alternatives in question seven and question eight provided various improvements to mobility and safety (in terms of total and injury crashes only). A screen shot of question seven is shown in Figure 4, the specific question seven text was:

> *A city is considering three projects at three different locations with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.*
>
> *Given competing needs for limited resources, which project would you recommend implementing first?*



Urban Streets Traffic Control Device Selection

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Question 7 of 11:

A city is considering three projects at three different locations with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	25	No Change	35	No Change	35	No Change
Average speed (mi/h)	9	19	13	21	9	27
Total delay (vehicle-hours/weekday)	1,420	250	970	380	1,650	170
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Given competing needs for limited resources, which project would you recommend implementing first?

Choose one of the following answers

- Project A with a cost of $7,300,000
- Project B with a cost of $4,900,000
- Project C with a cost of $9,200,000

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Figure 4. Question 7 – Selecting Project to Implement First.

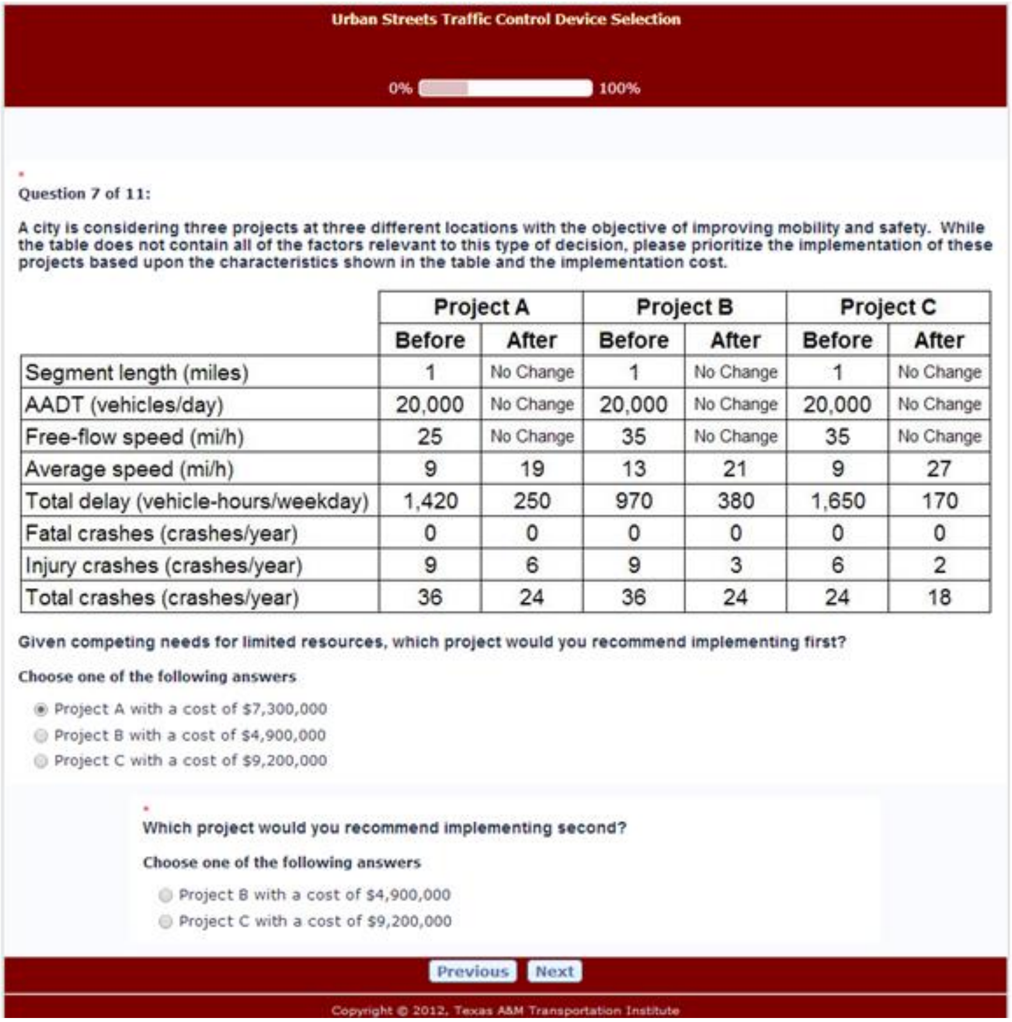
After a survey participant indicated the project they would implement first, they were then asked to select between the two remaining projects; indicating which project they would implement second. A screen shot of what this looked like to a survey participant is shown in Figure 5. The specific question text was:

Which project would you recommend implementing second?

After the participant indicated the project they would implement second, the survey participant moved on to question eight. In question eight, the project variables for mobility, cost, and safety were the same; however, the costs changed based upon the participants answers in question seven. The project costs changed using the following manner:

- If the project rank in question seven equaled fist, then the cost in question eight was the cost shown in question seven times 1.8.
- If the project rank in question seven equaled second, then the cost in question eight was the cost shown in question seven time 1.4.
- If the project rank in question seven equaled third, then the cost in question eight was the cost shown in question seven times 1.2.

Values were rounded to the nearest $100,000.



Urban Streets Traffic Control Device Selection

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*

Question 7 of 11:

A city is considering three projects at three different locations with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	25	No Change	35	No Change	35	No Change
Average speed (mi/h)	9	19	13	21	9	27
Total delay (vehicle-hours/weekday)	1,420	250	970	380	1,650	170
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Given competing needs for limited resources, which project would you recommend implementing first?

Choose one of the following answers

- (•) Project A with a cost of $7,300,000
- ( ) Project B with a cost of $4,900,000
- ( ) Project C with a cost of $9,200,000

*

Which project would you recommend implementing second?

Choose one of the following answers

- ( ) Project B with a cost of $4,900,000
- ( ) Project C with a cost of $9,200,000

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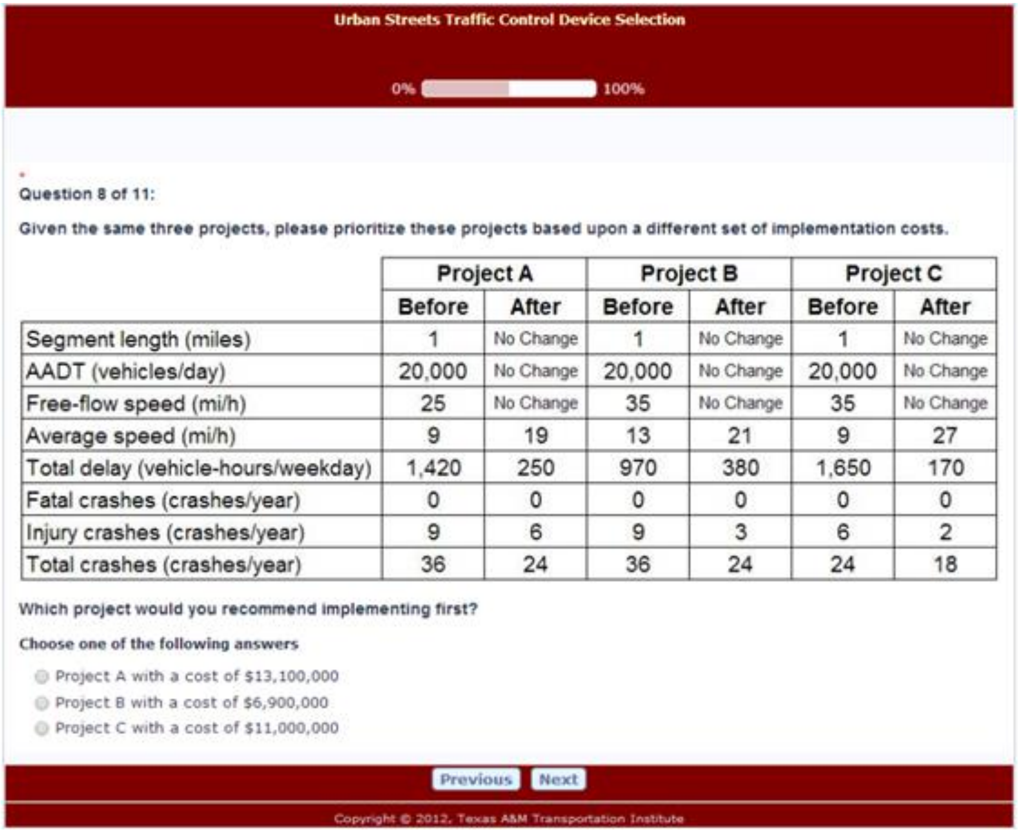
Figure 5. Question 7 – Second Project.

An example of how these costs were adjusted is shown in Figure 6. The projects in Figure 6 are same as the projects from Figure 4 and Figure 5; however, the costs in Figure 6 are those shown as if a participant were to recommend Project A first, Project B second, and Project C third. Mathematically, $13,100,000 is $7,300,000 multiplied by 1.8 and rounded to the nearest $100,000; $6,900,000 is $4,900,000 multiplied by 1.4 and rounded to the nearest $100,000; and, $11,000,000 is $9,200,000 multiplied by 1.2 and rounded to the nearest $100,000. Researchers included these adjustments in order to quantify the effect changes in cost might have on the ranking of project alternatives.


Urban Streets Traffic Control Device Selection

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Question 8 of 11:

Given the same three projects, please prioritize these projects based upon a different set of implementation costs.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	25	No Change	35	No Change	35	No Change
Average speed (mi/h)	9	19	13	21	9	27
Total delay (vehicle-hours/weekday)	1,420	250	970	380	1,650	170
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Which project would you recommend implementing first?

Choose one of the following answers

- Project A with a cost of $13,100,000
- Project B with a cost of $6,900,000
- Project C with a cost of $11,000,000

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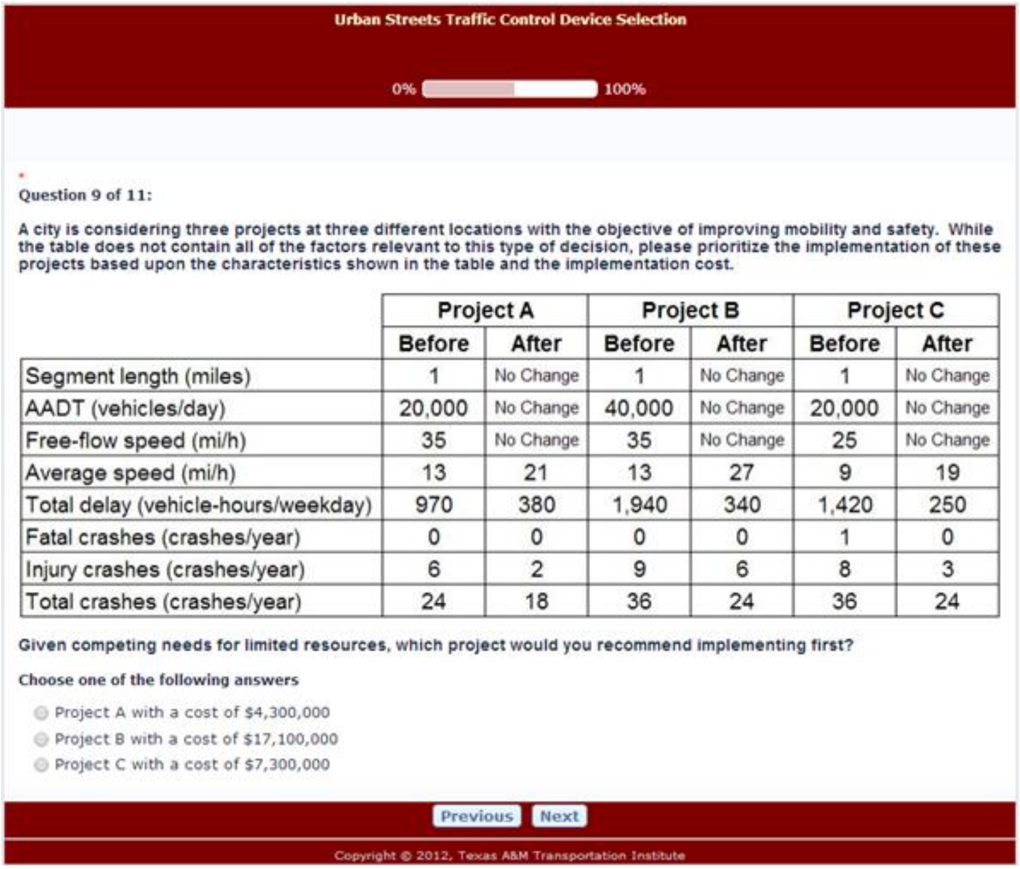
Figure 6. Question 8 – Same Three Projects with Different Costs.

Group One and Group Six – Fatal Crashes

For participants assigned to group one or group six, question nine and question ten looked at the relative importance of mobility and safety with Project C including a reduction from 1 fatal crash to 0 fatal crashes in the before and a reduction from 8 injury crashes in the before condition to 3 injury crashes in the after condition. A screen shot of this question is shown in Figure 7. The specific question text was:

> *A city is considering three projects at three different locations with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.*

After a participant indicates the project they recommend implementing first, question nine and question ten proceed in the same manner as question seven and question eight. To say it another way, after indicating the first project they would indicate the second project; then in question ten, the costs adjust based upon the answers in question nine using the same 1.2, 1.4, and 1.8 multipliers.



Urban Streets Traffic Control Device Selection

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Question 9 of 11:

A city is considering three projects at three different locations with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	40,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	35	No Change	25	No Change
Average speed (mi/h)	13	21	13	27	9	19
Total delay (vehicle-hours/weekday)	970	380	1,940	340	1,420	250
Fatal crashes (crashes/year)	0	0	0	0	1	0
Injury crashes (crashes/year)	6	2	9	6	8	3
Total crashes (crashes/year)	24	18	36	24	36	24

Given competing needs for limited resources, which project would you recommend implementing first?

Choose one of the following answers

- Project A with a cost of $4,300,000
- Project B with a cost of $17,100,000
- Project C with a cost of $7,300,000

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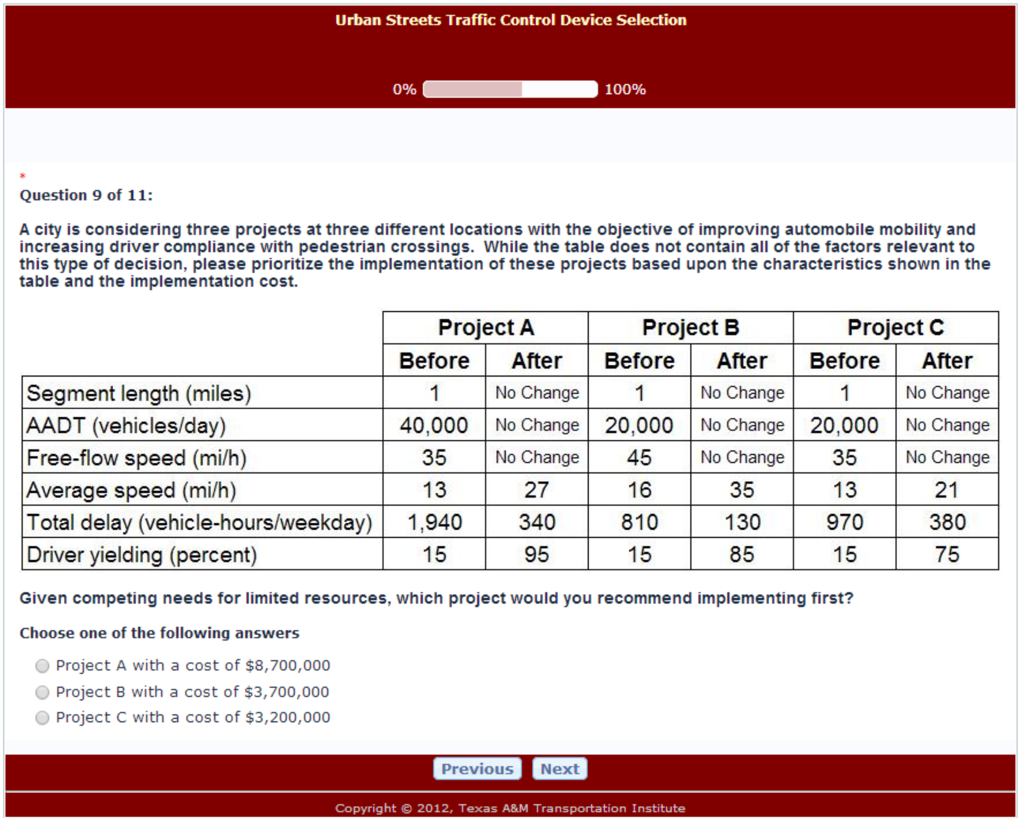
Figure 7. Question 9 – Fatal Crash Question.

Group Two and Group Four – Driver Compliance

For participants assigned to group two or group four, question nine and question ten looked at the relative importance of mobility and safety with driver yielding (driver compliance) acting as a surrogate measure for safety. A screen shot of this question as seen by survey participants is shown in Figure 8. The specific question text was:

> *A city is considering thee projects at three different locations with the objective of improving automobile mobility and increasing driver compliance with pedestrian crossings. While the table does not contain all of the factors relevant to this type of decision. Please prioritize the implementation of three projects based upon the characteristics shown in the table and the implementation cost.*



Urban Streets Traffic Control Device Selection

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*

Question 9 of 11:

A city is considering three projects at three different locations with the objective of improving automobile mobility and increasing driver compliance with pedestrian crossings. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	40,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	45	No Change	35	No Change
Average speed (mi/h)	13	27	16	35	13	21
Total delay (vehicle-hours/weekday)	1,940	340	810	130	970	380
Driver yielding (percent)	15	95	15	85	15	75

Given competing needs for limited resources, which project would you recommend implementing first?

Choose one of the following answers

- Project A with a cost of $8,700,000
- Project B with a cost of $3,700,000
- Project C with a cost of $3,200,000

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Figure 8. Question 9 – Driver Yielding Question.

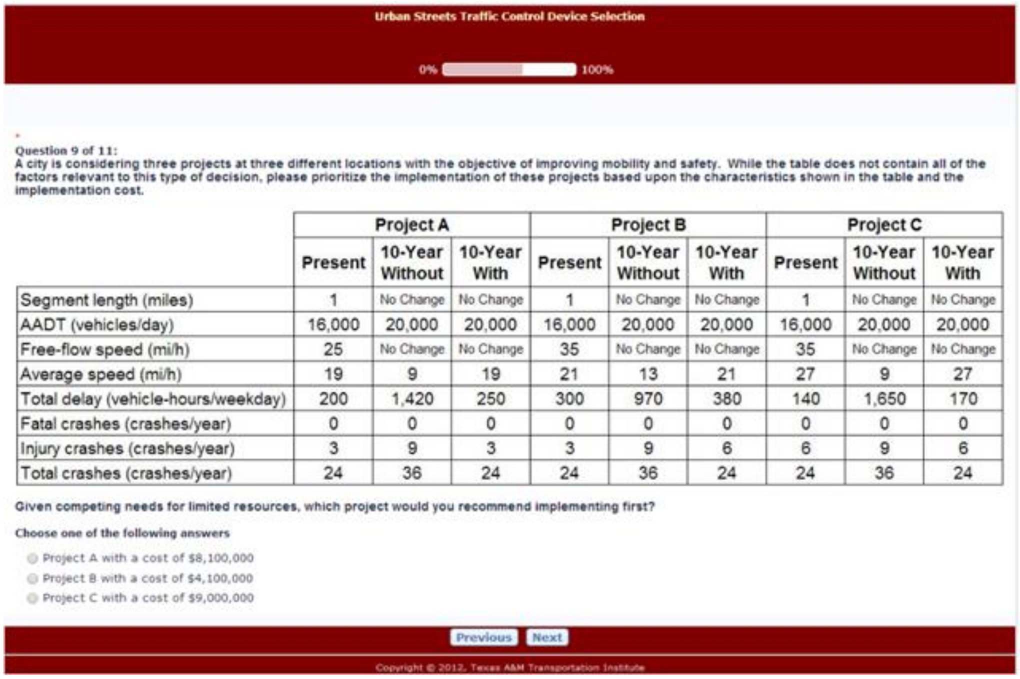
After a participant indicated the project they recommend implementing first, question nine and question ten proceed in the same manner as question seven and question eight. To say it another way, after indicating the first project they would indicate the second project; then in question ten, the costs adjust based upon the answers in question nine using the same 1.2, 1.4, and 1.8 multipliers.

Group Three and Group Five – Loss Aversion

For participants assigned to group three or group five, question nine and question ten looked at the relative importance of mobility and safety when the projects are implemented to avoid congestion and additional crashes that are expected to occur in the future (10 years). A screen shot of the question as seen by the survey participants is shown in Figure 9. The specific question text was:

> *A city is considering three projects at three different location with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.*

After a participant indicated the project they recommend implementing first, question nine and question ten proceed in the same manner as question seven and question eight. To say it another way, after indicating the first project they would indicate the second project; then in question ten, the costs adjust based upon the answers in question nine using the same 1.2, 1.4, and 1.8 multipliers.



Urban Streets Traffic Control Device Selection

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Question 9 of 11:
A city is considering three projects at three different locations with the objective of improving mobility and safety. While the table does not contain all of the factors relevant to this type of decision, please prioritize the implementation of these projects based upon the characteristics shown in the table and the implementation cost.

	Project A			Project B			Project C		
	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With
Segment length (miles)	1	No Change	No Change	1	No Change	No Change	1	No Change	No Change
AADT (vehicles/day)	16,000	20,000	20,000	16,000	20,000	20,000	16,000	20,000	20,000
Free-flow speed (mi/h)	25	No Change	No Change	35	No Change	No Change	35	No Change	No Change
Average speed (mi/h)	19	9	19	21	13	21	27	9	27
Total delay (vehicle-hours/weekday)	200	1,420	250	300	970	380	140	1,650	170
Fatal crashes (crashes/year)	0	0	0	0	0	0	0	0	0
Injury crashes (crashes/year)	3	9	3	3	9	6	6	9	6
Total crashes (crashes/year)	24	36	24	24	36	24	24	36	24

Given competing needs for limited resources, which project would you recommend implementing first?

Choose one of the following answers

- Project A with a cost of $8,100,000
- Project B with a cost of $4,100,000
- Project C with a cost of $9,000,000

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Figure 9. Question 9 – Loss Aversion Question.

Final Question and Exit Screen

The final question asked participants to provide comments concerning the survey, the specific question text was:

> *This is the last question. Please provide any comments concerning this survey.*

The comments from this question are documented in Appendix D.

Figure 10. Final Question.

After clicking the submit button, survey participants were sent to an exit screen. A screen shot of the exit screen is shown in Figure 11; the specific text is:

> *Thank you for taking time to complete this survey. Your responses will be helpful in developing a decision support tool for selecting traffic control devices.*
>
> *If you are interested in learning about the outcome of this study, please contact James Robertson at J-Robertson@tamu.edu.*

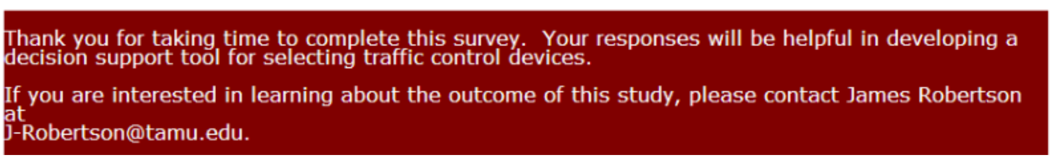

Figure 11. Exit Screen.

Note that J-Robertson@tamu.edu is no longer a valid email address.

MOBILITY AND SAFETY SCENARIOS FOR PART 3 OF THE SURVEY

Researchers developed the alternatives used within part three of the survey to determine how performance measures for transportation system efficiency and safety affect project rankings. For this investigation, researchers developed different scenarios and presented them to the six groups in a systemized manner.

Mobility Scenarios

For this report, researchers developed six mobility scenarios. Each survey participant observed three of these scenarios as part of question seven and question eight; then, they observed the other three scenarios as part of question nine and question ten. A summary of the mobility scenarios is provided in Table 5 and the assignment of mobility scenarios by group assignment is provided in Table 6.

Table 5. Mobility Scenarios.

Scenario	AADT (veh/day)	Free-Flow Speed (mi/h)	LOS Change	Speed Change (mi/h)	Total Delay Change (veh-hours/ weekday)
M1	20,000	35	E to B	13 to 27	970 to 170
M2	20,000	35	E to C	13 to 21	970 to 380
M3	20,000	35	F to B	9 to 27	1,650 to 170
M4	40,000	35	E to B	13 to 27	1,940 to 340
M5	20,000	25	E to B	9 to 19	1,420 to 250
M6	20,000	45	E to B	16 to 35	810 to 130

Table 6. Assignment of Mobility Scenarios by Group and Question Number.

Group	Question	Project A	Project B	Project C	Matches
1	7 & 8	M1	M3	M6	Group 4 – 9 & 10
	9 & 10	M2	M4	M5	Group 4 – 7 & 8
2	7 & 8	M3	M5	M4	Group 5 – 9 & 10
	9 & 10	M4	M6	M2	Group 5 – 7 & 8
3	7 & 8	M6	M1	M4	Group 6 – 9 & 10
	9 & 10	M5	M2	M3	Group 6 – 7 & 8
4	7 & 8	M2	M4	M5	Group 1 – 9 & 10
	9 & 10	M1	M3	M6	Group 1 – 7 & 8
5	7 & 8	M4	M6	M2	Group 2 – 9 & 10
	9 & 10	M3	M5	M4	Group 2 – 7 & 8
6	7 & 8	M5	M2	M3	Group 3 – 9 & 10
	9 & 10	M6	M1	M4	Group 3 – 7 & 8

Question 7 and Question 8 – Safety Scenarios

To investigate safety without fatal crashes, researchers developed three safety scenarios. These scenarios are provided in Table 7. For question seven and question eight, project A was always scenario S1, project B was always scenario S2, and project C was always scenario S3.

Table 7. Safety Scenarios for Question 7 and Question 8.

Scenario	Fatal Crash Change (crashes/year)	Injury Crash Change (crashes/year)	Total Crash Change (crashes/year)
S1	0 to 0	9 to 6	36 to 24
S2	0 to 0	9 to 3	36 to 24
S3	0 to 0	6 to 2	24 to 18

Groups One and Six – Questions 9 and 10 – Safety Scenarios

To investigate safety while including a reduction in fatal crashes, researchers developed three safety scenarios. These scenarios are provided in Table 8. For question seven and question eight, project A was always scenario S1, project B was always scenario S3, and project C was always scenario S4. S1 and S3 in Table 8 are the same as S1 and S3 in Table 7.

Table 8. Safety Scenarios for Groups One and Six, Questions 9 and 10.

Scenario	Fatal Crash Change (crashes/year)	Injury Crash Change (crashes/year)	Total Crash Change (crashes/year)
S1	0 to 0	9 to 6	36 to 24
S3	0 to 0	6 to 2	24 to 18
S4	1 to 0	8 to 3	36 to 24

Groups Two and Four – Questions 9 and 10 – Driver Yielding Scenarios

To investigate driver yielding (driver compliance) as a surrogate measure for safety, researchers developed three yielding scenarios, they are provided in Table 9. For groups two and four during questions 9 and 10, project A was always scenario Y1, project B was always scenario Y2, and project C was always scenario Y3.

Table 9. Yielding Scenarios for Groups Two and Four.

Scenario	Driver Yielding Change (percent)
Y1	15 to 95
Y2	15 to 85
Y3	15 to 75

Groups Three and Five – Questions 9 and 10 – Loss Aversion Scenarios

For the loss aversion questions, researchers developed three loss aversion scenarios, they are provided in Table 10. For group three and group five during question 9 and question 10, project A was always scenario L1, project B was always scenario L2, and project C was always scenario L3.

Table 10. Loss Aversion Scenarios for Groups Three and Five.

Scenario	Injury Crashes (crashes/year)			Total Crashes (crashes/year)		
	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With
L1	3	9	3	24	36	24
L2	3	9	6	24	36	24
L3	6	9	6	24	36	24

PROJECT COSTS FOR PART 3 OF THE SURVEY

The project costs for question seven and question nine are the annual benefits of the mobility and safety improvements in 2012 dollars. The calculated benefits per year for each mobility scenario is provided in Table 11; the value of time used in these calculations is $20.99 in 2012 dollars (Obr & Marek 2012). The calculated benefits per year for each safety scenario are provided in Table 12. The costs seen by a survey participant in question seven and question nine are the combined mobility and safety benefits from Table 11 and Table 12 for the project rounded to the nearest $100,000 dollars. For example, the monetary benefits for mobility scenario M1 is $4,365,920 and the monetary benefits of safety scenario S1 is $929,358; therefore, the cost for project A in group 1 question 7 is $5,300,000. This process is repeated for the combinations presented to each participant; the values can be found in Appendix C. For group two and group four, the values presented in question nine are the monetary benefits of the mobility improvements only, which assumes the monetary benefits of yielding are $0 per year.

Table 11. Benefits per Year for Each Mobility Scenario.

Scenario	Hours Saved Per Weekday	Value of Time ($/hour)	Weekdays per Year	Benefits Per Year ($)
M1	800	20.99	260	4,365,920
M2	590	20.99	260	3,219,866
M3	1,480	20.99	260	8,076,952
M4	1,600	20.99	260	8,731,840
M5	1,170	20.99	260	6,385,158
M6	680	20.99	260	3,711,032

Table 12. Benefits per Year for Each Safety Scenario.

Scenario	Fatal Crash Reduction (crashes/year)	Injury Crash Reduction (crashes/year)	Property Damage Only Reduction (crashes/year)	Benefits Per Year ($)
S1	0	3	9	929,358
S2	0	6	6	1,721,305
S3	0	4	2	1,124,635
S4	1	5	6	8,346,277
L1	0	6	6	1,721,305
L2	0	3	9	929,358
L3	0	3	9	929,358

For the values calculated in Table 12, researchers used the following values for determining the monetary benefits of crash reductions:

- $6,900,405 per fatal crash per year.
- $275,433 per injury crash per year.
- $11,451 per property damage only crash per year.

These values were calculated using 2009 Mid-Range Comprehensive Societal Costs documented by Fitzpatrick et al. (2010) in table 61 on page 99 of *NCHRP Web-Only Document 193: Development of Left-Turn Lane Warrants for Unsignalized Intersections*. These values are provided in Table 13. In addition to looking at the cost of a fatality, the values in Table 13 also account for the number of injuries or fatalities experienced in each crash (in general, more than 1 person is injured or killed in each injury or fatal crash).

Table 13. Cost per Crash by Crash Severity.

Crash Severity	2009 Comprehensive Societal Cost (Mid-Range)	Injuries or Deaths per Crash	2009 Cost per Crash	2012 Cost Per Crash
Fatality	$5,861,700	1.10	$6,447,870	$6,900,405
Incapacitating Injury	$313,500	1.42	$446,590	$477,933
Non-incapacitating Injury	$115,000	1.64	$188,600	$201,837
Possible Injury	$65,200	2.10	$136,920	$146,530
Property Damage Only	$10,700	0.00	$10,700	$11,451

After determining the 2009 cost per crash, these values were converted to 2012 dollars using the average consumer price index values for 2009 (214.537) and 2012 (229.594) (U.S. Department of Labor 2013). For determining the costs used in the survey, researchers averaged the cost of the three types of injury crashes, which means $275,433 is the average of $477,993, $201,837, and $146,530.

CHAPTER SUMMARY

This chapter documents the creation of a survey of transportation professionals. The purpose of this is to guide the selection of agency objectives and agency performance measures for use in a decision support tool for selecting TCDs. In the next two chapters, researchers evaluate data collected using this survey and uses the results of the evaluation to make recommendations for the decision support tool developed within Chapter VI of this report.

CHAPTER IV

AGENCY OBJECTIVES

FOR USE IN SELECTING TRAFFIC CONTROL DEVICES

In this chapter, researchers evaluate survey participant responses to demographic questions and the relative importance of agency objectives. The purpose of this evaluation is to determine which objectives to include within a decision support tool for selecting TCDs. Researchers evaluate part three of the survey in Chapter V. At the end of this chapter, researchers recommend evaluating only mobility and safety as engineering benefits within the decision support tool for selecting TCDs. While researchers do not recommend evaluating environmental sustainability and economic competitiveness benefits within the decision support tool at this time, future research may find that they should be included.

RELATIVE IMPORTANCE OF AGENCY OBJECTIVES

In this section, researchers document the statistical methods used, and results from, an evaluation of the following research questions:

1. When selecting TCDs, should agencies consider safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
2. If considered in a decision support tool for selecting TCDs, what is the relative importance of safety, mobility (efficiency and reliability), environmental sustainability, and economic activity as agency objectives?
3. Does employer type, area of practice, professional licensure, experience, or geographic region influence the consideration of each agency objective?
4. Does employer type, area of practice, professional licensure, experience, or geographic region influence the relative importance of considered agency objectives?

Within this report, researchers evaluate only responses from the 116 completed surveys.

Methods

To evaluate survey participants' allocation of points in question six of the survey of transportation professionals, researchers use two types of confidence intervals. First, researchers use confidence intervals for binomial proportions to evaluate the probability of a survey participant allocating more than zero points to an objective. In general, if transportation professionals are not allocating points to an objective, it may suggest that this objective is not driving the engineering decision to select TCDs and therefore not needed in a decision support tool for selecting TCDs. .

Second, researchers use confidence intervals for normal data to evaluate the number of points a survey participant allocates to an objective assuming that the participant allocated more than zero points to the objective. If, on average, transportation professional allocate more points to a specific objective, it may suggest that the objective is driving the engineering decision to select TCDs and therefore not needed in a decision support tool for selecting TCDs. Since these confidence intervals presume the data are normal, researchers use the chi-square goodness-of-fit test to determine if the data are statistically significantly different from being normally distributed (Spiegelman, Park, & Rilett 2011). In this evaluation, researchers found that the distribution for the responses to the agency objective of "other expectations and preferences" was statistically significantly different from a normal distribution. However, for consistency within this report, researchers use confidence intervals to evaluate all objectives, including this one.

This report presumes that an engineering evaluation of TCDs should be limited to objectives that transportation professionals most commonly consider and objectives that when considered are given the most weight. For this report, this means the objectives with the highest probability of a survey participant allocating more than zero points and the objectives with the most points allocated to them. Researchers consider objectives with the highest probability of more than zero points and objectives with the highest quantity of points to be objectives driving the decision to select TCDs.

By developing a decision support tool that quantifies only factors that drive the engineering decision, it is possible to develop a decision support tool that does not consider factors that are relevant to local needs and desires. However, within the decision support tool, researchers suggest a means for considering these factors within the decision support tool without a need to quantify them as part of the engineering evaluation. In general, researchers suggest limiting the alternatives evaluated within the decision support tool to those that the local community will support.

Calculation of Confidence Intervals for Categorical Data

Researchers calculate 95-percent confidence intervals for binomial proportions to evaluate the probability of a survey participant allocating more than 0 points to an objective (Agresti 2007). The specific equations used to calculate these confidence intervals are:

P_{yes} = N_yes / N_total   Equation 4-1

Upper Bound = $P_{yes} + 1.96 \times SE$ Equation 4-2

Lower Bound = $P_{yes} - 1.96 \times SE$ Equation 4-3

SE = $(P_{yes} \times [1 - P_{yes}] / N\_total)^{0.5}$ Equation 4-4

where:

- Pyes = Probability of a survey participant allocating more than zero points to an objective
- N_yes = Number of survey participants (that complete the full survey) allocating more than zero points to an objective.
- N_total = Total number of completed surveys.
- Upper Bound = The upper boundary for the 95^{th} percentile confidence interval.
- Lower Bound = The lower boundary for the 95^{th} percentile confidence interval.
- SE = Standard error for a binomial proportion confidence intervals.

A limitation of Equation 4-1 is that it may underestimate the confidence interval for probabilities near one and probabilities near zero (Agresti 2007). An example of a confidence interval with an underestimated range is one where the lower boundary of the confidence interval is a probability less than zero (0 percent) or a confidence interval with an upper boundary with probability greater than one (100 percent). Despite this limitation, confidence intervals for categorical data calculated using Equation 4-1 are useful in determining statistically significant differences between population groups (Agresti 2007).

Calculation of Confidence Intervals for Continuous Data

Researchers calculate 95-percent confidence intervals for normal data to evaluate the number of points a survey participant allocated to an objective given that the survey participant allocated more than zero points to the objective (Spiegelman, Park, & Rilett 2011). The specific equations used to calculate these confidence intervals are:

$$\text{Average Points} = \sum_i \text{Points}_i / \text{N\_yes} \quad \text{Equation 4-5}$$

$$\text{Upper Bound} = \text{Average Points} + 1.96 \times \text{STDEV} \quad \text{Equation 4-6}$$

$$\text{Lower Bound} = \text{Average Points} - 1.96 \text{ x STDEV} / \text{N\_yes}^{0.5} \quad \text{Equation 4-7}$$

$$\text{STDEV} = (\sum_i [\text{Points}_i - \text{Average Points}]^2)^{0.5} \quad \text{Equation 4-8}$$

where:

- Average Points = Probability of a survey participant allocating more than zero points to an objective
- N_yes = Number of survey participants (that complete the full survey) allocating more than zero points to an objective.
- $\sum_i$ = Sum over all i.
- Points_i = Points allocated by a survey participant to an objective given the survey participant allocated more than zero points to the objective.
- Upper Bound = The upper boundary for the 95th percentile confidence interval.
- Lower Bound = The lower boundary for the 95th percentile confidence interval.
- STDEV = Standard deviation for the average points allocated to an objective given the survey participant allocated more than zero points to the objective.

A limitation of this method is that it assumes the data are continuous and have a normal distribution, which may not be a valid assumption (Spiegelman, Park, & Rilett 2011). A reason that these data may violate this assumption is that the data are bounded at 1 and 100 points. These data are not bounded at one instead of zero because researchers calculate these confidence intervals using only data from participants than allocated more than zero points to the objective (this means N_yes varies depending on the objective and the demographic group).

Chi-Square Goodness-of-Fit Test

To determine if the continuous data have a normal distribution, researchers use the chi-square goodness-of-fit test (Spiegelman, Park, & Rilett 2011). Since the confidence intervals include only data from participants that allocated more than zero points to each objective, researchers calculate the chi-square goodness-of-fit test statistic using these same data. The equation for calculating the chi-square test statistic is:

$$\chi^2 = \sum_i (N_i - E_i)^2 / E_i \qquad \text{Equation 4-9}$$

where:

- χ^2 = The chi-square test statistic.
- $\sum_i$ = Sum over all i.
- N_i = Number of observations within the ith cell of the histogram for the collected data.
- Ei = Expected number of observation within the ith cell of a histogram that has a normal distribution with mean and standard deviation that is the same as the collected data.

The degrees of freedom for the chi-square test statistic are i-1, where i is the number of cells in a histogram of the data. When constructing a histogram for the chi-square goodness-of-fit test, 80 percent of the cells should have a minimum expected or actual count of five observations.

For the goodness-of-fit calculations investigating the normality of the continuous data, researchers provide a p-value for the chi-square test statistic. A p-value less than 0.05 indicates statistically significant evidence that these data are not normally distributed. If data are not normally distributed, statistically significant differences found using the calculated 95th percentile confidence interval might not be statistically significant findings. In this report, researchers do not develop conclusions based upon data that violate the normal assumption.

All Data

This portion of the report investigates the allocation of points to agency objectives without looking at demographic data. Researchers investigate the influence of demographic data in a later section of this chapter. The probability of a survey participant allocating more than zero points to each agency objectives is provided in Table 14 and the average number of points allocated to each agency objective assuming the participant allocated more than zero points in provided in Table 15. Additionally, the cumulative distribution of points allocated to each agency objective are provided in Appendix E. Based upon the chi-square goodness-of-fit test statistics in Appendix F, there is no statistically significant evidence that the data used to construct the confidence intervals for safety, mobility (reliability and efficiency), environmental sustainability, and economic activity were not normally distributed. However, here is statistically significant evidence that the distribution of the other expectations and preferences data are not normally distributed; the p-value is 0.0177, which is less than 0.05. Despite this finding and for consistency within this report, researchers still use confidence intervals to evaluate statistically significant differences in the allocation of points to each agency objective.

Table 14. Probability of a Survey Participant Allocating More than Zero Points to Each of the Five Agency Objectives.

Objective	N_total	N_Yes	%_Yes	SE	Lower Bound	Upper Bound
Safety	116	115	99	0.9	97	100
Reliability and Efficiency	116	113	97	1.5	95	100
Environmental Sustainability	116	77	66	4.4	58	75
Economic Activity	116	80	69	4.3	61	77
Other Expectations and Preferences	116	86	74	4.1	66	82

N_total = Total number of participants.
N_Yes = Total number including the specific objective.
%_Yes = Percent of respondents including the specific objective.
SE = Standard error.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 15. Average Number of Points Allocated to Each Objective Given the Participant Allocated More than Zero Points to the Objective.

Objectives	N_Yes	Average Points	STDEV	Lower Bound	Upper Bound
Safety	115	47	17.5	43.9	50.3
Reliability and Efficiency	113	31	12.9	28.4	33.2
Environmental Sustainability	77	12	7.4	10.3	13.7
Economic Activity	80	11	5.6	9.7	12.1
Other Expectations and Preferences*	86	11	6.2	9.3	11.9

N_Yes = Total number including the specific objective.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.
* There is statistically significant evidence that the data for this variable are not normally distributed with a p-value of 0.0177, which is less than 0.05.

Based upon the confidence intervals in Table 14, survey participants are statistically significantly more likely to allocate more than zero points to the objectives of safety and mobility (reliability and efficiency) than they were to allocate more than zero points to the other three objectives (environmental sustainability, economic activity, and other expectations and preferences. Additionally, on average, participants allocate more than zero points to safety 99 percent of the time and mobility 97 percent of the time while the percentage for environmental sustainability is 66 percent, the percentage for economic activity is 69 percent, and the percentage for other expectations and preferences is 74 percent.

Based upon the confidence intervals in Table 15, on average, survey participants allocate more points to safety than the other four agency objectives and more points to mobility (reliability and efficiency) than environmental sustainability, economic activity, and other expectations and preferences. These differences are statistically significant; additionally, based upon the chi-square test statistics in Appendix F, data used to construct confidence intervals in Table 15 do not violate the normal assumption.

These finding suggests safety and mobility are driving the selection of TCDs and that safety and mobility should be agency objectives considered within a decision support tool for use in selecting TCDs. Additionally, these data suggest not including the objectives of environmental sustainability, economic activity, and other expectations and preferences within the decisions support tool at this time. One reason for not including environmental sustainability, economic activity, and other community expectations and preferences is the lower number of participants allocating more than zero points to each of these objectives. A second reason for not including environmental sustainability, economic activity, and other community expectations and preferences is the low number of points allocated to each of these objectives by survey participants that did allocate more than zero points to the objectives.

Demographic Effects on Relative Importance

This portion of the report investigates if there are differences in the probability of allocating more than zero points to an objective and the number of points allocated given more than zero points are allocated to the objectives based upon the following survey participant demographic information:

- Employer type.
- Area of practice.
- Professional licensure.
- Experience.
- Geographic region.

The data presented within this chapter are restricted to tables that contain statistically significant differences; however, tables with confidence intervals for all of the data are provided in Appendix G. In this section, researchers check the normality of data only if the continuous data confidence intervals result in a statistically significant difference. Researchers provide the chi-square goodness-of-fit statistics for the statistically significant confidence interval data in Appendix H. Researchers do not calculate chi-square goodness-of-fit statistics for the other confidence intervals because there is no reason to believe these values are statistically significantly different from the population confidence intervals shown in the previous section, and, researchers already calculated chi-square goodness-of-fit statistics for the population confidence intervals earlier (see Appendix F).

Employer Type

The number of survey participants by employer type are provided in Table 16. Due to the number of survey participants from each employer type, the employer type analysis looks only at difference between the following:

- Government – City.
- Government – State.
- Private Consultant.
- University or College.

Table 16. Number of Participants by Employer Type.

Employer Type	Number of Participants
Government – City	33
Government – County	4
Government – State	17
Government – Federal	2
Nonprofit / Not-For-Profit	2
Private Consultant	41
Private Vendor / Industry	2
University or College	14
Other	1
Total	116

Based upon survey data (provided in Appendix G), there were no statistical differences in the probability of including a factor between employer type groups. Additionally, there was no statistically significant difference in the number of points allocated to the following objectives given more than zero points were allocated to the objectives:

- Provide a safe transportation system for all users.
- Provide an environmentally sustainable transportation system for all users.
- Support economic activity.
- Other community expectations and preferences.

A review of the confidence intervals shown in Table 17, does show a statistically significant difference between transportation professionals that work for state agencies as compared to transportation professionals that work for private consultants when it comes to the objective of providing a reliable and efficient transportation system for all users. On average, state government employees allocated 14 more points to providing a reliable and efficient transportation system for all users as compared to private consultant employees. Based upon the confidence intervals in Table 17, this difference is statistically significant; additionally, based upon the chi-square test statistics in Appendix H, data used to determine these confidence intervals do not violate the normal assumption. These numbers may suggest that state agencies place more emphasis on mobility (reliability and efficiency) than private consultants do; this makes sense since many state facilities (freeways and major arterials) are higher speed and higher volumes roadways.

Table 17. Number of Points Allocated to Reliability and Efficiency by Employer Type Given More than Zero Points were Allocated.

Reliability and Efficiency					
Employer Type	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
City Government	33	31	11.8	27.0	35.0
State Government	16	41	19.7	31.3	50.6
Private Consultant	39	27	8.8	24.6	30.2
University or College	14	26	10.5	20.9	31.8

N_Yes = Total number including the specific factor.
STDEV = Standard deviation
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Area of Practice

The distribution of responses by area of practice are provided within Table 18, survey participants could indicate more than one area of practice (for example, both planning and engineering), which means the total number of yes responses can be greater than the number of completed surveys (there were 116 completed surveys). However, the total number of yes plus the total number of no responses cannot exceed the total number of completed surveys; it could be less if a participant did not answer this question. Due to the low number of respondents identifying their area of practice as a technician, vendor, or other, this report looks only at differences in responses between participants that indicated they are engineers versus not engineers and participants identifying themselves as planners versus not planners. The three participants that responded other indicated their areas of practice were:

- Maintenance and construction.
- Research.
- Human factors.

Table 18. Distribution of Responses by Area of Practice.

Area of Practice	Yes	No
Engineering	109	7
Planning	32	84
Technician	4	112
Vendor	2	114
Other	3	113

Based upon the data, provided in Appendix G, there were no statistically significant differences in the responses between survey participants identifying their area of practice as engineering versus not engineering and no statistically significant differences in the responses between survey participants identifying their area of practice as planning versus not planning.

Professional Engineering License

Of the survey participants, 96 indicated they had a PE license or their country's equivalent and 20 participants indicated they did not have a PE license. Based upon the data provided in Appendix G, there is no statistical differences in the probability of including a factor between those with a PE license and those without a PE license for the following objectives:

- Provide a safe transportation system for all users.
- Provide a reliable and efficient transportation system for all users.
- Provide an environmentally sustainable transportation system for all users.
- Other community expectations and preferences.

Additionally, there was no statistically significant difference in the number of points allocated to any of these four objectives.

The only statistically significant difference was in the probability of allocating more than zero points to the objective of supporting economic activity, shown in Table 19. On average, the probability of a participant including economic activity is 65 percent for participants with a PE license and 90 percent for those without a PE license. However, there was no statistically significant difference in the average number of points allocated to each objective based upon having or not having a PE license. These findings suggest supporting economic activity may not be a driving factor when selecting TCDs among transportation professionals with a PE license.

Table 19. Probability of Allocating Points to Economic Activity by PE Licensure or No PE License.

Economic Activity						
License	**N_total**	**N_Yes**	**%_Yes**	**SE**	**Lower Bound**	**Upper Bound**
PE License	96	62	65	4.9	55	74
No PE License	20	18	90	6.7	77	100

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
SE = Standard error.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Experience

To evaluate years of experience, researchers use four groups of experience, they are:

- 0 to 10 years.
- 11 to 20 years.
- 21 to 30 years.
- 31 or more years.

Based upon the data, provided in Appendix G, there is no statistical differences in the probability of including a factor based upon years of experience for the following objectives:

- Provide a safe transportation system for all users.
- Provide a reliable and efficient transportation system for all users.
- Support economic activity.
- Other community expectations and preferences.

Additionally, there was no statistically significant differences in the number of points allocated to each factor for the following objectives:

- Provide a safe transportation system for all users.
- Support economic activity.
- Other community expectations and preferences.

Based upon the data in Table 20, survey participants with 0 to 10 years of experience are more likely to allocate more than zero points to environmental sustainability than were survey participants with more than 21 years of experience or more. This may suggests a generational difference between transportation professionals with 10 or fewer years of experience and generations with 21 or more years of experience. Additionally this suggests the younger generation is more likely to consider environmental sustainability when selecting TCDs.

Table 20. Probability of Allocating More than Zero Points to Environmental Sustainability by Years of Experience.

Environmental Sustainability						
Experience	**N_total**	**N_Yes**	**%_Yes**	**SE**	**Lower Bound**	**Upper Bound**
0 to 10 years	21	19	90	6.4	78	100
11 to 20 years	27	17	63	9.3	45	81
21 to 30 years	29	17	59	9.1	41	77
31 years or more	39	24	62	7.8	46	77

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
SE = Standard deviation
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Given the survey participant allocated more than zero points to mobility (reliability and efficiency), the data shown in Table 21 indicate, on average, that participants with 0 to 10 years of experience allocate eight fewer points to mobility than survey participants with 31 or more years of experience. Additionally, on average, participants with 0 to 10 years of experience allocate six more points to environmental sustainability than participants with 11 to 20 years of experience. Both findings are statistically significant and the chi-square test statistics in Appendix H indicate these data do not violate the normal assumption. The increased probability of including environmental sustainability and the lower number of points allocated to mobility, suggest the generation of transportation professionals with 0 to 10 years of experience could be okay with trading some mobility (reliability and efficiency) for environmental sustainability when selecting TCDs.

Table 21. Number of Points Allocated to Mobility and Environmental Sustainability by Experience Given More than Zero Points Were Allocated.

Reliability and Efficiency					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
0 to 10 years	20	24	9.4	19.7	27.9
11 to 20 years	26	29	11.3	24.8	33.5
21 to 30 years	28	29	13.7	24.4	34.5
31 years or more	39	32	12.2	28.3	36.0
Environmental Sustainability					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
0 to 10 years	19	13	6.1	10.0	15.4
11 to 20 years	17	7	5.7	3.9	9.3
21 to 30 years	17	8	8.2	4.5	12.4
31 years or more	24	8	10.1	3.9	12.0
N_Yes = Total number including the specific factor. STDEV = Standard deviation Lower Bound = Lower value of 95 percent confidence interval. Upper Bound = Upper value of 95 percent confidence interval					

Geographic Region

To determine geographic regions, researchers grouped participants into ITE districts. Researchers determined the survey participants ITE district based upon the participants answer to survey question number one (State or Country). The states associated with each ITE district are provided in Table 22. Because some ITE districts were under represented in the survey sample, researchers grouped the ITE districts to form the geographic regions as shown in Table 23. Based upon the data in Appendix G, there were no statistically significant differences in the responses associated with the grouping of survey participants into these geographic regions.

Table 22. ITE Districts and States or Countries Included Within Each District.

Number	Name	States or Countries
1	Northeastern District	Connecticut, Maine, *Massachusetts, New Hampshire*, New Jersey, *Ney York*, Rhode Island, Vermont
2	Mid-Colonial District	*Delaware*, District of Columbia, *Maryland, Pennsylvania*, West Virginia
3	Great Lakes District	Indiana, *Michigan, Ohio*
4	Midwestern District	Arkansas, *Iowa, Illinois, Kansas, Minnesota*, Missouri, *Nebraska*, North Dakota, *Oklahoma*, South Dakota, *Wisconsin*
5	Southern District	*Alabama*, Georgia, Kentucky, *Louisiana, Mississippi, North Carolina*, South Carolina, Tennessee, *Virginia*
6	Western District	*Alaska, Arizona, California, Colorado*, Hawaii, *Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming*
7	Canadian District	*Canada*
8	International District	All other countries (*Australia*)
9	Texas District	*Texas*
10	Florida District	*Florida*
Italicized states or countries appeared at least once in the survey responses.		

Table 23. Number of Survey Participants from Each Region.

Geographic Region	Number of Participants
Western District	32
Texas District	27
Northeastern District & Mid-Colonial District	15
Great Lakes District & Midwestern District	22
Southern District & Florida District	15
Canadian District & International District	5

Summary of Relative Importance of Agency Objectives Analysis

An evaluation of the relative importance of agency objectives indicates:

- Transportation professionals consider safety and mobility as objectives driving the selection of TCDs, which suggest considering these objectives within a decision support tool for selecting TCDs.
- Transportation professionals may not consider environmental sustainability and economic activity as factors driving the selection of TCDs, which suggests not considering these objectives within a decision support tool for selecting TCDs.
- Transportation professionals with 0 to 10 years of experience could be inclined to place less emphasis on mobility (efficiency and reliability) and increased emphasis on environmental sustainability than transportation professionals with more years of experience.
- On average, state government employees that responded to the survey allocated 14 more points to mobility (efficiency and reliability) than private consultant that participated in the survey, which may indicate state departments of transportation have increased focus

on mobility. This makes sense because the focus of the facilities they maintain is on mobility as opposed to access.

- Transportation professionals without a professional engineering license could be more likely to consider economic activity when selecting TCDs as opposed to engineering professionals that have an engineering license.
- For the data collected, area of practice (engineering or planning) within the transportation profession and geographic region were not associated with statistically significant differences in the probability of allocating more than zero points to an objective and the number of points allocated to each objective.

DECISION SUPPORT TOOL IMPLICATIONS

In this section of the chapter, researchers use the findings from an evaluation of survey participant demographics and the allocation of points to each agency objective to aid in the development of a decision support tool for use in selecting TCDs. This section begins with a discussion about framing TCD decisions and using the discussed framing of TCD decisions to select alternatives within a decision support tool for selecting TCDs. This section explains why researchers suggest including only the objectives for safety and mobility when selecting TCDs using the decision support tool developed within this report; researchers develop the decision support tool within Chapter VI of this report.

Framing Traffic Control Device Decisions

Conceptually, this report proposes that there are three fundamental factors for selecting TCDs. Those three fundamental factors are:

- Local needs and desires.
- Engineering principles and practice.
- Engineering benefits.

The best solution is a solution that satisfies local needs and desires; complies with engineering principles and practice; and provides an engineering benefit. A visual representation of this concept is shown in Figure 12.

The decision support tool developed within this report focuses on maximizing engineering benefits. This means the decision support tool presupposes that the alternatives evaluated within the process satisfy local needs and desires and comply with engineering principles and practice. In situations where an alternative does not satisfy local needs and desires, the community may reject the solution; this indicates there could be value in evaluating only alternatives that the community supports. In situations where an alternative does not comply with current engineering principles and practice, the agency may want to consider using an official process that allows for the experimental use of solutions that are outside current engineering practice and principles. For example, design exemptions or requests for experimentation, which are formal processes for using atypical engineering solutions (FHWA 2009).

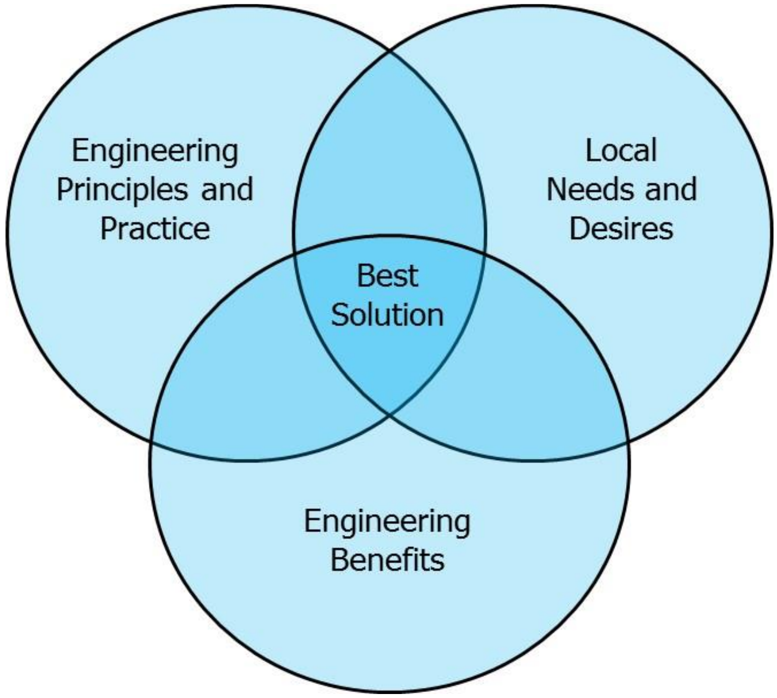

Figure 12. Visual Representation of Fundamental Factors for Selecting Traffic Control Devices.

Satisfying Local Needs and Desires

When selecting TCDs, alternatives satisfy local need and desires when the alternative meets objectives set by the community that are not quantified within the decision support tool. Based upon the survey of transportation professionals, potential agency objectives for selecting TCDs that could satisfy local need and desires while not being included in the decision support tool are:

- Support economic activity.
- Provide an environmentally sustainable transportation system.
- Meet other community expectations and preferences.

There are three reasons for not quantifying these three agency objectives within the decision support tool and instead consider them part of satisfying local needs and desires.

One reason are the values shown in Table 14, which show that the probability of a survey participant allocating more than zero points to the objective of economic activity, environmental sustainability, and other community expectations and preferences had probabilities of 69 percent, 66 percent, and 74 percent, respectively (see Table 14). These probabilities are statistically significantly lower than the probabilities of survey participants allocating more than zero points to safety or mobility (reliability and efficiency), which had probabilities of 99 percent and 97 percent, respectively.

A second reason for not evaluating environmental sustainability, economic activity, and other expectations and preferences as engineering benefits are the limited contribution they would have to the overall decision. This is because the average number of points allocated to each of these objectives is statistically significantly lower than the average number of points for safety and mobility (reliability and efficiency), see Table 15. Since each objectives effectiveness contribution within the proposed decision support tool is based upon the average point values in Table 15, these differences mean that the decision outcome for most decisions is unlikely to be influenced by changes in performance measures associated with sustainability, economic activity, and other expectations and preferences. For example, if all five factors were included, safety would contribute 42.0 effectiveness; mobility would contribute 27.7 effectiveness; sustainability would contribute 10.7 effectiveness; economic activity would contribute 9.9 effectiveness; and other expectations and preferences would contribute 9.8 effectiveness. These values mean moderate changes in sustainability, economic activity, or other expectations and preferences will have limit influence on the overall effectiveness score while even small changes in safety and mobility may have a lot of influence.

A third reason for not evaluating environmental sustainability, economic activity, and other expectations and preferences as engineering benefits is the unknown relationship between many TCDs and the performance measures associated with these objectives. Additionally, for the relationships that are known, the performance of measures for environmental sustainability and economic activity are tied in magnitude and direction to performance measures associated with mobility; these relationships are documented within Chapter 2 of the 2010 HCM (TRB 2011). For example, improved mobility often results in better economic outcomes and lower emissions. Therefore, in many TCD decisions, including environmental sustainability and economic activity as engineering benefits may place unintended emphasis on mobility, which changes the relative importance of safety in relation to mobility.

While the decision support tool developed in this report will not include an evaluation of environmental sustainability, economic activity, and other expectations and preferences as non-engineering benefits when selecting TCDs, these objectives could be engineering benefits for other types of transportation decisions. Additionally, as the profession evolves, these factors may become engineering benefits when selecting TCDs.

Meeting Engineering Principles and Practice

When selecting TCDs, alternatives meet engineering principles and practice when they comply with applicable statutes, regulations, and ordinances. For many TCDs, the MUTCD contains the applicable statutes, regulations, and ordinances. However, there could be applicable statutes, regulations, and ordinances that are not included within the MUTCD. For example, the MUTCD often does not contain information for experimental devices, does not contain information for devices with FHWA official interpretations, and does not contain information for devices with FHWA interim approval.

Providing Engineering Benefits

When selecting TCDs, an alternative provides an engineering benefit when it helps meet an agency objective that is driving the need for a TCD. Based upon the survey of transportation professionals, objectives for selecting TCDs that are driving the selection of TCDs are:

- Provide a safe transportation system for all users.
- Provide a reliable and efficient transportation system for all users.

This suggests a decision support tool for selecting TCDs should evaluate the safety and mobility (reliability and efficiency) benefits provided by a TCD alternative when determining engineering benefits.

Determining Traffic Control Device Alternatives

Based upon the presented framing of TCDs, a method for determining alternatives to evaluate within a decision support tool is to determine which alternatives would satisfy local needs and desires; and, then evaluating only the engineering benefits of these alternatives. A reason for evaluating only alternatives that the community finds acceptable is to avoid situations where the community rejects the alternative recommended in the analysis. Determining alternatives in this manner is similar to applying the concepts of context sensitive design or context sensitive solutions to the selection of TCDs (Neuman et al. 2002). In this case, and in context sensitive solutions, local needs and desires determine the context for the engineering evaluation.

Objectives for Evaluating Engineering Benefits

Based upon the survey of transportation professionals, objectives that should be included in a decision support tool for selecting TCDs are:

1. Provide a safe transportation system for all users.
2. Provide a reliable and efficient transportation system for all users.

There are three reasons that the objectives of environmental sustainability, economic activity, and other expectations and preferences are not included; they are:

- The lower probability of these objectives receiving more than zero points (Table 14).
- The low number of points they received when they did receive more than zero points (Table 15).
- An unknown relationship between many TCDs and these three objectives.

The probability of a transportation professional considering safety or mobility (efficiency and reliability) when selecting TCDs and the average number of points allocated to each objective given the transportation professional allocated more than zero points to the objective are provided in Table 24. For example, the probability of a transportation professional allocating more than zero points to providing a safe transportation system for all users is 99 percent; and, on average, a transportation professional that allocates more than zero points to providing a safe transportation system for all users would allocate 47 points to this objective.

Table 24. Probability of Including Safety and Mobility as Agency Objectives and Average Number of Points Given the Agency Objective is Included.

i	Objective	Prob.	A_Points_i
1	Provide a safe transportation system for all users	99 %	47
2	Provide a reliable and efficient transportation system for all users	97 %	31

i = Agency objective index number.
Prob. = The probability of a practitioner allocating more than zero points to the specific objective (values come from Table 14).
A_Points_i = Average number of points allocated to the objective by survey respondents allocating more than zero points to the objective (values comes from Table 15).

A method for determining the weight for each objective within a cost-effectiveness analysis is:

$$Obj\_W_i = A\_Points_i / \sum A\_Points_i \quad \text{Equation 4-9}$$

where:

- Obj_W_i = Weight for agency objective i.
- $Points_i$ = Average points for agency objective i selected from Table 24.
- $\sum A\_Points_i$ = Sum of average points for selected agency objectives (points for objectives not selected by the agency are not included in the sum).

In a situation where an agency elects to use Equation 4-9 to determine objective weights, the objective weights for safety and mobility (reliability and efficiency) are provided in Table 25. In Chapter V, researchers connect performance measures to each of these objectives.

Table 25. Objective Weights for Agency Objectives of Safety and Mobility.

i	Objective	A_Points_i	Obj_W_i*
1	Provide a safe transportation system for all users	47	60
2	Provide a reliable and efficient transportation system for all users	31	40
	$\sum A\_Points_i$	78	-

* Values may not sum to 100 due to rounding.

CHAPTER SUMMARY

In this chapter, researchers evaluated survey participant allocation of points to the objectives of safety, mobility, environmental sustainability, and economic activity. Based upon this evaluation, researchers find that a decision support tool for selecting TCDs should evaluate each alternatives contribution to the agency objectives of safety and mobility. Researchers also find that the decision support tool should not include an evaluation of each alternatives contribution to the potential agency objectives of environmental sustainability, economic activity, and other expectations and preferences. In Chapter VI, researchers use these findings to propose a decision support tool for use in selecting TCDs.

CHAPTER V

AGENCY PERFORMANCE MEASURES
FOR USE IN SELECTING TRAFFIC CONTROL DEVICES

In this chapter, researchers evaluate survey participant responses to questions in part three of the survey of transportation professionals. Questions in part three of the survey of transportation professionals asked participants to indicate which projects they would recommend implementing first based upon safety, mobility, and cost data. At the end of this chapter, based upon the findings of this evaluation and existing theory, researchers recommend performance measures for in the decision support tool developed within this report. In Chapter VI, researchers develop a decision support tool for use in selecting TCD using the performance measures presented within this chapter.

RANKING OF TRANSPORTATION ALTERNATIVES

In this section, researchers document the statistical methods used to evaluate participant responses to questions seven, eight, nine, and ten in the survey of transportation professionals. Researchers use these statistical methods to evaluate the following research questions:

5. Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, level of service, percent free-flow speed, and average vehicle speed.
6. Which safety performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include injury crashes, property damage only crashes, and total crashes.
7. How does a single fatal crash effect the ranking of transportation improvement alternatives?
8. Can compliance act as a surrogate measure of safety when ranking transportation improvement alternatives?
9. Do transportation professionals place increased value on avoiding losses versus achieving gains when selecting between three transportation improvement alternatives?

While this chapter considers all of these research questions, researchers chose to prioritize some of these research questions over other research questions. This means that researchers focus on two of these research questions while treating the other research questions as preliminary investigations. Specifically, researchers designed the survey to focus on research question number five and number six (evaluated using survey question number seven and number eight) while treating research questions seven, eight, and nine as preliminary investigations (evaluated using survey question number nine and number ten). This deliberate choice resulted in a situation where the data for investigating research question four and research question five are more robust than the data available to investigate research questions seven, eight, and nine.

Additionally, the structure of the survey chosen by the researchers resulted in correlation between cost, efficiency, and safety performance values for the data used to evaluate research question seven, eight, and nine. One reason this occurred was that the preliminary investigation uses data from only two of the six randomly assigned groups to investigate each of the three research questions. Specifically:

- Research question seven uses only data from survey question nine and question ten for survey participants randomly assigned to group one and group six.
- Research question eight uses only data from survey question nine and question ten for survey participants randomly assigned to group two and group four.
- Research question nine uses only data from survey question nine and question ten for survey participants randomly assigned to group three and group five.

For comparison, when evaluating research question five and research question six within survey question seven and survey question eight, researchers use all six groups.

A second reason that the correlation between independent variables occurred for data used in the preliminary investigations was that the variable values presented to participants within each of the two groups were always the same. While a better method for conducting this survey portion would have been to assign random variable values within a certain range, researchers did not foresee the resulting issue when developing the survey and elected to use predetermined variable values for each scenario. This issue does limit the value of the results from the preliminary investigations.

However, an advantage of the method used by the researchers is the ability to construct comparison models for the question nine and question ten data using data from questions seven and question eight. This is possible because mobility data were the same in question seven and question eight as they were in survey question nine and question ten; and, the safety data were often similar or changed slightly. In Table 26, researchers provides the group assignments for survey participants whose data are used to develop the best-fit models and the comparison group models when investigating research questions seven, eight, and nine. More information about the structure of the survey, group assignments, and specific variable values is available in Chapter III and in Appendix D.

Table 26. Group Assignment for Best-Fit Model and Comparison Model by Research Question Number.

Research Question Number	Group Assignment for Best-Fit Model	Group Assignment for Comparison Model
7	1 and 6	3 and 4
8	2 and 4	1 and 5
9	3 and 5	2 and 6

Methods

For the evaluations in this chapter, researchers use cumulative logistic regression, the deviance statistic, and 95th percentile confidence intervals for normal data. Researchers use the deviance statistic to select parameters for inclusion in the logistic regression model and the 95th percentile confidence intervals to compare the parameter estimates of different models. In the next four subsections, researchers describe cumulative logistic regression, the use of the deviance statistic when selecting parameters for statistical models, model parameter statistical significance, and the use of 95^{th} percentile confidence intervals to compare parameter estimates in different models.

Cumulative Logistic Regression

To evaluate survey participant's ranking of alternative projects, researchers used the VGAM package for the statistics program R to develop cumulative logistic regression models (R Development Core Team 2008; Yee 2010). Cumulative logistic regression models are a method for calculating the probability of a response less than or equal to a specific value for ordinal response data (Agresti 2007). A basic form for the cumulative logistic regression model is:

$$\text{Logit}(\ P(\text{rank} \le j)\ ) = \alpha_j + \beta_i \times X_i \qquad \text{Equation 5-1}$$

where:

Logit(p)	= ln(p) – ln(1-p).
p	= P(rank ≤ j).
ln	= The natural log function.
P(rank ≤ j)	= Probability of a project's ranking being less than j (for j = 1 or j = 2).
α_j	= Intercept value (for j = 1 or j = 2).
β_i	= ith parameter value.
X_i	= ith variable.
rank	= Participant ranking of the project (possible values of 1, 2 or 3).

Model Selection using Deviance Statistic

To select a best-fit model for each project ranking analysis, researchers use the deviance statistic to perform stepwise variable selection. The deviance statistic is an output from the statistics program. Stepwise variable selection begins with a model that includes fewer parameters and evaluates the improved fit provided by the inclusion of an additional variable (Agresti 2007). After finding the variable that provides the greatest statistically significant decrease in the deviance statistic, the evaluator adds this variable to the model and repeats the process until adding a parameter does not provide a statistically significant decrease in the deviance statistic. The difference in the deviance statistic between a model without a variable and a model with a variable is calculated as:

$$\text{Difference} = D_{without} - D_{with} \qquad \text{Equation 5-2}$$

where:

Difference	= Difference in the deviance statistic.
$D_{without}$	= Deviance statistic for the model without the new variable.
D_{with}	= Deviance statistic for the model with the new variable.

For large sample sizes, the difference in the deviance has a chi-square distribution with degrees of freedom equal to the difference in the degrees of freedom between each model (Agresti 2007). The minimum difference in deviance for various degrees of freedom and statistical significance based upon p-values less than 0.10 ($P < 0.10$) and p-values less than 0.05 ($P < 0.05$) are provided within Table 27 (Freedman, Pisani, and Purves 1998). For model selection within this report, researchers only add the next variable to the model if the statistical significance of the difference in deviance had a p-value of less than 0.10.

Table 27. Minimum Difference in Deviance by Difference in Degrees of Freedom and Statistical Significance (Freedman, Pisani, and Purves 1998).

Difference in Degrees of Freedom	P < 0.10	P < 0.05
1	2.71	3.84
2	4.60	5.99
3	6.25	7.82
4	7.78	9.49
5	9.24	11.07

For this report, researchers did not investigate the inclusion of cross terms in the logistic regression models. This was done because the survey data were not robust enough to provide useful interpretations if the cross terms were included.

Parameter Significance

Within this report, researchers begin building each best-fit model with the cost variable automatically being included within the model. In some situations, after including additional parameters, the cost parameter is no longer statistically significant. However, conceptually, the models make little sense if the cost variable is not included; therefore, to control for the role of cost within the cumulative logistic regression models, the cost variable is always included in best-fit model, even when it is not statistically significant.

The statistical significance of the cost variable and other variables can be determined using the z statistic, which the VGAM package for the statistics program R provides in the form of a z-value (Yee 2010). A z-value greater than 1.96 or less than -1.96 indicates a p-value less than 0.05; and, a z-value greater than 1.64 or less than -1.64 indicates a p-value less than 0.10 (Freedman, Pisani, and Purves 1998).

Comparison between Parameters in Different Models

Within the survey of transportation professionals, researchers designed the scenarios with a focus on constructing logistic regression models for survey question seven and survey question eight data in order to evaluate the following research questions:

5. Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, level of service, percent free-flow speed, and average vehicle speed.
6. Which safety performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include injury crashes, property damage only crashes, and total crashes.

This decision creates issues when evaluating the data from participant responses in questions nine and question ten because here is correlation between some of the cost, efficiency, and safety performance values that survey participants saw.

Therefore, when evaluating question nine and question ten data, researchers first develop a best-fit model based upon the responses to question nine and question ten. Then, researchers create comparison models using question seven and question eight data that contain the same mobility scenario combinations as those used to develop the best-fit model. These comparison models contain the same parameters as those in the best-fit model. The lone exception to this is the comparison model used to evaluate driver compliance as a measure of safety performance; in this case, researchers use injury crashes in the comparison model instead of driver yielding (a measure of compliance).

Researchers compare parameter estimates in the best-fit model to parameter estimates in the comparison model using 95th percentile confidence intervals. Researchers calculate the 95th percentile confidence intervals using the following equations:

$$\text{Upper Bound} = \text{Estimate} + 1.96 \times S_{ERROR} \qquad \text{Equation 5-3}$$

$$\text{Lower Bound} = \text{Estimate} + 1.96 \times S_{ERROR} \qquad \text{Equation 5-4}$$

where:

Estimate = Parameter estimate, an output from the statistics program.
S_{ERROR} = Standard error, an output from the statistics program.
Upper Bound = The upper boundary for the 95th percentile confidence interval.
Lower Bound = The lower boundary for the 95th percentile confidence interval.

If the confidence intervals do not overlap, there is statistically significant evidence that the parameter estimates are different. Otherwise, there is not enough evidence to suggest the parameter estimates are statistically significantly different.

Variables

Researchers classified the variables into six variable types, they are:

- Rank – the y variable in the analysis.
- Cost – models the difference in cost between alternatives.
- Volume – models the difference in automobile volume between alternatives.
- Efficiency – models the difference in automobile efficiency between alternatives.
- Safety – models the difference in crashes or yielding percentage between alternatives.

A reason researchers classified the variables into these six types is to indicate which variables are correlated with each other. In general, having correlated variables within a model results in over specification of the model. And, over specified models provide parameter estimates that are difficult to interpret (Agresti 2007). Therefore, when specifying models within this report, researchers include only one variable of each type within each logistic regression model. The variables evaluated within the ranking of project alternatives analysis and the variable type for each variable is provided within Table 28. Specific values for each variable presented to survey participants in each group are provided in Appendix C.

Table 28. Variables Evaluated to Identify Efficiency and Safety Performance Measures.

Variable	Definition[1]	Variable Type
rank	Project ranking (1, 2, or 3)	Rank
c_m_d	Difference in cost (in millions of dollars)	Cost
aadt_d	Difference in average annual daily traffic (in thousands of vehicles/day)	Volume
avg_s_d	Difference in average speed gained (mi/h)	Efficiency
del_d	Difference in total daily delay (in thousands of vehicle-hours/day)	Efficiency
x_ffs_d	Difference in percent free-flow speed (mi/h)	Efficiency
los_d	Difference in level of service gained (# of letter grades)	Efficiency
fatal_d	Difference in fatal crashes reduced (crashes per year)	Safety
inj_d	Difference in injury crashes reduced (crashes/year). In these models, fatal crashes are not a form of injury crash.	Safety
pdo_d	Difference in property damage only crashes reduced (crashes/year)	Safety
total_d	Difference in total crashes reduced (crashes per year)	Safety
y_d	Difference in percent yielding (percent)	Safety

[1] Difference is calculated as the difference between the alternative in question and the lowest costing alternative of the three options, which means all variables for the lowest costing alternative have values of 0.

Project Ranking Based Upon Efficiency and Crashes (Not Including Fatal Crashes)

The project ranking analysis investigating the effects of efficiency and crashes (not including fatal crashes) and uses participant responses to question seven and question eight from all 116 completed surveys. The data in these questions did not include project alternatives that reduced fatal crashes; project alternatives that reduce the number of fatal crashes occurred in question 9 and question 10 for participants assigned to group one and group six, researchers evaluate these data in a later section of this chapter. The purpose of this evaluation is to investigate the following research questions:

5. Which efficiency performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include total delay, level of service, percent free-flow speed, and average vehicle speed.
6. Which safety performance measure has a higher correlation with the ranking of transportation improvement alternatives? Potential performance measures include fatal crashes, injury crashes, property damage only crashes, and total crashes.

Within Table 29, researchers provide deviance statistics, degrees of freedom, and statistical improvement data for each considered model. Researchers added variables to the model based upon the deviance statistic. This process results in researchers adding variables to the model in the following order:

1. Difference in cost (c_m_d), always added first.
2. Difference in average annual daily traffic (aadt_d).
3. Difference in injury crashes (inj_d).
4. Difference in average speed gained (avg_s_d).

Researchers added the aadt_d variable when it was determined that a two-part model including aadt_d has the lowest deviance statistic and provided a statistically significant improvement over the cost only model (c_m_d); this created a model with two independent variables (c_m_d + aadt_d). Researchers then added the inj_d variable to the model with three independent variables because the three-part model including inj_d has the lowest deviance statistic and provides a statistical significant improvement; this created a model with three independent variables (c_m_d + aadt_d + inj_d). Researchers added avg_s_d to the model as the fourth and final variable because avg_s_d has the lowest deviance statistic and provides a statistical improvement over the model with only three independent variables. Researchers did not add a fifth variable because after including avg_s_d there was one of each variable type included within the model and the addition of any other variable would result in over specification.

Table 29. Selecting a Best Fit Safety, Mobility, and Cost Model for All Question 7 and Question 8 Data.

Model	Deviance	Degrees of Freedom	Statistical Improvement
c_m_d	1528.114	1389	-
c_m_d + total_d	1528.109	1388	No
c_m_d + los_d	1528.095	1388	No
c_m_d + x_ffs_d	1528.095	1388	No
c_m_d + pdo_d	1527.138	1388	No
c_m_d + avg_s_d	1526.473	1388	No
c_m_d + del_d	1526.126	1388	No
c_m_d + inj_d	1520.159	1388	p < 0.05
c_m_d + aadt_d	*1517.720*	*1388*	*p < 0.05*
c_m_d + aadt_d + los_d	1517.688	1387	No
c_m_d + aadt_d + x_ffs_d	1517.643	1387	No
c_m_d + aadt_d + pdo_d	1517.572	1387	No
c_m_d + aadt_d + del_d	1517.424	1387	No
c_m_d + aadt_d + total_d	1517.420	1387	No
c_m_d + aadt_d + avg_s_d	1515.492	1387	No
c_m_d + aadt_d + inj_d	*1511.772*	*1387*	*p < 0.05*
c_m_d + aadt_d + inj_d + del_d	1511.412	1386	No
c_m_d + aadt_d + inj_d + los_d	1509.002	1386	p < 0.10
c_m_d + aadt_d + inj_d + x_ffs_d	1508.858	1386	p < 0.10
c_m_d + aadt_d + inj_d + avg_s_d	**1505.928**	**1386**	**p < 0.05**
Best-fit model for efficiency and crashes (not including fatal crashes) based upon deviance statistic. *Best-fit model with that number of parameters included based upon deviance statistic.*			

The parameter estimates for the best-fit model is provided in Table 30. There are two intercepts because intercept 1 is for modeling rank equals one or less and intercept 2 is for modeling rank equals two or less. The parameter estimates indicate that as cost increases the probability of a survey participant ranking a project first or second decreases. Additionally, the probability of survey participant ranking a project first or second increases as average annual daily traffic increases, injury crash reductions increases, and average speed gained increases. To say it another way, as volume increases, safety improves, and efficiency improves the probability of a survey participant ranking a project first or second increases. All of the variables within the best-fit model are statistically significant.

Table 30. Parameter Estimates for Best-Fit Model Based Upon Efficiency and Non-Fatal Crashes.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-0.6356	0.1009	-6.2972	< 0.05
Intercept 2	0.7884	0.1026	7.6847	< 0.05
c_m_d	-0.0841	0.0256	-3.2793	< 0.05
aadt_d	0.0317	0.0109	2.8984	< 0.05
inj_d	0.1465	0.0481	3.0481	< 0.05
avg_s_d	0.0415	0.0177	2.3509	< 0.05

Using the values in Table 30, the probability of a project being ranked first and the probability of a project being ranked first or second can be determined from the following equations:

$$\text{Logit}(P(\text{rank} \le 1)) = -0.6356 - 0.0841 \times \text{c\_m\_d} + 0.0317 \times \text{aadt\_d} + 0.1465 \times \text{inj\_d} + 0.0415 \times \text{avg\_s\_d} \quad \text{Equation 5-3}$$

$$\text{Logit}(P(\text{rank} \le 2)) = 0.7884 - 0.0841 \times \text{c\_m\_d} + 0.0317 \times \text{aadt\_d} + 0.1465 \times \text{inj\_d} + 0.0415 \times \text{avg\_s\_d} \quad \text{Equation 5-4}$$

where:

- Logit(p) = ln(p) – ln(1-p).
- p = P(rank ≤ 1) or P(rank ≤ 2).
- ln = The natural log function.
- P(rank ≤ 1) = Probability of a project's ranking being less than or equal to 1.
- P(rank ≤ 2) = Probability of a project's ranking being less than or equal to 2.
- rank = Participant ranking of the project (possible values of 1, 2 or 3).
- c_m_d = Difference in cost (in millions of dollars).
- aadt_d = Difference in average annual daily traffic (in thousands of vehicles/day).
- inj_d = Difference in injury crashes reduced (crashes/year).
- avg_s_d = Difference in average speed gained (mi/h).

Based upon the z-values in Table 30, cost has the highest statistical significance when selecting between transportation alternatives. This conclusion in based upon the absolute value of the z-values for each of the parameters with the cost z-value having an absolute value of 3.2793, which is greater than injury crashes z-value of 3.0481. This finding suggests transportation decision makers consider cost when making their decisions. Therefore, a decision support tool for selecting TCDs should include a consideration of cost.

Pertaining to the research question on performance measures for transportation system efficiency; these results suggest average automobile speed has a higher correlation with the ranking of transportation alternatives than total daily delay, percent free-flow speed, or LOS. Researchers base this conclusion upon average automobile speed having the lowest deviance value when added to the model during model selection (see Table 29). This suggests considering average automobile speed within a decision support tool for selecting TCDs.

Pertaining to the research question on performance measures for transportation system safety; these results suggest reduction in injury crashes has a higher correlation with the ranking of transportation alternatives than total crashes and property damage only crashes. This conclusion is based upon injury cashes having a lower deviance value than total crashes and property damage only crashes when it was added to the model during model selection (see Table 29). This suggests considering number of injury crashes within a decision support tool for selecting TCDs.

Additionally, the inclusion of average annual daily traffic suggests transportation professionals prefer alternatives that help the largest number of system users (in this specific case, automobile users). This result suggests considering automobile volume or user volume within a decision support tool for selecting TCDs.

Project Ranking Based Upon Efficiency and Crashes (Including a Fatal Crashes)

The analysis of project ranking based upon efficiency and crashes (including fatal crashes) uses participant responses to question nine and question ten for participants assigned to group one or group six. Due to random assignment, group one has 26 completed surveys and group six has 28 completed surveys, for a total of 54 out of 116 completed surveys. The comparison model uses participant responses to question seven and question eight for participants assigned to group three and group four. Due to random assignment, group three has 16 completed surveys and group four has 15 completed surveys for a total of 31 out of 116 total completed surveys.

The purpose of this evaluation is to investigate the research question:

7. How does a single fatal crash effect the ranking of transportation improvement alternatives?

Based upon the deviance values, shown Table 31, researchers added variables to the model in the following order:

1. Difference in cost (c_m_d), always added first.
2. Difference in injury crashes (inj_d).
3. Difference in average speed gained (avg_s_d)

The logic used by researchers when adding variables to the best fit model is the same as the logic used to develop the best fit model for the evaluation of project ranking based upon efficiency and crashes (not including fatal crashes).

The parameter estimates for the best-fit model are provided within Table 32. The parameter estimates for the comparison model are shown in Table 33. Readers should note that the injury crash reductions in these models do not include reductions in fatal crashes. The scenario descriptions in Appendix D best illustrate why this is true; for each scenario, survey participants see changes in injury crashes and changes in fatal crashes in different and separate rows.

Table 31. Selecting Best-Fit Model Based Upon Efficiency and Crashes (Including a Fatal Crash).

Model	Deviance	Degrees of Freedom	Statistical Improvement
c_m_d	702.921	645	-
c_m_d + total_d	700.703	644	No
c_m_d + los_d	696.027	644	< 0.05
c_m_d + avg_s_d	695.023	644	< 0.05
c_m_d + x_ffs_d	694.986	644	< 0.05
c_m_d + aadt_d	692.016	644	< 0.05
c_m_d + del_d	683.201	644	< 0.05
c_m_d + fatal_d	682.829	644	< 0.05
c_m_d + pdo_d	662.779	644	< 0.05
c_m_d + inj_d	*659.978*	*644*	*< 0.05*
c_m_d + inj_d + aadt_d	659.942	643	No
c_m_d + inj_d + los_d	659.071	643	No
c_m_d + inj_d + del_d	658.566	643	No
c_m_d + inj_d + x_ffs_d	657.822	643	No
c_m_d + inj_d + avg_s_d	**645.315**	**643**	**< 0.05**
c_m_d + inj_d + avg_s_d + aadt_d	645.029	642	No
Best-fit model for efficiency and crashes (including a fatal crash) based upon deviance statistic. *Best-fit model with that number of parameters included based upon deviance statistic.*			

Table 32. Parameter Estimates for Best-Fit Model for Data with a Fatal Crash.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-0.7186	0.1715	-4.1899	< 0.05
Intercept 2	0.9120	0.1756	5.1946	< 0.05
c_m_d	-0.0162	0.0204	-0.7946	> 0.10
inj_d	1.0378	0.1565	6.6320	< 0.05
avg_s_d	0.1136	0.0302	3.7621	< 0.05

Table 33. Parameter Estimates for Question 7 and Question 8 Comparison Data to Evaluate the Effect of a Single Fatal Crash on Participant Responses.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-0.5867	0.2097	-2.7978	< 0.05
Intercept 2	0.8145	0.2141	3.8043	< 0.05
c_m_d	-0.0838	0.0542	-1.5457	> 0.10
inj_d	0.1353	0.1481	0.9136	> 0.10
avg_s_d	0.0145	0.0382	0.3789	> 0.10
The deviance for this model is 406.2 with 367 degrees of freedom.				

Using the values in Table 32, the probability of a project being ranked first and the probability of a project being ranked first or second can be determined from the following equations:

$$\text{Logit}(\ P(\text{rank} \leq 1)\ ) = -0.7186 - 0.0162 \times c\_m\_d + 1.0378 \times inj\_d + 0.1136 \times avg\_s\_d \qquad \text{Equation 5-5}$$

$$\text{Logit}(\ P(\text{rank} \leq 2)\ ) = 0.9120 - 0.0162 \times c\_m\_d + 1.0378 \times inj\_d + 0.1136 \times avg\_s\_d \qquad \text{Equation 5-6}$$

where:

Logit(p) = ln(p) – ln(1-p).
p = P(rank ≤ 1) or P(rank ≤ 2).
ln = The natural log function.
P(rank ≤ 1) = Probability of a project's ranking being less than or equal to 1.
P(rank ≤ 2) = Probability of a project's ranking being less than or equal to 2.
rank = Participant ranking of the project (possible values of 1, 2 or 3).
c_m_d = Difference in cost (in millions of dollars).
inj_d = Difference in injury crashes reduced (crashes/year).
avg_s_d = Difference in average speed gained (mi/h).

The equations created by the values in Table 33 should not be used to estimate the probability of project being ranked first or second; instead, this should be done using the best fit model for the question seven and question eight data, which is documented in Table 30. The purpose of the parameter estimates in Table 33 is the comparison of the parameter estimates in Table 33 to the parameter estimates in Table 32 using the confidence intervals shown in Table 34.

Table 34. Confidence Intervals for Best-Fit and Comparison Models to Investigate the Effect of a Single Fatal Crash on Participant Responses.

Parameter	Best Fit Model (with a Fatal Crash)		Comparison Model (Without a Fatal Crash)	
	Upper Bound	Lower Bound	Upper Bound	Lower Bound
c_m_d	0.0238	-0.0366	0.0224	-0.1900
inj_d	1.3445	0.7311	0.4256	-0.1550
avg_s_d	0.1763	0.0544	0.0894	-0.0604

The confidence intervals for cost and average speed overlap; this means there is no statistically significant difference in the way participants responded to those variables between the scenarios with a fatal crash (questions nine and ten) and the scenarios without a fatal crash (questions seven and eight).

The confidence intervals for injury crashes do not overlap, which means there is a statistically significant difference in the way participants responded to the scenarios with a fatal crash and the comparison scenarios that did not include a fatal crash. According to the parameter estimates, participants placed increased emphasis on injury crashes (or safety in general), when one of the alternatives mitigated a fatal crash. This finding suggests the presence of a fatal crash shifts the way transportation professionals make decisions when selecting between project alternatives.

Pertaining to the research question on the effect of fatal crashes on the ranking of project alternatives, these data suggest fatal crashes increase the emphasis on safety when ranking project alternatives. This suggests considering the number of fatal crashes and the number of injury crashes as performance measures within a decision support tool for selecting TCDs. This conclusion about the effect of fatal crashes is based upon the comparison of the confidence intervals in Table 34. The conclusion about the effect of injury crashes is based upon the model in Table 30, which researchers presented in an early section of this chapter.

Alternatively, based upon concepts included within prospect theory, an increased emphasis on safety when a fatal crash is present may indicate a bias towards safety when fatal crashes are involved. While this report does not have sufficient data to deny or support this alternative conclusion, this possible interpretation present a research opportunity that deserves further attention.

Project Ranking Based Upon Efficiency and Driver Compliance

The analysis of project ranking based upon efficiency and driver compliance (quantified as driver yielding within the survey of transportation professionals) uses participant responses to question nine and question ten for participants assigned to group two or group four. Due to random assignment, group two had 18 completed surveys and group four had 15 completed surveys, for a total of 33 out of 116 total surveys. The comparison model uses participant responses to question seven and question eight for participants assigned to group one and group five. Due to random assignment, group one has 26 completed surveys and group five has 13 completed surveys, for a total of 29 out of 116 total completed surveys.

The purpose of this evaluation is to investigate the research question:

8. Can compliance act as a surrogate measure of safety when ranking transportation improvement alternatives?

Based upon the deviance values, shown Table 35, researchers added variables to the model in the following order (note that yielding was the measure for compliance):

1. Difference in cost (c_m_d), always added first.
2. Difference in driver yielding (y_d).
3. Difference in total delay reduced (del_d)

The logic used by researchers when adding variables to the best-fit model is the same as the logic used to develop the best fit model for the evaluation of project ranking based upon efficiency and crashes (not including fatal crashes).

The parameter estimates for the best-fit model are provided within Table 36. The parameter estimates for the comparison model are shown in Table 37. In this evaluation, the comparison model does not include driver yielding (a measure of compliance) because the survey did not present participants with yielding data within in question seven and question eight. Instead, the comparison model includes injury crashes. Researchers do this to determine if compliance can serve in the same capacity as crashes within a decision support tool for selecting TCDs.

Table 35. Selecting Best-Fit Model Based Upon Efficiency and Driver Yielding.

Model	Deviance	Degrees of Freedom	Statistical Improvement
c_m_d	432.486	393	-
c_m_d + aadt_d	431.454	392	No
c_m_d + avg_s_d	431.381	392	No
c_m_d + los_d	430.266	392	No
c_m_d + del_d	429.978	392	No
c_m_d + x_ffs_d	429.844	392	No
c_m_d + y_d	*413.727*	*392*	*< 0.05*
c_m_d + y_d + los_d	413.401	391	No
c_m_d + y_d + x_ffs_d	413.325	391	No
c_m_d + y_d + avg_s_d	413.119	391	No
c_m_d + y_d + aadt_d	408.113	391	< 0.05
c_m_d + y_d + del_d	**405.727**	**391**	**< 0.05**
c_m_d + y_d + del_d + aadt_d	404.315	390	No
Best-fit model for efficiency and driver yielding based upon deviance statistic. *Best-fit model with that number of parameters included based upon deviance statistic.*			

Table 36. Parameter Estimates for Best-Fit Model Based Upon Efficiency and Driver Yielding.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-1.3897	0.2345	-5.9264	< 0.05
Intercept 2	0.1735	0.2099	0.8265	> 0.10
c_m_d	0.1675	0.0844	1.9853	< 0.05
y_d	0.0960	0.0207	4.6253	< 0.05
del_d	-2.1625	0.7229	-2.9914	< 0.05

Table 37. Parameter Estimates for Question 7 and Question 8 Comparison Data to Evaluate if Driver Compliance Can be a Surrogate Measure for Safety.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-0.7535	0.1731	-4.3538	< 0.05
Intercept 2	0.6750	0.1715	3.9348	< 0.05
c_m_d	0.0731	0.0687	1.0631	> 0.10
inj_d	0.2025	0.1032	1.9616	< 0.05
del_d	-0.9022	0.5764	-1.5652	> 0.10
The deviance for this model is 505.5 with 463 degrees of freedom.				

Because the parameter values in Table 36 indicate increased cost is a good thing and decreased delay is a bad thing, this model should not be used to determine the probability of a project being ranked first or second. Additionally, the purpose of the values in Table 37 is to construct the confidence intervals in Table 38, which means the values in Table 37 should not be used to estimate the probability of a project being ranked first or second.

Table 38. Confidence Intervals for Best-Fit and Comparison Models to Investigate the use of Driver Compliance as a Performance Measure.

Parameter	Best Fit Model (with a Fatal Crash)		Comparison Model (Without a Fatal Crash)	
	Upper Bound	Lower Bound	Upper Bound	Lower Bound
c_m_d	0.3329	0.0021	0.2078	-0.0616
y_d	0.1366	0.0554	NA	NA
inj_d	NA	NA	0.4048	0.0002
del_d	-0.7456	-3.5793	0.2275	-2.0319
NA = Not applicable because this parameter was not included in this mode.				

An important limitation of the parameter estimates within Table 36 and Table 37 is that the estimate for cost is positive and the estimate for difference in delay reduction is negative. These parameter signs indicate that as cost increases the probability of a participant ranking the project first increases; and, as difference in total delay reduced increases the probability of a participant ranking the project first decreases. These results are counter intuitive (higher costs should be worse and lower delay should be better), which suggests there is correlation among the variables within the model. Upon further review, researchers realized that the project with the lowest yielding rate and lowest reduction in crashes also had the lowest reductions in delay, which creates correlation between the yielding rate and total delay variables and this limits the usefulness of the data from this analysis. Researchers did not catch this mistake before sending out the survey and collecting the data.

While the presence of correlation in the variables creates issues when using these models to quantify the influence of compliance (driver yielding) for making decisions using the model develop from these data, it is still possible to investigate the research question using the confidence intervals presented in Table 38. The research question asks if compliance (driver yielding) can serve as a surrogate measure of safety. For this to be true, the models need to show that:

- The parameter estimate for driver yielding and injury crashes are statistically significantly different from zero.
- The sign of the parameter estimates for driver yielding and injury crashes are the same.
- There is not statistically significant evidence that the other parameter estimates are different (this means the 95th percentile confidence intervals for the other parameters overlap).

In Table 38, the confidence intervals indicate that the parameter estimates for driver yielding in the best-fit model and injury crashes in the comparison model are statistically significantly different from zero. Additionally, the parameter estimates are both positive. Furthermore, the confidence intervals cost and difference in delay overlap, which means there is not enough statistical evidence to suggest survey participants differed in how they treat these parameters in their responses to question seven and question eight versus question nine and question ten.

Pertaining to the research question, these findings suggest compliance has potential as a surrogate measure of safety. While the evidence for this conclusion within this report are not strong, it does suggest there is value in the profession investigating this relationship further using data that are more robust. However, given that research used to support changes to the MUTCD have used compliance to measure device effectiveness (see Fitzpatrick et al. 2014), researchers move forward in this report presuming that compliance is a legitimate surrogate measure of safety and compliance has potential as a performance measure within a decision support tool for selecting TCDs.

Project Ranking Based Upon Loss Avoidance

The analysis of project ranking based upon loss avoidance uses responses to question nine and question ten for participants assigned to group two or group four. Due to random assignment, group three has 16 completed surveys and group five has 13 completed surveys, for a total of 29 out of 116 completed surveys. The comparison model uses participant responses to question seven and question eight for participants assigned to group two and group six. Due to random assignment, group two has 18 completed surveys and group six has 28 completed surveys, for a total of 46 out of 116 completed surveys.

The purpose of this evaluation is to investigate the research question:

9. Do transportation professionals place increased value on avoiding losses versus achieving gains when selecting between three transportation improvement alternatives?

Based upon the deviance values, shown Table 39, researchers added variables to the model in the following order:

1. Difference in cost (c_m_d), always added first.
2. Difference in total delay reduced (del_d).

The logic used by researchers when adding variables to the best-fit model is the same as the logic used to develop the best fit model for the evaluation of project ranking based upon efficiency and crashes (not including fatal crashes).

Table 39. Selecting Best-Fit Model for Loss Avoidance Questions.

Model	Deviance	Degrees of Freedom	Statistical Improvement
c_m_d	382.250	345	-
c_m_d + avg_s_d	382.247	344	No
c_m_d + inj_d	381.604	344	No
c_m_d + pdo_d	381.604	344	No
c_m_d + total_d	381.604	344	No
c_m_d + x_ffs_d	381.688	344	No
c_m_d + los_d	381.044	344	No
c_m_d + del_d	**378.732**	**344**	**< 0.10**
c_m_d + del_d + inj_d	378.327	343	No
c_m_d + del_d + pdo_d	378.326	343	No
c_m_d + del_d + total_d	378.326	343	No
Best-fit model for loss avoidance based upon deviance statistic. *Best-fit model with that number of parameters included based upon deviance statistic.*			

The parameter estimates for the best-fit model are provided within Table 40. . The parameter estimates for the comparison model are shown in Table 41. It should be noted that AADT did not vary between scenarios within the data used to develop the best-fit and comparison models, which means it could not be included within these models as a variable

Table 40. Parameter Estimates for Best-Fit Model for Loss Avoidance Questions.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-0.8578	0.2423	-3.5397	< 0.05
Intercept 2	0.5519	0.2367	2.3322	< 0.05
c_m_d	-0.1144	0.0690	-1.6573	< 0.10
del_d	1.3066	0.6927	1.8864	< 0.10

Table 41. Parameter Estimates for Question 7 and Question 8 Comparison Data to Evaluate if Loss Avoidance Effects the Ranking of Project Alternatives.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept 1	-0.4315	0.1758	-2.4549	< 0.05
Intercept 2	0.9786	0.1843	5.3112	< 0.05
c_m_d	0.0410	0.0647	0.6346	> 0.10
del_d	-0.9261	0.4686	-1.9765	< 0.05
The deviance for this model is 505.5 with 463 degrees of freedom.				

Because the parameter estimates for neither cost nor delay within Table 40 have a p-value less than 0.05, this model should not be used to determine the probability of a project being ranked first or second. Additionally, the purpose of the values in Table 41 is to construct the confidence intervals in Table 42, which means the values in Table 41 should not be used to estimate the probability of a project being ranked first or second. As indicated earlier, the positive parameter estimate for cost and negative parameter estimate for delay within the comparison model are the result of the preliminary investigations using data from only two of the six groups that participants could be randomly assigned to.

Table 42. Confidence Mode for Best-Fit and Comparison Models to Investigate the Effect of Loss Avoidance on Participant Responses.

Parameter	Best Fit Model (with a Fatal Crash)		Comparison Model (Without a Fatal Crash)	
	Upper Bound	Lower Bound	Upper Bound	Lower Bound
c_m_d	0.0208	-0.2496	0.1678	-0.0858
del_d	2.6643	-0.0511	-0.0076	-1.8446

In Table 42, the confidence intervals for the cost parameter estimate in the best-fit and comparison models overlap; additionally, the confidence intervals for the delay parameter estimate in the best-fit and comparison models overlap. The confidences intervals overlapping suggest there is no statistically significant evidence that the parameter estimates in the best-fit and comparison models are different.

Pertaining to the research question on the influence of loss aversion on project ranking, these data do not provide evidence that transportation professionals place increased emphasis on projects that avoided the greatest quantity of loss. This suggests, based upon data in this analysis, that it might not be appropriate to incorporate the concepts of loss aversion within a decision support tool for selecting TCDs. However, since the data used in this analysis could be more robust, it could be useful to investigate this concept in more detail using alternative methods.

Summary of Project Ranking Analysis

An evaluation of the project ranking analysis indicates:

- A decision support tool for use in selecting TCDs should include a consideration of cost.
- Average automobile speed has a higher correlation with the ranking of transportation improvement alternatives than total delay, LOS, and percent free-flow speed.
- Injury crashes has a higher correlation with the ranking of transportation improvement alternative than total crashes and property damage only crashes.
- Transportation professionals prefer alternatives that help the largest number of users.
- The presence of a fatal crash and the ability to mitigate a fatal crash increases the emphasis on safety when ranking project alternatives. This increased emphasis could indicate bias towards safety when fatal crashes are part of the decision.

- Compliance has potential as a surrogate measure of safety.
- This report did not find evidence that transportation professionals place increased emphasis on projects that avoid the greatest quantity of loss.

These findings suggests considering the following as potential performance measures within a decision support tool for selecting TCDs.

- Average automobile speed (mi/h) as a measure of efficiency.
- Total automobile delay (vehicle-hours/weekday) as a measure of efficiency.
- Injury crashes (number/year) as a measure of safety.
- Fatal crashes (number/year) as a measure of safety.
- Compliance or driver yielding (percent yielding) as a measure of safety and alternative to crashes.

Alternatively, similar but easier to obtain performance measures that quantify changes in these quantities should be considered as well. For example, calculating expected injury and fatal crashes can be data intensive; however, crash modification factors (CMFs) and crash reduction factors (CRFs) are available within the HSM and safety literature and might be more useful than expected differences in injury and fatal crashes when selecting TCDs.

Additionally, the ranking of project alternatives analysis suggest considering cost and the number of users benefited within a decision support tool for selecting TCDs. While these findings do not influence the discussion in the remainder of this chapter, it does effect the decision support tool developed in the next chapter.

DECISION SUPPORT TOOL IMPLICATIONS

The purpose of this chapter is to use findings from the survey of transportation professionals and existing theory to connect performance measures to the agency objectives identified at the end of Chapter IV. As a reminder, the agency objectives are:

1. Provide a safe transportation system for all users.
2. Provide a reliable and efficient transportation system for all users.

This section of this chapter connects performance measures to these two objectives. Within this section, researchers indicate the aspects of the performance measures that come from the results of the survey of transportation professionals and the aspects that come from existing theory.

To move forward with assigning performance measures to the two objectives, the phrase “all users” needs a more specific definition. For this report, researchers limit the phrase “all users” to automobile users, bicycle users, and pedestrian users. While there are other user groups, researchers limit this report to these groups because these groups most often receive benefits and disbenefits associated with the selection of TCDs.

The remainder of this chapter uses the project ranking analysis results and existing theory to specify performance measures for use in a decision support tool for use in selecting TCDs. This section first looks at performance measures for evaluating safety benefits and then looks at performance measures for evaluating mobility benefits.

Performance Measures for Evaluating Safety Benefits or Disbenefits

While existing theory and the survey of transportation professionals supports the use of crashes in the evaluation of safety benefits, the survey of professional professionals also suggests compliance has potential as a surrogate measure of safety when selecting TCDs. Therefore, researchers recommend four potential safety performance measures for use within a decision support tool for selecting TCDs, they are:

- Crash reduction factor (fatal and injury crashes).
- Automobile user compliance.
- Bicycle user compliance.
- Pedestrian user compliance.

Crash reduction factors (CRFs) are a means for quantifying a reduction in fatal and injury crashes. In general, CRFs are the percent reduction in crashes expected from an alternative. Researchers base the decision to use CRFs as a performance measure based upon existing theory and the survey of transportation professionals. Researchers base the decision to limit the application of CRF to injury crashes based upon the survey of transportation professionals finding that reductions in injury crashes have a higher correlation with the ranking of transportation alternatives than total crashes and property damage only crashes. Researchers include fatal crashes in addition to injury crashes based upon the survey of transportation professionals finding that the presence of a fatal crash and ability to mitigate a fatal crash increases the emphasis on safety when ranking transportation improvement alternatives.

In this report, researchers define compliance as a TCDs ability to elicit a desired response from a transportation system user. For example, a desired response from automobile and bicycle users at a stop sign is for automobile users and bicycle users to stop before proceeding through the intersection (a form of yielding); additionally, a desired response from an automobile following a curve warning sign is for an automobile user to travel through the curve at an appropriate speed. Researchers base the decision to use automobile compliance, bicycle compliance, and pedestrian compliance as performance measures because existing theory suggests transportation agencies are making some TCD decisions based upon compliance; additionally, the survey of transportation professionals provides some evidence that the role compliance is playing in these decisions is similar to the role played by crashes. While the evidence within this report is not definitive, it does suggest moving forward with a decision support tool that considers compliance as a surrogate for crashes when evaluating safety. Then, future research efforts can evaluate its use using alternative methods to discover evidence that is more definitive or disprove its usefulness within a decision support tool for selecting TCDs.

The next two sections provide methods for quantifying the effectiveness contribution of CRFs for fatal and injury crashes, automobile compliance, bicycle compliance, and pedestrian compliance for use within a decision support tool for selecting TCDs.

Crash Reduction Factor (Fatal and Injury Crashes)

It is possible to calculate CRFs using CMFs, which are available in the *HSM* and safety research literature. Alternatively, it is possible to calculate a CRF if the number of crashes before implementing the alternative is known and the expected number of crashes after implementing the alternative is estimated. A potential means for quantify performance level for CRF within a decision support tool for selecting TCDs is provided Table 43. Researchers did not use existing theory or the survey of transportation professionals to determine the effectiveness scores associated with each CRF percentage. Future research efforts could collect data that helps transportation professionals refine these values.

Table 43. Performance Levels for Crash Reduction Factor.

<table>
<tr><td colspan="3">Description:
Crash reduction factor is the expected reduction in the percentage of crashes as the result of implementing an alternative.</td></tr>
<tr><td colspan="3">Calculation:
$CRF = 100 \times (1 - CMF)$ or $CRF = 100 \times [\, B\_Crashes - A\_Crashes \,] / B\_Crashes$

where:
CRF = Fatal and injury crash reduction factor associated with implementing an alternative (percent).
CMF = Fatal and injury crash modification factor associated with implanting an alternative. .
B_Crashes = Number of fatal and injury crashes before implementing an alternative.
A_Crashes = Estimated number of fatal and injury crashes after implementing an alternative.</td></tr>
<tr><td rowspan="12">Performance Level:</td><td>Crash Reduction Factor</td><td>Effectiveness Score</td></tr>
<tr><td>≤ 00 %</td><td>0</td></tr>
<tr><td>≥ 00 %</td><td>1</td></tr>
<tr><td>≥ 10 %</td><td>2</td></tr>
<tr><td>≥ 20 %</td><td>3</td></tr>
<tr><td>≥ 30 %</td><td>4</td></tr>
<tr><td>≥ 40 %</td><td>5</td></tr>
<tr><td>≥ 50 %</td><td>6</td></tr>
<tr><td>≥ 60 %</td><td>7</td></tr>
<tr><td>≥ 70 %</td><td>8</td></tr>
<tr><td>≥ 80 %</td><td>9</td></tr>
<tr><td>≥ 90 %</td><td>10</td></tr>
</table>

Expected User Compliance

Researchers provide potential a potential method for quantifying the performance level for automobile compliance within in Table 44, a method for pedestrian compliance in Table 45, and a method for bicycle compliance in Table 46. While compliance in the before condition must be measured, expected compliance in the after condition could be based upon values found in the research literature. Researchers did not use existing theory or the survey of transportation professionals to determine the effectiveness scores associated with each use compliance percentage. Future research efforts could collect data that helps transportation professionals refine these values.

Table 44. Performance Levels for Automobile User Compliance.

Description:
Automobile user compliance is the percentage of automobiles performing a desired response. For automobile users, potential desired responses are:

- Yielding, stopping, or speed selection.
- Appropriate turning movement (for tuning movement restrictions).
- Appropriate lane changes (for lane change restrictions).

Calculation:
Auto_Compliance = [Auto_Comply × 100] / [Auto_Comply + Auto_No_Comply]

where:
Auto_Compliance = Percentage of automobile users complying with a traffic control device.
Auto_Comply = Number of automobile users complying with a traffic control device.
Auto_No_Comply = Number of automobile users not complying with a traffic control device.

Performance Level:	**Automobile User Compliance**	**Score**
	≤ 05 %	0
	≥ 05 %	1
	≥ 15 %	2
	≥ 25 %	3
	≥ 35 %	4
	≥ 45 %	5
	≥ 55 %	6
	≥ 65 %	7
	≥ 75 %	8
	≥ 85 %	9
	≥ 95 %	10

Table 45. Performance Levels for Pedestrian User Compliance.

Description: Pedestrian user compliance is the percentage of pedestrian users performing a desired response. For pedestrian users, potential desired responses are: • Yielding or stopping. • Appropriate crossing (at a crosswalk as opposed to outside of a crosswalk).		
Calculation: Ped_Compliance = [Ped_Comply × 100] / [Ped_Comply + Ped_No_Comply] where: Ped_Compliance = Percentage of pedestrian users complying with a traffic control device. Ped_Comply = Number of pedestrian users complying with a traffic control device. Ped_No_Comply = Number of pedestrian users not complying with a traffic control device.		
Performance Level:	**Pedestrian User Compliance**	**Score**
	≤ 05 %	0
	≥ 05 %	1
	≥ 15 %	2
	≥ 25 %	3
	≥ 35 %	4
	≥ 45 %	5
	≥ 55 %	6
	≥ 65 %	7
	≥ 75 %	8
	≥ 85 %	9
	≥ 95 %	10

Table 46. Performance Levels for Bicycle User Compliance.

<table>
<tr><td colspan="3">Description:
Bicycle user compliance is the percentage of bicycle users performing a desired response. For bicycle users, potential desired responses are:
• Yielding, stopping, or speed selection (for different speed limits).
• Appropriate turning movement (for tuning movement restrictions).
• Appropriate lane changes (for lane change restrictions).</td></tr>
<tr><td colspan="3">Calculation:
Bike_Compliance (Percent) = [Bike_Comply × 100] / [Bike_Comply + Bike_No_Comply]

where:
Bike_Compliance = Percentage of bicycle users complying with a traffic control device.
Bike_Comply = Number of bicycle users complying with a traffic control device.
Bike_No_Comply = Number of bicycle users not complying with a traffic control device.</td></tr>
<tr><td rowspan="12">Performance Level:</td><td>Bicycle User Compliance</td><td>Score</td></tr>
<tr><td>≤ 05 %</td><td>0</td></tr>
<tr><td>≥ 05 %</td><td>1</td></tr>
<tr><td>≥ 15 %</td><td>2</td></tr>
<tr><td>≥ 25 %</td><td>3</td></tr>
<tr><td>≥ 35 %</td><td>4</td></tr>
<tr><td>≥ 45 %</td><td>5</td></tr>
<tr><td>≥ 55 %</td><td>6</td></tr>
<tr><td>≥ 65 %</td><td>7</td></tr>
<tr><td>≥ 75 %</td><td>8</td></tr>
<tr><td>≥ 85 %</td><td>9</td></tr>
<tr><td>≥ 95 %</td><td>10</td></tr>
</table>

Performance Measures for Evaluating Mobility Benefits or Disbenefits

This section documents potential performance measures for evaluating mobility benefits or disbenefits based upon existing literature. In general, researchers do not use the ranking of transportation alternatives analysis to suggest performance measures for selecting TCD alternatives. One reason for this is that the survey of transportation professionals investigated only performance measures for automobile mobility and did not investigate performance measures for bicycle or pedestrian mobility. A second reason for this is that the performance measures found within existing theory come from more robust data sources than the data used within the ranking of transportation alternatives analysis.

In general, the ranking of transportation alternatives evaluation primarily demonstrated that transportation professionals do consider mobility in addition to safety and cost when making transportation decisions. If this were not true, the parameter estimate for mobility would not have been statistically significant. This finding provides further support to have mobility as an objective within the decision support tool. However, it is better to use performance measures from existing theory for performance measures within the decision support tool because data used to develop existing theory are more robust than data contained within this report.

For evaluating automobile mobility, researchers propose the use of one subjective performance measure or the use of one of three possible quantifiable performance measures. For evaluating bicycle mobility, researchers propose the use of one subjective performance measure or the use of one of two possible quantifiable performance measures. For evaluating pedestrian mobility, researchers propose the use of one subjective performance measure or the use of one of two possible quantifiable performance measures.

For all three transportation user groups, the potential quantifiable performance measures come from either the *2000 HCM* or the *2010 HCM*. While the performance measures within the 2010 HCM use data that are more robust, these methods are also data intensive. Therefore, there are situations were using less data intensive methods might be preferred; it is for these situations that researchers suggest the use of performance measures from the 2000 HCM.

One reason for using a less data intensive measure could be the cost of the TCD alternatives an agency is considering. For example, it may not be reasonable for an agency to spend thousands of dollars to quantify the effects of a $500 sign; in this situation, a less data intensive measure is desirable and sufficient. Another reason for using the less data intensive measures could be that the expected quantifiable performance of an alternative is unknown; it is for these situations that researchers provide the subjective performance measures.

The next three sections document the potential subjective and quantifiable mobility performance measures for automobile mobility, bicycle mobility, and pedestrian mobility. In each of these sections, researchers document where the performance measures come from and how the performance levels for effectiveness were determined.

Automobile Mobility

Potential performance levels for use in a subjective evaluation of automobile mobility are provided in Table 47; potential performance levels for use in an objective evaluation of automobile mobility are provided in Table 48. Objective performance measures include:

- Automobile control delay (s/veh), lower is better and higher is worse.
- Automobile spatial stop-rate (stops/mi), lower is better and higher is worse.
- Automobile percent free-flow speed (percent), higher is better and lower is worse.

Table 47. Subjective Performance Levels for Automobile Mobility.

Description: This is a subjective method for determining performance levels for automobile mobility.	
Performance Level	
Score	**Automobile Mobility**
0	Automobile mobility with this alternative is undesirable.
1	
2	
3	
4	
5	Automobile mobility with this alternative is neither desirable nor undesirable.
6	
7	
8	
9	
10	Automobile mobility with this alternative is desirable.

Table 48. Objective Performance Levels for Automobile Mobility.

Description:
This is an objective method for determining performance levels for automobile mobility.
Objective factors include:

- Control delay, seconds / vehicle (fewer seconds / vehicle is better).
- Percent free-flow speed, percent (higher percentage is better).
- Spatial stop-rate, stops / mile (fewer stops / mile is better).

Performance Level			
Score	**Automobile Control Delay**	**Percent Free-Flow Speed**	**Spatial Stop-Rate**
0	≥ 270 s / veh	≤ 40 percent	> 10.2 stops / mi
1	-	-	-
2	< 135 s /veh	-	-
3	-	-	-
4	< 80 s / veh	-	-
5	-	> 50 percent	< 6.4 stops / mi
6	< 55 s / veh	-	-
7	-	-	-
8	< 35 s / veh	-	-
9	-	-	-
10	< 20 s / veh	> 67 percent	< 2.4 stops / mi

Automobile control delay is useful for evaluating the selection of TCDs at intersections and this performance measure comes from the *2010 HCM*. Many of the performance level values, shown in Table 48, come from the *2010 HCM* and are associated with the maximum control delay values for LOS B (20 s/veh), LOS C (35 s/veh), LOS D (55 s/veh), and LOS E (80 s/veh) at traffic signals. Additionally, the value of 270 s/veh comes from research that suggests congestion causing delay greater than 270 s/trip may have a negative effect on economic activity within a region (Sweet 2014). The expected automobile control delay can be determined using methods within the *2010 HCM* or simulation software.

Automobile percent free-flow speed is useful for evaluating the selection of TCDs along street segments and corridors; this performance measure comes from the *2010 HCM*. The values shown in Table 48 for percent free-flow speed are the minimum percent free-flow speeds from the *2010 HCM* for LOS B (67 percent), LOS C (50 percent), and LOS D (40 percent) along urban street segments. The expected automobile percent free-flow speed can be determined using methods within the 2010 HCM or simulation software.

Automobile spatial stop-rate is useful for evaluating the selection of TCDs along urban street segments. This performance measure is an alternative method for evaluating automobile mobility along urban streets segments; transportation professionals can find it at the end of Chapter 17 of the 2010 HCM; researchers developed as part of the research documented within NCHRP Report 616 (Dowling et al. 2008). The research within NCHRP Report 616 actually suggests that spatial stop-rate could be a better predictor of the perceived performance of a facility from the automobile user perspective than percent free-flow speed; however, the *2010 HCM* methodology still uses percent free-flow speed to determine LOS. The values shown in Table 48 for spatial stop-rate are the maximum values for LOS B (2.4 stops/mi), LOS C (6.4 stops/mi), and LOS D (10.2 stops/mi) along urban street segments; these values were calculated using the the methodology within NCHRP Report 616 (Dowling et al. 2008). The expected automobile spatial stop-rate can be determined using methods within the 2010 HCM or simulation software.

Pedestrian Mobility

Potential performance levels for use in a subjective evaluation of pedestrian mobility are provided in Table 49; potential performance measures for use in an objective evaluation are provided in Table 50. Objective performance measures include:

- Pedestrian control delay (s/crossing), lower is better and higher is worse.
- Pedestrian LOS score (number), lower is better and higher is worse.

Table 49. Subjective Performance Levels for Pedestrian Mobility.

Description: This is a subjective method for determining performance levels for pedestrian mobility.	
Performance Level	
Score	**Pedestrian Mobility**
0	Pedestrian mobility with this alternative is undesirable.
1	
2	
3	
4	
5	Pedestrian mobility with this alternative is neither desirable nor undesirable.
6	
7	
8	
9	
10	Pedestrian mobility with this alternative is desirable.

Table 50. Objective Performance Levels for Pedestrian Mobility.

Description: This is an objective method for determining performance levels for pedestrian mobility. Objective factors include: • Pedestrian control delay, seconds / crossing (fewer seconds / crossing is better). • Pedestrian level of service score, number (lower values are better)		
Performance Level		
Score	**Pedestrian Control Delay**	**Pedestrian Level of Service Score**
0	> 30 s / crossing	> 4.25
1	-	-
2	-	-
3	-	-
4	-	-
5	< 20 s / crossing	< 3.50
6	-	-
7	-	-
8	-	-
9	-	-
10	< 10 s / crossing	< 2.75

Pedestrian control delay is useful for evaluating the selection of TCDs at intersections and the performance level values comes from the 2000 HCM. The values shown in Table 49 for pedestrian control delay are the maximum values for LOS B (10 s/crossing), LOS C (20 s/crossing), and LOS D (30 s/crossing) at urban intersections in the 2000 HCM. In the 2010 HCM, pedestrian control delay became part of the equation used to determine pedestrian LOS score, which considers other factors such as the presence of sidewalks and pedestrian crossing distance; however, these calculations can be data intensive and may not provide useful information when evaluating some TCD alternatives. It is possible to estimate pedestrian control delay using methods within the 2010 HCM or simulation software.

Pedestrian LOS score (a numeric value used to determine LOS letter grades within the *2010 HCM*) is useful for evaluating the selection of TCDs along urban street segments and at intersections. The values shown in Table 49 are the maximum value for LOS B (2.75), LOS C (3.50), and LOS D (4.25) along urban street segments, which are found within the 2010 HCM. It is possible to estimate pedestrian LOS score using methods documented within the 2010 HCM or simulation software.

Bicycle Mobility

Potential performance levels for use in a subjective evaluation of bicycle mobility are provided in Table 51; performance measures for an objective evaluation are provided in Table 52. The objective performance measures are:

- Bicycle LOS score (number), lower is better and higher is worse.
- Bicycle control delay (s/bicycle), lower is better and higher is worse.

Table 51. Subjective Performance Levels for Bicycle Mobility.

Description: This is a subjective method for determining performance levels for bicycle mobility.	
Performance Level	
Score	**Bicycle Mobility**
0	Bicycle mobility with this alternative is undesirable.
1	
2	
3	
4	
5	Bicycle mobility with this alternative is neither desirable nor undesirable.
6	
7	
8	
9	
10	Bicycle mobility with this alternative is desirable.

Table 52. Objective Performance Levels for Bicycle Mobility.

Description: This is an objective method for determining performance levels for bicycle mobility. Objective factors include: • Bicycle control delay, seconds / bicycle (fewer seconds / bicycle is better). • Bicycle level of service score, number (lower values are better)		
Performance Level		
Score	**Bicycle Control Delay**	**Bicycle Level of Service Score**
0	> 40 s / bicycle	> 4.25
1	-	-
2	-	-
3	-	-
4	-	-
5	< 30 s / bicycle	< 3.50
6	-	-
7	-	-
8	-	-
9	-	-
10	< 20 s / bicycle	< 2.75

Bicycle control delay is useful for evaluating the selection of TCDs at intersections and the performance level values come from the *2000 HCM*. The values shown in Table 52 for bicycle control delay are the maximum values for LOS B (20 s/bicycle), LOS C (30 s/bicycle), and LOS D (40 s/bicycle) at urban intersections. In the *2010 HCM*, bicycle intersection LOS score replaced control delay as a method for evaluating bicycle LOS at intersection; however, the *2010 HCM* method is data intensive and does not apply to all facility types. It is possible to estimate pedestrian control delay using methods within the *2010 HCM* and simulation programs. It is possible to estimate bicycle control delay using methods documented within the *2010 HCM* or simulation software.

Pedestrian control delay is useful for evaluating the selection of TCDs at intersections and the performance level values comes from the *2000 HCM*. The values shown in Table 49 for pedestrian control delay are the maximum values for LOS B (10 s/crossing), LOS C (20 s/crossing), and LOS D (30 s/crossing) at urban intersections in the *2000 HCM*. In the *2010 HCM*, pedestrian control delay became part of the equation used to determine pedestrian LOS score, which considers other factors such as the presence of sidewalks and pedestrian crossing distance; however, these calculations can be data intensive and may not provide useful information when evaluating some TCD alternatives.

Bicycle LOS score (a numeric value used to determine LOS letter grades within the HCM) is useful for evaluating the selection of TCDs along urban street segments and at intersections; bicycle LOS score comes from the *2010 HCM*. The values shown in Table 52 for bicycle LOS score are the maximum values for LOS B (2.75), LOS C (3.50), and LOS D (4.25) on urban streets. It is possible to estimate bicycle LOS score using methods documented within the *2010 HCM*.

CHAPTER SUMMARY

In this chapter, researchers evaluate survey participant responses to questions in part three of the survey of transportation professionals. Based upon the findings from this evaluation, researchers document four performance measures for use when objectively evaluating safety, three performance measures for use when subjectively evaluating mobility, and three performance measures for use when objectively evaluating mobility. In Chapter VI, researchers use these performance measures to document a decision support tool for use in selecting TCDs.

CHAPTER VI

DECISION SUPPORT TOOL

FOR USE IN SELECTING TRAFFIC CONTROL DEVICES

In this chapter, researchers develop a decision support tool for use in selecting TCDs on urban streets. The contents of this decision support tool come from existing theory, the evaluation of agency objectives within this report, and the evaluation of performance measures within this report. In this chapter, researchers document a nine-step decision support tool. Researchers then provides a set of example calculation demonstrating the use of this decision support tool to select between a two-way stop, all-way stop, or marked pedestrian crossing. The purpose of this decision support tool is to move the transportation profession towards consistency in the process transportation professionals use to select TCDs.

DECISION SUPPORT TOOL

A method for evaluating TCDs includes following steps:

1. Define the problem as a desired engineering outcome for a specific area.
2. Evaluate existing crash data within the specific area.
3. Determine performance measures for this specific decision.
4. Calculate the performance measure weights.
5. Quantify the performance level of the existing conditions.
6. Identify alternatives that satisfy local needs and desires.
7. Quantify the expected performance of each alternative.
8. Quantify the marginal cost of installing and maintaining each alternative.
9. Rank the alternatives using cost-effectiveness ratios.

Disclaimer: this decision support tool is not a substitute for engineering studies and engineering judgment; nor is it a substitute for the standards, guidance, and options contained within the MUCTD. A professional engineer or someone under the direct supervision of a professional engineer should be responsible for the application of this tool when selecting TCDs.

Step 1: Define the Problem as a Desired Engineering Outcome for a Specific Area

The first step in this decision support tool is to define the problem as a desired engineering outcome for a specific area. In some situations, communities bring transportation problems to transportation professionals as a desire for a specific solution; for example, this intersection needs a traffic signal. However, evaluating the problem as traffic signal versus no traffic signal is a textbook example of the narrow framing bias. To avoid narrow framing, it is better for a decision-maker to define the problem in terms of a desired engineering outcome within a specific geographic area. For example, desired engineering outcomes at intersections might be improved safety, improved mobility, or both; and, the geographic area could be a single intersection, a specific roadway segment, or roadway network (such as a downtown area).

While there could be other desired engineering outcomes, the decision support tool developed within this report is capable of evaluating only the following:

- Improved safety in the form of reductions in crashes.
- Improved safety in the form of increased user compliance.
- Improved mobility in the form of improved efficiency.

If the desired outcomes from a decision do not include one of these three outcomes, this decision support tool may not be useful in determining a solution. Alternatively, if the desired outcomes from a decision do not include safety or mobility, it is possible that the solutions that would provide these outcomes do not involve the use of TCDs.

Step 2: Evaluate Existing Crash Data within the Specific Area

The second step in this decision support tool is to evaluate the past 36 months (if possible) of crash data within the specific area; the decision maker defines the specific area in Step 1. This step involves acquiring crash data within the specific area. The purpose of acquiring crash data is to obtain an objective view of safety within the geographic area. In situations where there are reported crashes, the crash data are useful in guiding the selection of alternatives by aiding transportation professionals in determining crash type(s) (for example, rear-end crashes, run-off-road crashes, and right-angle crashes). Additionally, crash data help justify the use of CRF as a performance measure for safety within the remaining steps of the decision support tool when the alternatives address the identified crash type(s). In situations where there are no reported crashes, knowing there are no reported crashes helps justify the use of compliance as a performance measure for safety within the remaining steps of the decision support tool.

Step 3: Select Performance Measures for this Specific Decision.

The third step in this decision support tool is to select performance measures for this specific decision. In this step, the decision-maker must decide which performance measures they will use to evaluate safety and which performance measures they will use to evaluate mobility. This step occurs before identifying alternatives in order to avoid confirmation bias, which would occur if a decision-maker were to select performance measures that favor a preconceived solution.

Selecting Safety Performance Measures

At this time this decision support tool is capable of evaluating only the selection of TCDs using either crashes or user compliance; it cannot do both within the same evaluation. It is not possible to use both crash and compliance within the decision support tool because this report did not establish the relative importance between crashes and user compliance. This means a decision maker must decide if the evaluation should use crash reduction factor or compliance as the performance measure for safety. There are two reasons for using compliance instead of crashes as the performance measure for safety within an evaluation; they are:

1. The decision-maker finds that there were few crashes, zero crashes, or crash data are unavailable for the past 36 months.
2. The decision-maker is concern that an alternative considered in step 6 will not have a known CMF.

If neither of these reasons are a concern, the decision-maker may prefer to use crash reduction factor as the performance measure for safety.

Selecting Mobility Performance Measures

At this point, the decision-maker needs to decide if the evaluation of mobility will use subjective performance measures, use objective performance measures, and, if using objective performances measures, which objective performance measures to use. The decision-maker needs to make this decision for each user type (automobile users, pedestrian users, and bicycle users). For this decision support tool, decision-makers should use only one mobility performance measure for each user type; otherwise, a decision-maker could place unintended emphasis on user types with multiple mobility performance measures. In general, the researchers that prepared this report suggest that decision-makers should use objective performance measures whenever possible and limit the use of subjective evaluations to situation where doing so is the only option.

A decision-maker could elect to use a subjective evaluation of automobile mobility if:

1. The decision-maker is concerned that is not possible to quantify the automobile mobility effects of a potential alternative.
2. The data necessary for evaluating the automobile mobility effects for the given situation are cost prohibitive.

If neither of these conditions are a concern, the decision maker should consider one of the three objective performance measures documented in Table 48. If the evaluation involves a single intersection, automobile control delay is the most reasonable alternative. If the evaluation involves a roadway segment or roadway network, both percent free-flow speed and spatial stop-rate are reasonable options.

Similar to automobile mobility, a decision-maker could elect to use a subjective evaluation of pedestrian mobility if:

1. The decision-maker is concerned that is not possible to quantify the pedestrian mobility effects of a potential alternative.
2. The data necessary for evaluating the pedestrian mobility effects for the given situation are cost prohibitive.

If neither of these conditions are a concern, the decision maker should consider one of the two objective performance measures documented in Table 50. If the analysis is evaluating a single intersection, both pedestrian control delay and pedestrian LOS score are reasonable objective performance measures for evaluating pedestrian mobility. If the evaluation is for roadway segments and roadway networks, a decision-maker should use pedestrian LOS score. However, while the data used to develop the methods to determine pedestrian LOS score in the HCM 2010 are more robust than the data used to associate pedestrian LOS to pedestrian control delay, the pedestrian LOS score methods are also data intensive. Since decision-makers can often use the data collected to determine automobile control delay when determining pedestrian control delay, many decision-makers may find pedestrian control delay to be a more useful objective performance measure for evaluating pedestrian mobility than pedestrian LOS score.

Similar to automobile and pedestrian mobility, a decision-maker could elect to use a subjective evaluation of bicycle mobility if:

1. The decision-maker is concerned that is not possible to quantify the bicycle mobility effects of a potential alternative.

2. The data necessary for evaluating the bicycle mobility effects for the given situation are cost prohibitive.

If neither of these conditions are a concern, the decision maker should consider one of the two objective performance measures documented in Table 52. If the evaluation involves a single intersection, both bicycle control delay or bicycle LOS score are potential objective performance measures for bicycle mobility. If the evaluation involves a roadway segment or roadway network, a decision maker should use bicycle LOS score. Similar to the HCM 2010 methods for calculating pedestrian LOS score, the methods for calculating bicycle LOS score come from research that used data that are more robust than the data used to associate bicycle control delay to bicycle LOS within the *HCM 2000*. However, also like the pedestrian LOS score methods, the bicycle LOS methods within the HCM 2010 are data intensive. Since decision-makers can often calculate bicycle control delay using the same data used to determine automobile control delay, a decision-maker may find bicycle control delay to be a more useful objective performance measure of bicycle mobility than bicycle LOS score.

Step 4: Calculate the Performance Measure Weights

The fourth step in this decision support tool is to calculate the performance measure weights for each of the performance measures selected in Step 3. Within this step, there is the option of adjusting the relative weights between agency objectives and the performance measures for each of the agency objectives.

At this time, the agency objectives included within this decision support tool are:

- Provide a safe transportation system for all users.
- Provide a reliable and efficient transportation system for all users.

In this decision support tool, all users includes automobiles, pedestrians, and bicycles. By default, this report presumes that the average allocation of points to each of these objectives within the survey of transportation professionals represents a reasonable allocation of objective weights within this decision support tool. Therefore, a reasonable default weight for the objective of safety is 60 out of 100 points and a reasonable default weight for the objective of mobility is 40 out of 100 points; these values come from Table 25. While these are reasonable default values, some decision-makers may find it useful to adjust these values if their agency would like to place more emphasis on either safety or mobility than the default allocation presented within this decision support tool. However, because this report did not investigate how these values might shift depending on agency priorities, researchers do not provide recommended alternative values within this decision support tool; decision-makers could make such adjustments using engineering judgment or engineering study.

Because this report did not investigate the relative importance of different user types (as in the relative importance of automobile, pedestrian, and bicycle users), researchers presume that performance measures for automobiles, pedestrians, and bicycles have the same relative weight. This means that, out of 100 points, the relative weight for a performance measure for each user type is 33.3 points. However, some agencies may find it useful to adjust the relative weights for each user type if there are areas where the mobility of one user is more critical than the mobility of other modes. For example, the weight for bicycle users could be higher along identified bicycle corridors or the weight for pedestrians could be higher for identified pedestrian areas.

However, this report did not explore how decision-makers would adjust these values for different priorities; therefore, the researchers do not provide recommendations for making this type of adjustment; decision-makers could make such adjustments using engineering judgment or engineering study.

Once the relative weight for each objective and user type are determined, a decision-maker can calculate performance measure weights using the following equation:

$$PM\_Weight_{i\_j} = Obj\_W_i \times R\_Weight_{i\_j} / 100 \qquad \text{Equation 6-1}$$

where:

$PM\_Weight_{i\_j}$ = Weight of performance measure j for objective i.
Obj_W_i = Weight of objective i (from Table 25 in Chapter IV).
$R\_Weight_{i\_j}$ = Relative weight of performance measure j for objective i. Relative weights within a single objective need to sum to 100.

Assuming a relative weight of 33.3 points for each mode, performance measure weights for an evaluation that uses CRF as a measure of safety is provided in Table 53; and, performance measure weights for an evaluation that uses compliance as a measure of safety is provided in Table 54.

Table 53. Performance Measure Weights for Use in an Evaluation Using Crash Reduction Factor as a Measure of Safety.

Number (i_j)	Performance Measure	Obj_W_i	$R\_Weight_{i\_j}$	$PM\_Weight_{i\_j*}$
1_1	Crash reduction factor	60.0	100.0	60.0
2_1	Automobile mobility	40.0	33.3	13.3
2_2	Pedestrian mobility	40.0	33.3	13.3
2_3	Bicycle mobility	40.0	33.3	13.3
* The sum of $PM\_Weight_{i\_j}$ may not add up to 100 due to rounding.				

Table 54. Performance Measure Weights for
Use in an Evaluation Using Compliance as a Measure of Safety.

Number (i_j)	Performance Measure	Obj_W_i	$R\_Weight_{i\_j}$	$PM\_Weight_{i\_j}$*
1_2	Automobile user compliance	60.0	33.3	20.0
1_3	Pedestrian user compliance	60.0	33.3	20.0
1_4	Bicycle user compliance	60.0	33.3	20.0
2_1	Automobile mobility	40.0	33.3	13.3
2_2	Pedestrian mobility	40.0	33.3	13.3
2_3	Bicycle mobility	40.0	33.3	13.3
* The sum of $PM\_Weight_{i\_j}$ may not add up to 100 due to rounding.				

Step 5: Quantify the Performance Level of the Existing Conditions

The fifth step in this decision support tool is to quantify the performance level of the existing conditions for the performance measures selected in step 3. The tables for calculating subjective or objective performance levels for the performance measures are provided in Table 55.

Table 55. Performance Measures and
Tables for Calculating Subjective or Objective Performance Levels.

Number (i_j)	Performance Measure	Performance Level	
		Subjective	Objective
1_1	Crash reduction factor	-	Table 43
1_2	Automobile compliance	-	Table 44
1_3	Pedestrian compliance	-	Table 45
1_4	Bicycle compliance	-	Table 46
2_1	Automobile mobility	Table 47	Table 48
2_2	Pedestrian mobility	Table 49	Table 50
2_3	Bicycle mobility	Table 51	Table 52

Step 6: Identify Alternatives that Satisfy Local Needs and Desires

The sixth step in this decision support tool is to identify two or more alternatives that satisfy local needs and desires. These two alternatives are in addition to a third alternative, which is to do nothing. This step involves identifying two or more alternatives (in addition to doing nothing) because research suggests decision outcomes improve when decision makers consider multiple alternatives (Nutt 1993). Each alternative may consist of one or more TCDs and agencies should focus on alternatives that improve the performance level of performance measures that had lower scores in Step 5.

Within the context of this decision support tool, a transportation professional determines which alternatives will satisfy local needs and desires through public engagement and experience. For many situations, the decision-maker should use this step to make sure large segments of the population will not oppose the alternatives under consideration. Factors that may result in public opposition are alternatives with negative impacts on businesses, the environment, or other community expectations and preferences of which the decision-maker is aware.

To aid in the identification of alternatives, a decision-maker should review existing literature on engineering principles and practice. At a minimum, this review should include:

- The federal MUTCD or state equivalent.
- FHWA official interpretations pertaining to the MUTCD.
- FHWA interim approvals.
- The HSM.

During this review, the evaluator should focus on engineering principles and practice that satisfy the agency objectives, identified in Step 1.

Step 7: Quantify the Expected Performance of Each Alternative

The seventh step in this decision support tool is to quantify the expected performance of each alternative. An evaluator does this by determining the expected performance level for each alternative in the after condition. The decision-maker should quantify performance using the same performance measures used to quantify the existing conditions in step 4.

Step 8: Quantify the Installation and Maintenance Cost for Each Alternative

The eighth step in the decision support tool is to quantify the cost of installing and maintaining each alternative. The decision-maker should use values that are specific to the agency's experience in paying for the installation and maintenance of each alternative.

Step 9: Rank the Alternatives Using Cost-Effectiveness Ratio

The ninth step in this decision support tool is to prioritize the alternatives based upon cost-effectiveness ratio; a lower cost-effectiveness ratio is better. In this decision support tool, cost-effectiveness ratio is calculated using the following equations:

$$CER_k = Cost_k / Effect\_After_k \qquad \text{Equation 6-2}$$

$$Effect\_After_k = \Sigma_{i\_j\_k} \left([\ Score_{i\_j\_k} / 10\ ] \times PM\_Weight_{i\_j} \right) \qquad \text{Equation 6-3}$$

$$Cost_k = Intall\_Cost_k + Maint\_Cost_k \qquad \text{Equation 6-5}$$

where:

CER_k = Cost effectiveness ratio for alternative k, lower cost effectiveness ratios are better.

$Effect\_After_k$ = Effectiveness of the alternative k in the after condition.

$Score_{i\_j\_k}$ = Performance level for objective i and performance measure j for alternative k (calculated in Step 6).

$PM\_Weight_{i\_j}$ = Performance measure weight for objective i and performance measure j.

$Cost_k$	= Cost of alternative k in dollars.
$Install\_Cost_k$	= Instillation cost for alternative k (calculated in Step 8).
$Maint\_Cost_k$	= Maintenance costs for alternative k (calculated in Step 8).
$\Sigma_{i\_j\_k}$	= Summation over all objectives and measures for alternative k.

This method for calculating the cost effectiveness ratio requires for the cost in the before condition to be the same for all alternatives. This means decision-makers should use this tool only to determine the alternatives at a specific location. If an agency is trying to determine which intersection to address or which intersection to address first, then the agency will need to use another tool to set priorities; this other tool will need to be able to consider effectiveness in the before condition.

EXAMPLE CALCULATIONS

This section provides example calculations using the decision support tool developed earlier in chapter. In this example, a citizen group has requested the installation of an all-way stop intersection. At this time, the intersection has stop signs on the minor approaches only. After further discussion, the agency determined that the citizens have a desire to improve the safety and mobility of pedestrians crossing from parking lots to the north of the uncontrolled major roadway (the roadway that does not have to stop at the intersection) to destinations on the other side of the uncontrolled major roadway.

Step 1: Define the Problem as a Desired Engineering Outcome for a Specific Area

Based upon community feedback, desired engineering outcomes are driver compliance with the pedestrian crossing at the intersection, improved pedestrian mobility, and pedestrian safety.

Step 2: Evaluate Existing Crash Data within the Specific area

A request for crash reports found that there were zero crashes at or near the intersection within the prior 12 months. This suggest the more useful performance measure for evaluating safety is compliance.

Step 3: Select Performance Measures for this Specific Decision

Given the lack of crash data in the area, the more useful performance measures for evaluating safety are automobile compliance (yielding to pedestrians), pedestrian compliance (crossing within available crosswalks), and bicycle compliance (yielding to pedestrians). For this evaluation, the agency prefers to use an objective evaluation of mobility for all user groups. Since the location is a single intersection and given the agencies available resources, the most reasonable performance measure for automobile mobility is automobile control delay. Given that the agency does not have sufficient resources to obtain the data necessary to evaluate pedestrian LOS score and bicycle LOS score for this intersection, the most reasonable performance measure for pedestrian mobility is pedestrian control delay and the most reasonable performance measure for bicycle mobility is bicycle control delay.

Step 4: Determine Performance Measure Weights

For this evaluation, the agency found there was no reason to adjust the relative weights for each of the user types and that there was no reason to adjust the relative importance of the agency objectives of safety and mobility. This means the agency should use the performance measure weights shown within Table 54.

Step 5: Quantify the Performance Level of the Existing Conditions

For this evaluation, the agency collected the data necessary to determine compliance values and control delay values for the three types of users. After collecting these data, the agency used the 2010 HCM methodologies to determine the mobility values for a two-way stop intersection. The performance measure values and the performance levels obtained using the tables listed within Table 55 are provided in Table 56.

Table 56. Performance Levels for Existing Two-Way Stop.

Performance Measure	Objective Factor	Value	Performance Level
Automobile compliance	Yielding (uncontrolled crossings)	35 %	4
Pedestrian compliance	Crossing within crosswalks (uncontrolled crossings)	80 %	9
Bicycle compliance	Yielding (uncontrolled crossings)	35 %	4
Automobile mobility	Control delay (all approaches)	11 s / veh	10
Pedestrian mobility	Control delay (uncontrolled crossings)	19 s / crossing	5
Bicycle mobility	Control delay (all approaches)	11 s / bike	10

Step 6: Identify Alternatives that Satisfy Local Needs and Desires

Two alternatives for this location that satisfy local needs and desires are:

- Convert the intersection from a two-way stop intersection to an all-way stop intersection.
- Add pedestrian crossing signs, yield here to pedestrians signs, and yield markings to the pedestrian crossings across the uncontrolled roadway.

Step 7: Quantify the Expected Performance of each Alternative

Expected performance level for each alternative is provided in Table 57. These values are based upon the following expected outcomes:

- Automobile and bicycle compliance of 95 percent with an all-way stop.
- Automobile and bicycle compliance of 65 percent with the improved pedestrian crossing signs and markings.

- No change in pedestrian compliance between each alternative.
- Automobile and bicycle delay of 23 seconds per vehicle with an all-way stop.
- Automobile and bicycle delay of 12 seconds per vehicle with the improved pedestrian crossing signs and markings. .
- Pedestrian delay of zero seconds per crossing with an all-way stop.
- Pedestrian delay of 14 seconds per crossing with the improved pedestrian crossing signs and markings.

Table 57. Expected Performance Level for Each Performance Measure for Each Alternative.

Performance Measure	Do Nothing	All-Way Stop	Improved Crosswalk
Automobile compliance	4	10	7
Pedestrian compliance	9	9	9
Bicycle compliance	4	10	7
Automobile mobility	10	9	10
Pedestrian mobility	5	10	8
Bicycle mobility	10	8	10

Step 8: Quantify the Cost of Installing and Maintaining Each Alternative

For this evaluation, the agency chose to evaluate the 10-year lifecycle cost of each alternative. An explanation of these costs are provided within the next three paragraphs.

For the do nothing option, the 10-year lifecycle cost is the cost of maintaining the stop signs and stop bars on the minor approaches; it also includes the cost of maintaining the pavement markings. For this agency, it cost $750 per approach over 10 years for each stop sign and stop bar (this also happens to be the installation cost); this means the cost for maintaining the stop signs for the two-way stop intersection is $1,500 over 10 years. Additionally, the cost of maintaining crosswalk markings is approximately $125 per year per travel lane per approach. For this intersection, the cost of maintaining crosswalk markings on all four approaches is $1,000 per year over 10 years. This means the total cost for the do nothing option is $11,500 over the next 10 years, which is $1,500 (to maintain the existing stop signs) plus $10,000 (to maintain the existing crosswalk markings).

For the all-way stop option, it will cost the agency $1,500 to install the new stop signs and stop bars and an additional $150 per year to maintain these additional signs and markings. This means the total cost for the all-way stop intersection is $14,500, which is $11,500 (maintaining what is already there) plus $3,000 (the marginal cost for the new devices).

The improved pedestrian crossing option, it will cost the agency $2,500 to install the new pedestrian crossing signs, new yield here to pedestrian signs, and new yield markings at the intersection. It will also cost the agency $250 per year to maintain these devices over 10 years.

This means the total cost for the improved pedestrian crossing option is $16,500, which is $11,500 (maintaining what is already there) plus $5,000 (the marginal cost for the new devices).

Step 9: Rank the Alternatives Using Cost-Effectiveness Ratios

The expected effectiveness for the three alternatives and the values used to calculate the effectiveness are provided in Table 58. The ranking of the alternatives based upon the cost effectiveness ratio is provided in Table 59. Based upon the data presented in Steps 1 through Step 7, the most cost-effective alternative at this location is the all-way stop intersection.

Table 58. Calculation of the Effectiveness of Each Alternative in the After Condition Using Equation 6-4.

Performance Measure	PM_Weights	Do Nothing	All-Way Stop	Marked Crosswalk
Automobile compliance	20	4	10	7
Pedestrian compliance	20	9	9	9
Bicycle compliance	20	4	10	7
Automobile mobility	13.3	10	9	10
Pedestrian mobility	13.3	5	10	8
Bicycle mobility	13.3	10	8	10
Effectiveness (points)	-	67.3	93.9	83.2

Table 59. Ranking of Alternatives Using Cost Effectiveness Ratio Calculated Using Equation 6-2.

Rank	Alternative	Before (points)	After (points)	Cost	CE Ratio
1	All-Way Stop	67.3	93.9	$14,500	$154 / point
3	Do Nothing	67.3	67.3	$11,500	$171 / point
2	Marked Crosswalk	67.3	83.2	$16,500	$198 / point

CHAPTER SUMMARY

In this chapter, the researchers documented a decision support tool for use in selecting TCDs on urban streets and provided a set of example calculations using this decision support tool. This tool provides transportation professionals with a reasonable method for evaluating TCD decisions in a structured manner. The next step for the profession is to use this tool to make TCD decisions while monitoring if the decision support tool made a correct decision. Using these data, transportation professionals can refine this tool and move the profession towards consistency in the process used to select TCDs.

CHAPTER VII

FINDINGS, CONCLUSIONS, AND IMPLICATIONS

This report develops a decision support tool for use in selecting TCDs. The decision support tool developed within this report builds upon existing theory using survey responses from a survey of transportation professionals. To the researchers' knowledge, this report is the first attempt at applying concepts from behavioral economics and performance based decision-making to the problem of TCD selection. The researchers intend for this decision support tool to begin a conversation that will lead towards a manual to aid transportation professionals in making consistent decisions when selecting TCDs. The next step for the profession is to use the tool developed within this report to make TCD decisions while monitoring if the decision support tool made a correct decision. This chapter documents the important findings, conclusions, and implications of the research contained within this report.

SUMMARY OF THE REPORT

The decision support tool developed within this report is an effort to move the transportation profession towards consistency in the process used to select TCDs. While the profession has obtained a great deal of uniformity and consistency in the design, installation, operation, and maintenance of TCDs, consistency in the selection of TCDs has lagged behind. A method for creating consistency in the selection of TCDs is a structured decision support tool.

One reason for the lack of a structured decision support tool is disagreement within the transportation profession on the objectives that are most critical to the selection of TCDs. To address this concern, this report uses a portion of a survey of transportation professionals to determine the agency objectives that should drive the selection of TCDs. Based upon the evaluation of survey responses, the researchers find that respondents believe agency objectives of safety and mobility (efficiency and reliability) should drive the selection of TCDs.

After determining the agency objectives that should drive the selection of TCDs, the researchers connect performance measures to each objective. To accomplish this, the researchers primarily rely on existing theory; however, the researchers also use a portion of a survey of transportation professionals to inform the selection of performance measures. Based upon existing theory and survey results, the researchers recommend the use of crashes and compliance as performance measures for safety. Additionally, the researchers recommend:

- The use of automobile control delay, percent free-flow speed, and spatial stop-rate to evaluate automobile mobility.
- The use of pedestrian control delay and pedestrian LOS score to evaluate pedestrian mobility.
- The use of bicycle control delay and bicycle LOS score to evaluate bicycle mobility.

After connecting performance measures to each objective, the researchers develop a decision support tool for use in selecting TCDs. The developed decision support tool uses the objectives and performance measures identified within this report to guide the evaluation of TCD alternatives. Ultimately, the decision support tool ranks TCD alternatives using cost-effectiveness ratios. Within the decision support tool, effectiveness is an alternatives ability to contribute to performance measures associated with agency objectives of safety and mobility (efficiency and reliability). The costs accounted for within the decision support tool include installation and maintenance costs.

FINDINGS AND CONCLUSIONS

As part of the review of existing theory, researchers identified nine research questions to evaluate using a survey of transportation professionals. Researchers used the analysis of the first four research questions to conclude that safety and mobility (reliability and efficiency) should drive the selection of TCDs. Researchers used the analysis of the five remaining research questions to conclude that crashes and user compliance are potential performance measures for use in evaluating safety. Additionally, researchers conclude that the decision support tool should use existing performance measures for mobility and include a consideration of cost. In the next three sections, researchers highlight the findings and existing theory that led to these conclusions.

Agency Objectives for Selecting TCDs

In the evaluation of agency objectives, researchers conclude that the objectives of safety and mobility (reliability and efficiency) should drive the selection of TCDs within the decision support tool. Researchers reached this conclusion based upon the relative importance of agency objectives analysis in Chapter IV and existing theory.

The first finding in this report that supports this conclusion was the probability of survey respondent allocating more than zero points to the agency objectives of safety, mobility (efficiency and reliability), environmental sustainability, and economic activity. On average, the probability of a survey respondent allocating more than zero points to safety was 99 percent and the probability of a survey respondent allocating more than zero points to mobility (efficiency and reliability) was 97 percent. Both of these values were statistically significantly greater than the probability of a survey respondent allocating more than zero points to environmental sustainability (66 percent) and economic activity (69 percent).

The second finding that supports this conclusion was the number of points allocated to each objective given the survey respondent allocated more than zero points to the objective. On average, if they allocated more than zero points to the objective, survey respondents allocated 47 points out of 100 to the agency objective of safety and survey respondents allocated points 31 points out of 100 to the agency objective of mobility. Both of these values were statistically significantly greater than the average number of points allocated the agency objectives of environmental sustainability (12 points) and economic activity (11 points).

From existing theory, there is additional support for the researchers' conclusion that environmental sustainability and economic activity should not be included in the decision support tool at this time. One reason, for not including the objectives of environmental sustainability and economic activity is an unknown relationship between many TCDs and the performance measures associated with these objectives. Additionally, for relationships that research has documented, the performance measures for environmental sustainability and economic activity are often correlated in magnitude and direction to performance measures associated with mobility; some of these relationships are documented within Chapter 2 of the 2010 HCM (TRB 2011). One implication of using performance measures correlated with mobility within the tool (such as environmental sustainability and economic activity) is the potential unintended emphasis on mobility, which changes the relative importance of safety within the decision process. For example, with only mobility and safety, the relative importance of safety is 60 out of 100 points (47 divided by 78); however, if you add in economic activity and environmental sustainability, the relative importance of safety becomes 47 out of 100 points (47 divided by 101 points).

While the findings and conclusions of this report do not support the inclusion of environmental sustainability and economic activity within the decision support tool at this time, these findings do not suggest that agencies should not consider these objectives in other areas of engineering decision-making. Additionally, as the transportation profession evolves and priorities change, it is possible that the objectives of environmental sustainability and economic activity should become objectives considered within a decision support tool for selecting TCDs.

Performance Measures for Selecting TCDs

In the evaluation of performance measures, researchers conclude that crashes and user compliance are potential performance measures for evaluating the agency objective of safety. Additionally, researchers conclude that it would be best to use exiting performance measures for mobility rather than performance measures evaluated within this report. Researchers reached these conclusions based upon the ranking of transportation improvements analysis in Chapter V and existing theory.

Researchers support the conclusion that crashes are a potential performance measure for safety using the findings of this report and existing theory. The finding in this report that supports this conclusion is the positive relationship between reductions in injury crashes and the probability of a survey respondent ranking an alternative first or second. The existing theory that supports this conclusion is the HSM and research used to create the HSM. The HSM and research used to create the HSM suggests that safety should be measured using the difference in the number of expected crashes (AASHTO 2010).

Researchers support the conclusion that user compliance is a potential performance measure for safety based upon findings in this report and existing theory. Within this report, researchers demonstrate this by replacing crashes in one set of scenarios with driver yielding and comparing participant responses. Then, given the following three findings, researchers demonstrate the potential use of compliance as a performance measure for safety:

1. The parameter estimate for driver yielding (driver compliance) for the best-fit model and injury crashes for the comparison model are statistically significantly different from zero, which means there is statistically significant evidence that survey respondents were reacting to driver yielding (compliance) numbers and crash numbers when responding to the survey.

2. The signs for the parameter estimates for driver yielding (driver compliance) and injury crashes are the same, which means that survey respondents reacted to improvements in yielding (compliance) in the same manner that they would react to improvements in number of crashes.
3. There is no statistically significant evidence that the other parameter estimates are different based upon the 95th percentile confidence intervals overlapping, which suggest survey respondents were reacting to these other variables in a similar manner within both models.

Additionally, existing theory supports this conclusion because it is common practice to evaluate newer TCDs using compliance when there is limited or no crash data available for an evaluation (Chrysler et al. 2011, Fitzpatrick et al. 2014).

In general, to suggest mobility performance for selecting TCDs, researchers use existing theory instead of the ranking of transportation improvement alternatives. One reason for this is that the survey of transportation professionals investigated only automobile mobility; and, to be useful to the transportation profession, the decision support tool needs mobility performance measures for other modes of transportation, including pedestrians and bicycles. Another reason for using performance measures found in existing theory is that the performance measures found in the 2010 HCM and 2000 HCM come from data sets that are more robust than the data in the ranking of transportation improvement alternatives analysis.

Considering the Cost of TCD Alternatives

While it was not a specific research question, researchers conclude that a decision support tool for use in selecting TCDs should include a consideration of cost. Researchers reach this conclusion based upon the finding that cost was statistically significant when selecting between transportation alternatives. This finding suggests that transportation decision-makers consider cost when selecting between alternatives. Therefore, a decision support tool for use in selecting TCDs should include a consideration of cost. Researchers consider cost within the decision support tool using cost-effectiveness analysis. The costs considered within the decision support tool are implementation cost and maintenance cost.

LIMITATIONS AND FUTURE RESEARCH

While the developed decision support tool is a good first step in developing a consistent method for selecting TCDs, there are limitations that should be addressed in future research efforts. This section of the chapter documents the most critical limitations and describes future research that transportation professionals could use to address these limitations. By addressing these limitations, the decision support tool within this report could become a valued resource within the transportation profession.

One issue is that is that the decision support tool, as developed within this report, cannot include performance measures for reductions in crashes and increases in compliance within the same evaluation. Additionally, the decision support tool cannot evaluate improved mobility in the form of improved reliability and improved mobility in the form of improved efficiency within the same evaluation. One reason that the decision support tool cannot look at these aspects within the same evaluation is that this report did not look at the relative importance of reductions in crashes versus increases in compliance; nor did this report look at the relative importance of increased efficiency versus increased reliability. While not having this ability does not mean that decision-makers cannot use the decision support tool, having this ability could increase the decision support tools usefulness. One method of addressing this concern could be research that investigates the research question: *How do transportation professionals allocate points among the performance measures of crashes for all users, compliance of all users, reliability for all users, and efficiency for all users?* Answering this research question would allow the decision support tool to investigate crashes and compliance within the same evaluation; this would also allow the decision support tool to investigate efficiency and reliability within the same evaluation.

Besides determining the relative importance of improvements in efficiency and improvements in reliability, there is additional research needed before the decision support tool could include an evaluation mobility in the form of reliability. What the transportation profession still needs is research that provides methods for estimating the impact of selecting TCDs on transportation system reliability (80^{th}, 95^{th} percentile travel time, or planning time index). Additionally, there is a need for research that connects different levels of transportation system reliability to subjective ratings of quality of service. The research that could answer these questions would be similar to the research documented within NCHRP Report 616; however, this research would focus on transportation system reliability rather than multimodal efficiency.

A limitation of the way this decision support tool calculates cost-effectiveness is that the tool considers only effectiveness in the after condition. This method for cost-effectiveness analysis requires that the effectiveness in the before condition be the same for all alternatives. If a decision-maker were to use the decision support tool within this report to compare alternatives at different locations, the effectiveness for each alternative in the before condition would not be the same. This means that while this tool can aid decision-makers in evaluating alternatives at a specific location, decision-makers cannot use this tool to determine which locations to address first. To determine which intersections should be addressed first, the cost-effectiveness ratio would need to consider effectiveness in the before condition. However, calculating cost effectiveness ratio while considering both effectiveness before and effectiveness after could result in the do nothing alternative having a cost-effectiveness ratio equal to infinity. This occurs when effectiveness in the before condition is equal to effectiveness in the after condition and the denominator becomes zero. Therefore, future research will need to develop a different tool that can aid in prioritizing TCD alternatives at different locations. To build on the findings in this report, this future tool could use the decision support tool within this report to determine the alternatives that should be implemented for each intersection while using effectiveness in the before condition to determine the order that these alternatives will be implemented.

While the relative importance of different performance measures deserves additional attention, there is also a need to investigate the relative importance of different modes on different facilities. At this time, the decision support tool presumes that the relative importance of automobiles, pedestrians, and bicycles have the same relative weight regardless of the demand or facility type. In general, there could be situations where an agency or jurisdiction would prefer to prioritize bicycle and pedestrian mobility over automobile mobility or vice versa. For example, in a central business district, agencies may prefer to prioritize bicycle and pedestrian mobility; and, along controlled access facilities, agencies may prefer to prioritize automobile mobility. An understanding of the degree to which this is true deserves further attention. One method of addressing this concern could be research that investigates the research question: *Within the decision support tool, how should transportation professionals adjust the relative importance of automobiles, pedestrians, and bicycles to account for differences between facility types or modal demand (volume)?*

While this report concludes that compliance is a legitimate surrogate measure for crashes when evaluating safety, there is need for more robust data to justify the use of compliance as a performance measure of safety. In general, data within this report and existing theory may not be sufficient justification. More compelling evidence would connect increased compliance to reductions in crashes. While this is a presumed relationship within the transportation profession, establishing a correlation between increases in compliance and reductions in crashes would be much more convincing. Additionally, such research could aid in estimating the crash benefits of new and emerging TCDs that have not been in use long enough for researchers to establish the crash reductions associated with these devices.

Alternatively, another useful method for justifying the use of compliance within the decision support tool is through the quantification of the benefit, in dollars, associated with increases in user compliance with TCDs. For example, it would be useful to determine transportation professionals' willingness to pay when it comes to improvements in user compliance with TCDs. A benefit of quantifying the monetary value of compliance could be the development of cost-benefit analysis methods for use in selecting TCDs.

IMPLICATIONS

This report is a first step in the development of a structured method for evaluating and comparing TCD alternatives. As a first step, the decision support tool within this report needs to be further developed using theoretical research and practical application. As such, the next step for the profession is to use this tool to make TCD decisions while monitoring if the decision support tool made a correct decision. Such a tool deserves attention because the transportation profession needs a structured method for selecting TCDs in a consistent manner. In general, consistency in the process used to select TCDs has potential to improve safety and mobility for all road users. This section of the report address this and other implications of the research within this report.

One implication of this tool is that it aids transportation agencies in focusing on the objectives that transportation professionals indicated they felt were most critical to TCD decisions. Based upon the survey responses, transportation agencies should select TCDs based upon their ability to provide safety and mobility (reliability and efficiency) to all users. An advantage of this focus is that this decision support tool provides a method for evaluating TCDs without creating too much burden on the decision-maker. For example, this decision support tool allows agencies to use subjective performance measures if objective data are not available. Such flexibility reminds a decision-maker that they should be considering the factor but does not create a situation where considering these factors places undue burden on an agency.

A disadvantage of the decision support tool's focus on safety and mobility is that it may lead transportation agencies to situations where they implement an alternative that does not satisfy local needs and desires. In such situations, the public may reject the solution that the agency suggests. Factors that may result in public opposition are alternatives with negative impacts on businesses, the environment, or other community expectations and preferences of which the decision-maker is aware. To address this concern, the decision support tool limits the alternatives to those that satisfy local needs and desires. Within the context of this decision support tool, a transportation professional determines which alternatives will satisfy local needs and desires through public engagement and experience. The implication of this step in the decision support tool is that it reminds the decision-maker to consider the public needs and desires without forcing the decision-maker into making a political decision instead of an engineering decision. This aspect of the decision support tool should make decision-makers more comfortable with using this tool and developing it further. This aspect of the tool may also increase the public faith in TCD decisions because the public has a role in the decision-making process.

With implementation and refinement, this decision support tool has the potential to lead the profession towards a manual that aids in the consistent selection of TCDs. Researchers envision a manual for TCD selection that has similar standing in the profession as the HCM and HSM. While the work in this report is not robust enough to create a manual that aids in the consistent selection of TCDs, the work in this report does suggest that such a manual should focus on the safety (crashes and compliance) and mobility (efficiency and reliability) contributions of TCDs. This report also provides a decision-making model that could form the core steps of evaluations within a manual on selecting TCDs.

A next step is to begin refining this tool for implementation on specific facility types in a manner similar to the HCM. For example, refining the tool for use at intersections and along roadway segment. At this time, the best way for the profession to move this forward is for transportation agencies to try using this tool in their day-to-day decision-making and documenting the aspects that are most useful and the aspects that should be revised. Researchers encourage transportation agencies to try using the developed decision support tool because the profession needs practical application of this tool in order to move towards a manual that aids in the consistent selection of TCDs.

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APPENDIX A

View Profile
Blog This

From: Mr. James A. Robertson

To: All Member Forum

Posted: Aug 01, 2013 11:53 PM

Subject: Urban Streets, Traffic Control Device Selection Survey

Message:

Dear Colleagues,

We are asking for your assistance in better defining the process for selecting traffic control devices on urban streets. This survey is part of a Texas A&M Transportation Institute (TTI) research study sponsored by the Southwest University Transportation Center (SWUTC).

While you are under no obligation to participate in this survey, we would appreciate your participation and will use the survey results to develop a decision support tool for selecting traffic control devices. This decision support tool will aid professionals with limited experience in making more informed traffic control decisions and will not be a replacement for engineering judgment nor engineering study. Your answers on the survey will be confidential and not used in any way to identify you.

The survey should take between 15 and 30 minutes to complete and consists of 20 questions. To protect the integrity of the research and the final decision support tool, we ask that you do not share your responses to these questions with individuals that have not taken the survey.

To access the survey, please proceed to the following webpage (or copy and paste the link into your internet browser):

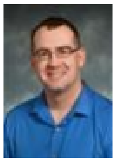
www.tcdsurveys.org

If you have any questions regarding this survey, please contact James Robertson at (979) 845-9896 or J-Robertson@tamu.edu. Thank you for your participation.

Sincerely,
James Robertson, Ph.D. Student
H. Gene Hawkins, Ph.D., P.E., Principle Investigator

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you may contact these offices at (979) 458-4067 or irb@tamu.edu. IRB Reference Number 006057.

Figure 13. Initial Recruitment Message.



View Profile
Blog This

From: Mr. James A. Robertson

To: All Member Forum

Posted: Aug 12, 2013 12:23 AM

Subject: Reminder: Urban Streets, Traffic Control Device Selection Survey

Message:

Dear Colleagues,

This survey will close at midnight on August 16, 2013. If you have already participated, we thank you for your valued input.

This survey is part of a Texas A&M Transportation Institute (TTI) research study looking to better define the process for selecting traffic control devices on urban streets and is sponsored by the Southwest University Transportation Center (SWUTC).

While you are under no obligation to participate in this survey, we would appreciate your participation and will use the survey results to develop a decision support tool for selecting traffic control devices. This decision support tool will aid professionals with limited experience in making more informed traffic control decisions and will not be a replacement for engineering judgment nor engineering study. Your answers on the survey will be confidential and not used in any way to identify you.

The survey should take between 15 and 30 minutes to complete and consists of 11 questions. To protect the integrity of the research and the final decision support tool, we ask that you do not share your responses to these questions with individuals that have not taken the survey.

To access the survey, please proceed to the following webpage (or copy and paste the link into your internet browser):

http://tti-surveys.org/public_html/LimeSurvey4/index.php/87128/lang-en

If you have any questions regarding this survey, please contact James Robertson (979) 845-9896 or J-Robertson@tamu.edu. Thank you for your participation.

Sincerely,

James Robertson, Ph.D. Student

H. Gene Hawkins, Ph.D., P.E., Principle Investigator

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you may contact these offices at (979) 458-4067 or irb@tamu.edu. IRB Reference Number 006057.

Figure 14. Reminder Recruitment Message.

APPENDIX B

Table 60. Question 6 Comments – ITE All Member Forum Responses.

Participant ID	Comment
9	A combination of the two reasons for which I have provided an assessment should serve to promote the third reason listed as well.
17	I felt that while community and environment are factors, safety, reliability, efficiency, and economic growth are the corner stones of why a transportation network exists the first place. The community often does not look at the big picture and consider all users and the costs vs. the benefits. The impacts to the environment need to considered and minimized but the safety benefits and reliability benefits need to be given a much higher priority. By addressing safety, reliability, and efficiency, environmental impacts are reduced.
34	The selection of traffic control should be based on traffic operations and safety.
35	I would note that the definition of "safe" from the professional standpoint may not be the same as from the citizen's or layperson's standpoint--but safety is always the overriding factor.
46	Professionally safety is #1; expectation and economic activity are realities of practice.
49	The primary issues to address are the safety and efficiency of the transportation system. Most standard traffic control devises were designed with those issues in mind.
53	Your categories appear to overlap. More diverse reasons would have helped with the analysis.
56	One must balance safety with mobility and the needs of all users. With regard to sustainability, we should look beyond environmental and look at total sustainability to include installation, maintenance, compliance and enforceability.
57	Safety is paramount when developing a trabsportation system. It must also be as efficient and reliable as possible, but if it's not safe, being efficient and reliable won't matter much!
58	Most of the reasons have overlaps. I.e., a safe transportation system also supports economic activity.
62	Safety is paramount. If constraints permit, then efficiency and community expectations are evaluated. Roadways are part of the community, and should not be barriers within the community.

Table 61. Question 6 Comments – Dr. Robertson Email Responses.

Participant ID	Comment
2	An urban setting requires traffic control that addresses safety and mobility fo all modes and tries to find the right balance for the context of the corridor.
4	Providing a safe a reliable transportation system is the backbone for economic growth and improves the quality of life for the users of the roadways.
16	Signals are crucial in creating an efficient and safe transportation system for ALL MODES. Cyclists can highly benefit from signals as these traffic control devices provide the ability to moderate the speed of vehicles so that they do not travel faster than the average speed of bikes. Also, signals should be used to increase access and provide safe crossings to cyclists and pedestrians.

Table 62. Question 6 Comments – Dr. Hawkins or Dr. Carlson Email Responses.

Participant ID	Comment
9	As a public servant, the foremost purpose of providing a traffic control device is safety. All other reasons fall after that to some degree.
12	Safety is the most important,uniformity is also important as it aids in education.
13	Of the 3 reasons not selected, environmental sustainability is the most important, but safety, reliability, and efficiency are of paramount importance.
16	Divided my points on the premise that "reliable and efficient" completely encloses "safe".
22	Questions 1 & 3 are really one question. A system must be all three to be of any real value. If it does not support economic activity it rather becomes a "fun ride" to no where.
24	In my urban traffic engineering experience, safety is number 1, then efficient and community expectations.
25	Supporting economic activity and environmental sustainability are broad goals that would pertain to the transportation system as a whole and not to signs, pavement markings and traffic signals.
26	First and formost, the TCD has to do what it is intended. It should improve the operating efficiency as well as make the sysytem safer. The other factors are secondary and are icing on the cake.
27	Reliable and efficient for the reasonable and prudent road user, impossible to make a safe system for all users. User (expectations) expectancy is critical to the success of the TCD to meet it anticipated result.
29	There is really no simple answer but each situation must be evaluated to consider safety, reliable sustainable efficient movement of goods and people.
39	Transportation systems (freeways, roads, transit lines, ports, etc.)tend to reflect aspirations for economic activity and environmental sustainability (as imprecise as that term is). However, traffic control devices are primarily supportive of the decided transportation systems and are installed primarily for reasons of safe and efficient transportation.
40	through the provision of a reliable and efficient transportation system for all users, we provide for all othe other resasons, as well!
44	There are signs placed for economic reasons that are not TCDs. They are not included in my totals.
47	Only my professional opinion from working in urban setting for most of my career.
48	If you asked how much I spend on each, you’d get different answers!
49	Both the goals of "Provide a reliable and efficient transportation system for all users" and "Provide a safe transportation system for all users" should be considered and often it may be the case that a TCD meets both goals. I put 100 in case there is a conflict, in which case presumably safety would be paramount.

APPENDIX C

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	35	No Change	45	No Change
Average speed (mi/h)	13	27	9	27	16	35
Total delay (vehicle-hours/weekday)	970	170	1,650	170	810	130
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Question 7 and 8 Project Benefits.

Project	Question 7 Values	Question 8 Values - Based Upon Question 7 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	5,300,000	9,500,000	9,500,000	7,400,000	6,400,000	7,400,000	6,400,000
B	9,800,000	13,700,000	11,800,000	17,600,000	17,600,000	11,800,000	13,700,000
C	4,800,000	5,800,000	6,700,000	5,800,000	6,700,000	8,600,000	8,600,000

Question 7 and 8 Cost Values.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	40,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	35	No Change	25	No Change
Average speed (mi/h)	13	21	13	27	9	19
Total delay (vehicle-hours/weekday)	970	380	1,940	340	1,420	250
Fatal crashes (crashes/year)	0	0	0	0	1	0
Injury crashes (crashes/year)	6	2	9	6	8	3
Total crashes (crashes/year)	24	18	36	24	36	24

Question 9 and 10 Project Benefits.

Project	Question 9 Values	Question 10 Values - Based Upon Question 9 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	4,300,000	7,700,000	7,700,000	6,000,000	5,200,000	6,000,000	5,200,000
B	17,100,000	23,900,000	20,500,000	30,800,000	30,800,000	20,500,000	23,900,000
C	7,300,000	8,800,000	10,200,000	8,800,000	10,200,000	13,100,000	13,100,000

Question 9 and 10 Project Costs.

Figure 15. Group One Values Used in Questions 7, 8, 9, and 10.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	25	No Change	35	No Change
Average speed (mi/h)	9	27	9	19	13	27
Total delay (vehicle-hours/weekday)	1,650	170	1,420	250	970	170
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Question 7 and 8 Project Benefits

Project	Question 7 Values	Question 8 Values - Based Upon Question 7 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	9,000,000	16,200,000	16,200,000	12,600,000	10,800,000	12,600,000	10,800,000
B	8,100,000	11,300,000	9,700,000	14,600,000	14,600,000	9,700,000	11,300,000
C	5,500,000	6,600,000	7,700,000	6,600,000	7,700,000	9,900,000	9,900,000

Question 7 and 8 Cost Values.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	40,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	45	No Change	35	No Change
Average speed (mi/h)	13	27	16	35	13	21
Total delay (vehicle-hours/weekday)	1,940	340	810	130	970	380
Driver yielding (percent)	15	95	15	85	15	75

Question 9 and 10 Project Benefits

Project	Question 9 Values	Question 10 Values - Based Upon Question 9 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	8,700,000	15,700,000	15,700,000	12,200,000	10,400,000	12,200,000	10,400,000
B	3,700,000	5,200,000	4,400,000	6,700,000	6,700,000	4,400,000	5,200,000
C	3,200,000	3,800,000	4,500,000	3,800,000	4,500,000	5,800,000	5,800,000

Question 9 and 10 Cost Values.

Figure 16. Group Two Values Used in Questions 7, 8, 9, and 10.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	40,000	No Change
Free-flow speed (mi/h)	45	No Change	35	No Change	35	No Change
Average speed (mi/h)	16	35	13	27	13	27
Total delay (vehicle-hours/weekday)	810	130	970	170	1,940	340
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Question 7 and 8 Project Benefits.

Project	Question 7 Values	Question 8 Values - Based Upon Question 7 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	4,600,000	9,300,000	9,300,000	8,000,000	6,600,000	8,000,000	6,600,000
B	6,100,000	14,700,000	12,300,000	17,200,000	17,200,000	12,300,000	14,700,000
C	9,900,000	6,000,000	7,200,000	6,000,000	7,200,000	8,400,000	8,400,000

Question 7 and 8 Cost Values.

	Project A			Project B			Project C		
	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With
Segment length (miles)	1	No Change	No Change	1	No Change	No Change	1	No Change	No Change
AADT (vehicles/day)	16,000	20,000	20,000	16,000	20,000	20,000	16,000	20,000	20,000
Free-flow speed (mi/h)	25	No Change	No Change	35	No Change	No Change	35	No Change	No Change
Average speed (mi/h)	19	9	19	21	13	21	27	9	27
Total delay (vehicle-hours/weekday)	200	1,420	250	300	970	380	140	1,650	170
Fatal crashes (crashes/year)	0	0	0	0	0	0	0	0	0
Injury crashes (crashes/year)	3	9	3	3	9	6	6	9	6
Total crashes (crashes/year)	24	36	24	24	36	24	24	36	24

Question 9 and 10 Project Benefits.

Project	Question 9 Values	Question 10 Values - Based Upon Question 9 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	8,100,000	14,600,000	14,600,000	11,300,000	9,700,000	11,300,000	9,700,000
B	4,100,000	5,700,000	4,900,000	7,400,000	7,400,000	4,900,000	5,700,000
C	9,000,000	10,800,000	12,600,000	10,800,000	12,600,000	16,200,000	16,200,000

Question 9 and 10 Project Costs.

Figure 17. Group Three Values Used in Questions 7, 8, 9, and 10.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	40,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	35	No Change	25	No Change
Average speed (mi/h)	13	21	13	27	9	19
Total delay (vehicle-hours/weekday)	970	380	1,940	340	1,420	250
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Question 7 and 8 Project Benefits

Project	Question 7 Values	Question 8 Values - Based Upon Question 7 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	4,100,000	7,400,000	7,400,000	5,700,000	4,900,000	5,700,000	4,900,000
B	10,500,000	14,700,000	12,600,000	18,900,000	18,900,000	12,600,000	14,700,000
C	7,500,000	9,000,000	10,500,000	9,000,000	10,500,000	13,500,000	13,500,000

Question 7 and 8 Cost Values.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	35	No Change	45	No Change
Average speed (mi/h)	13	27	9	27	16	35
Total delay (vehicle-hours/weekday)	970	170	1,650	170	810	130
Driver yielding (percent)	15	95	15	85	15	75

Question 9 and 10 Project Benefits

Project	Question 9 Values	Question 10 Values - Based Upon Question 9 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	4,400,000	7,900,000	7,900,000	6,200,000	5,300,000	6,200,000	5,300,000
B	8,100,000	11,300,000	9,700,000	14,600,000	14,600,000	9,700,000	11,300,000
C	3,700,000	4,400,000	5,200,000	4,400,000	5,200,000	6,700,000	6,700,000

Question 9 and 10 Cost Values.

Figure 18. Group Four Values Used in Questions 7, 8, 9, and 10.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	40,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	35	No Change	45	No Change	35	No Change
Average speed (mi/h)	13	27	16	35	13	21
Total delay (vehicle-hours/weekday)	1,940	340	810	130	970	380
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Question 7 and 8 Project Benefits.

Project	Question 7 Values	Question 8 Values - Based Upon Question 7 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	9,700,000	17,500,000	17,500,000	13,600,000	11,600,000	13,600,000	11,600,000
B	5,400,000	7,600,000	6,500,000	9,700,000	9,700,000	6,500,000	7,600,000
C	4,300,000	5,200,000	6,000,000	5,200,000	6,000,000	7,700,000	7,700,000

Question 7 and 8 Cost Values.

	Project A			Project B			Project C		
	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With	Present	10-Year Without	10-Year With
Segment length (miles)	1	No Change	No Change	1	No Change	No Change	1	No Change	No Change
AADT (vehicles/day)	16,000	20,000	20,000	16,000	20,000	20,000	16,000	20,000	20,000
Free-flow speed (mi/h)	35	No Change	No Change	25	No Change	No Change	35	No Change	No Change
Average speed (mi/h)	27	9	27	19	9	19	27	13	27
Total delay (vehicle-hours/weekday)	140	1,650	170	200	1,420	250	140	970	170
Fatal crashes (crashes/year)	0	0	0	0	0	0	0	0	0
Injury crashes (crashes/year)	3	9	3	3	9	6	6	9	6
Total crashes (crashes/year)	24	36	24	24	36	24	24	36	24

Question 9 and 10 Project Benefits.

Project	Question 9 Values	Question 10 Values - Based Upon Question 9 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	9,800,000	17,600,000	17,600,000	13,700,000	11,800,000	13,700,000	11,800,000
B	7,300,000	10,200,000	8,800,000	13,100,000	13,100,000	8,800,000	10,200,000
C	5,300,000	6,400,000	7,400,000	6,400,000	7,400,000	9,500,000	9,500,000

Question 9 and 10 Project Costs.

Figure 19. Group Five Values Used in Questions 7, 8, 9, and 10.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	20,000	No Change
Free-flow speed (mi/h)	25	No Change	35	No Change	35	No Change
Average speed (mi/h)	9	19	13	21	9	27
Total delay (vehicle-hours/weekday)	1,420	250	970	380	1,650	170
Fatal crashes (crashes/year)	0	0	0	0	0	0
Injury crashes (crashes/year)	9	6	9	3	6	2
Total crashes (crashes/year)	36	24	36	24	24	18

Question 7 and 8 Project Benefits

Project	Question 7 Values	Question 8 Values - Based Upon Question 7 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	7,300,000	13,100,000	13,100,000	10,200,000	8,800,000	10,200,000	8,800,000
B	4,900,000	6,900,000	5,900,000	8,800,000	8,800,000	5,900,000	6,900,000
C	9,200,000	11,000,000	12,900,000	11,000,000	12,900,000	16,600,000	16,600,000

Question 7 and 8 Cost Values.

	Project A		Project B		Project C	
	Before	After	Before	After	Before	After
Segment length (miles)	1	No Change	1	No Change	1	No Change
AADT (vehicles/day)	20,000	No Change	20,000	No Change	40,000	No Change
Free-flow speed (mi/h)	45	No Change	35	No Change	35	No Change
Average speed (mi/h)	16	35	13	27	13	27
Total delay (vehicle-hours/weekday)	810	130	970	170	1,940	340
Fatal crashes (crashes/year)	0	0	0	0	1	0
Injury crashes (crashes/year)	6	2	9	6	8	3
Total crashes (crashes/year)	24	18	36	24	36	24

Question 9 and 10 Project Benefits

Project	Question 9 Values	Question 10 Values - Based Upon Question 9 Order					
		If Order = ABC	If Order = ACB	If Order = BAC	If Order = BCA	If Order = CAB	If Order = CBA
A	4,800,000	8,600,000	8,600,000	6,700,000	5,800,000	6,700,000	5,800,000
B	12,700,000	17,800,000	15,200,000	22,900,000	22,900,000	15,200,000	17,800,000
C	9,700,000	11,600,000	13,600,000	11,600,000	13,600,000	17,500,000	17,500,000

Question 9 and 10 Cost Values.

Figure 20. Group Six Values Used in Questions 7, 8, 9, and 10.

APPENDIX D

Table 63. Question 11 Comments – ITE All Members Forum Responses.

Participant ID	Comment
39	Interesting.
45	I think safety for users of all modes is our highest responsibility when planning public facilities.
47	Total delay for all travelers (transit, pedestrian, bike) in addition to vehicle (auto) delay should be considered.
49	This was interesting, especially the decision making process regarding the project choices. The context of the project relative to the urban area, e.g., the growth or decline of the area in which the project is located,how the corridor fits into the area master plan, the network connectivity, potential impact on areas beyond the corridor, etc., is very important in the decision making process and this could not be conveyed in the limit format of this survey. The survey also cannot convey the thought process the respondent used to arrive at their answer.
51	Interesting choice of scenarios!
52	This survey was focused solely on travel speeds and ADT. There was no consideration to bicycle or pedestrian traffic or crossings. These days, we are actually avoiding the "make the road faster for motor vehicles" and instead spending millions on making them multimodal, where all users (motor vehicles, transit, bikes, peds) are considered in the overall picture. This survey looks more like something from 80's and 90's traffic engineering mentalities, maybe even the 60's. The answers I gave were not really what I have needed to focus on, and I would hope that TTI would also refocus their efforts to multimodal, like many traffic engineers (and politicians) have been doing.
53	Raod safety project decisions devoid of adjacent land use information obscures total benefits.
54	a good range of performance v cost.
56	The budgets provided for each project exceed our cities total Capitol Improvement Budget. We are forced into making much smaller improvements to accomplish our objectives.
67	Survey was vague, metrics interesting but are limited (as suggested) to properly make an assessment.
71	Not clear the meaning of those scenario design.
76	Safety is a priority and should be a major consideration in all project decisions. Delay and speed are also inputs to be considered.
79	My brain is too tired late on a Friday afternoon to mentally complete the b/c ratios that I would normally look at to prioritize projects. Not that I always go with it!

Table 64. Question 11 Comments – Dr. Robertson Email Responses.

Participant ID	Comment
2	While you many be able to do some conjoint analysis on what people prioritize cost wise with these question I think you have too many variable to really get at what people are balancing when making their decision.
7	Factors such as available budget and city politics would have some of the biggest draws as to what projects were selected first.
9	The questions were not what I expected. I'll be interested to see your results.
12	Good work. The end.
17	Responses depend on value of crash types and time if using B/C, but may be affected by agency priority for mobility and safety.
18	A lot of factors changed at once between the various scenarios. City's are challenged to find funding these days. This puts cost higher on the list than an Engineer may prefer.
21	I'm not sure what the goal of the "3 projects" question was. In most cases I make decisions on transportation improvements based on safety improvements overall. This typically means projects with lower speeds and lower rates of accidents in our urban setting. The questions in this survey did seem to relate more to a suburban experience where higher vehicle speeds and increased throughput is the goal.
26	Rankings very likely to change based upon additional information.

Table 65. Question 11 Comments – Dr. Hawkins or Dr. Carlson Email Responses.

Participant ID	Comment
2	Difficult to prioritize project implementation without knowing what the funding constraints might be. While the more expensive project improves traffic flow (average speed), in some cases, both of the other projects could be implemented, with funding remaining (based on the difference between project B and the sum of projects A and C) to complete other work. – ID 2
3	I don't make decisions about TCDs using these parameters. We tend to use HCM and HCS to justify the work but reliabilty for devices.
6	The choices made were highly subjective and did not afford an opportunity to explain WHY the choices were selected.
11	Good survey!....not much different that happens in real life!...thanks for giving us the chance to participate...Best wishes in your future!
12	A process considering accident reduction and delay reduction would be helpful.
13	While analyzing competing public projects can be challenging, and safety is the most important objective, efficient mobility must also be given strong consideration. Operational efficiency can be a powerful tool in gaining public support for increased transportation funding.
22	Money comes from the people. If they believe that the money first spent gave them great benefit, they are more likely to support the next project. While accident rate is important, average daily speed and delay are far more likely to make a greater impression. If the goal is to get all three built, the answer may be different than if the goal is to build only one.
24	In my experience, large projects of this kind, the local agency tends to implement them in phases as funds became available. Local agencies also tend to pursue grants that pay for some projects but not others depending on the goal the grant is intended to achieve.
26	I was somewhat disappointed with the survey as I didn't see the point of this exercise. I thought it was about selecting TCDs. I was trying to make gut decisions on priority w/o benefit of doing an B/C analysis. I was looking for the proverbial biggest bang for the buck in making selections put emphasis on mobility and safety.
29	Budget consideration is very important with the available funding in this economy.
30	This has nothing to do with traffic control devices per se, but is instead an artificial exercise in engineering economy. Also, in my experience, these decisions are made by political bodies, and non-listed factors are often dominant in the decisions. Not a good survey.
33	did you really suppose that respondents would actually do some calcs w/numbers provided? don't think that results will be very good--answers probably not robust
34	Very difficult to make a reasonable assessment given the information provided. Also unclear how this is related to traffic control device selection - seems to be civil projects of a relatively large scale.

Table 65 Continued.
Question 11 Comments – Dr. Hawkins or Dr. Carlson Email Responses.

Participant ID	Comment
39	The answers for the last two question were influenced solely by total costs, since the three projects would achieve no long-term net benefit over current conditions.
49	In the survey questions I interpreted the before/after impacts as 100% correct (e.g., if I make an investment in project C, I will definitely eliminate a fatal crash whereas if I don't first invest in procect C, I will definitely not eliminate a fatal crash.) I would think such wording would definitely influence your survey results--that's not necessarily a bad thing but is something you should point out in your analysis. The other aspect is that the survey presumes the safety analyst may choose not to spend monies on a project, whereas in practice there usually is a constraint (say one has $20 Million and one must decide which project will not be undertaken.) Again, a nuance that does not eliminate the utility of the survey but which should be considered when you discuss the results.

APPENDIX E

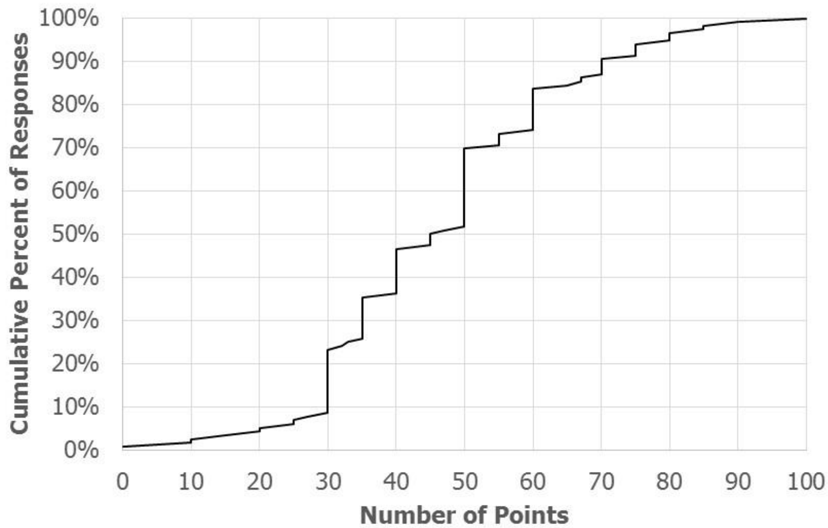


Figure 21. Cumulative Distribution of Points Allocated to the Objective of Safety.

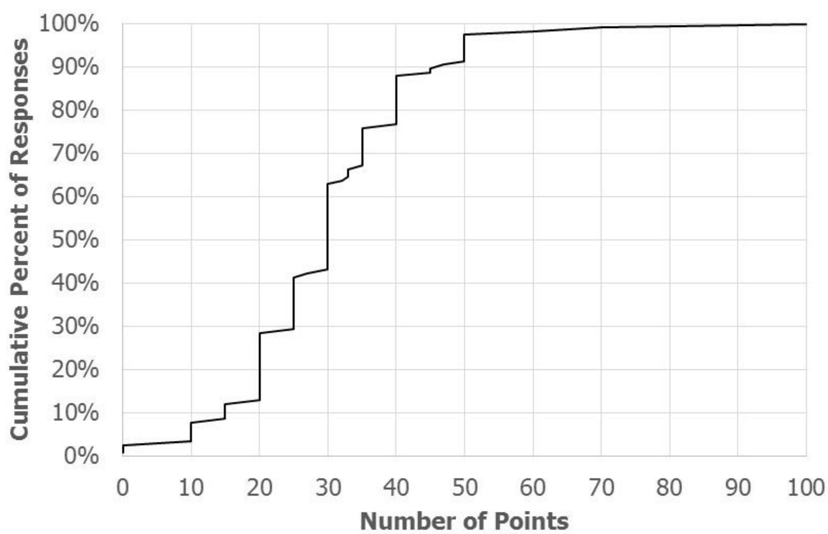


Figure 22. Cumulative Distribution of Points Allocated to the Objective of Reliability and Efficiency (Mobility).

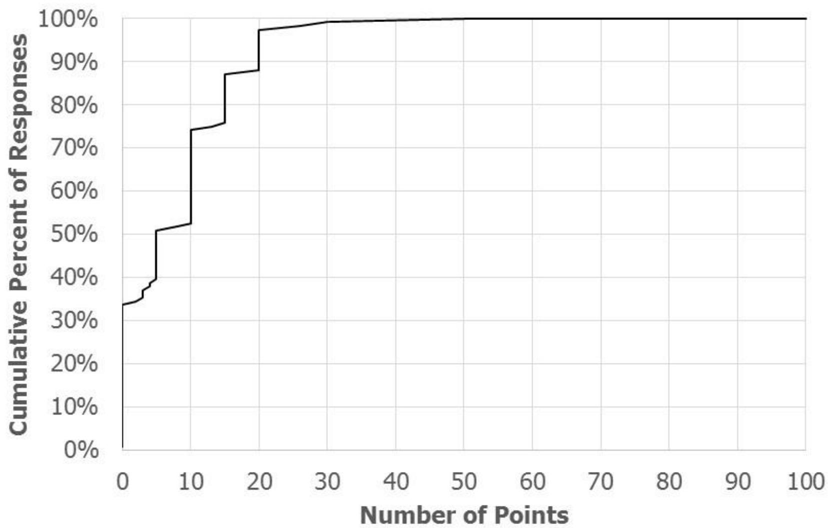


Figure 23. Cumulative Distribution of Points Allocated to the Objective of Environmental Sustainability.

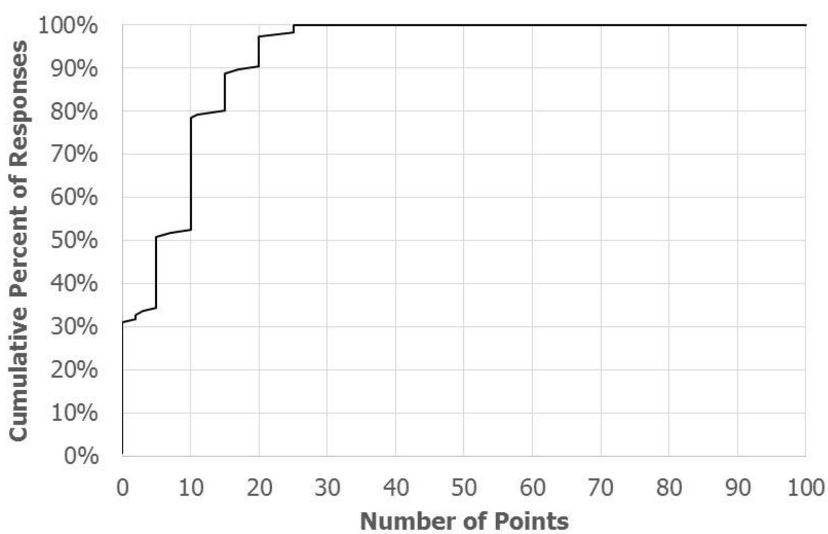


Figure 24. Cumulative Distribution of Points Allocated to the Objective of Economic Activity.

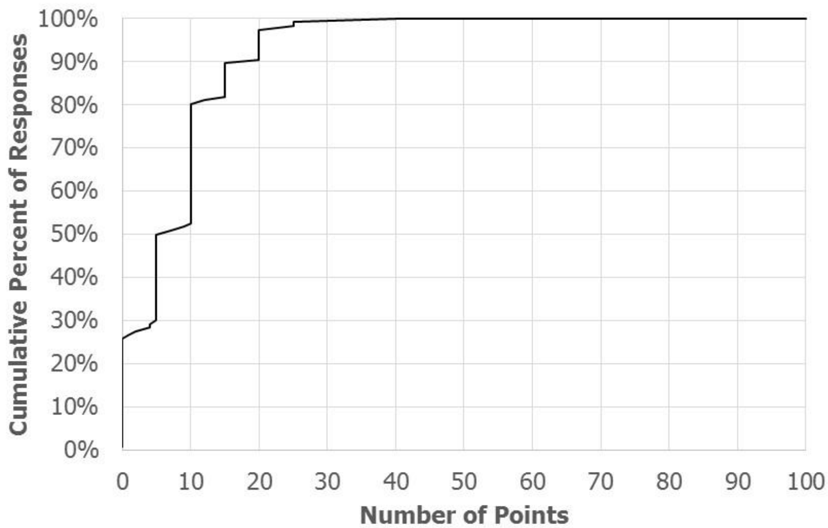


Figure 25. Cumulative Distribution of Points Allocated to the Objective of Other Community Expectations and Preferences.

APPENDIX F

Table 66. Chi-Square Test Statistic for Number of Points Allocated to Safety Given More than Zero Points Were Allocated to the Objective.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 22.5	9	6
22.5 to 32.5	14	22
32.5 to 42.5	22	25
42.5 to 52.5	26	27
52.5 to 62.5	22	16
62.5 to 72.5	13	8
> 72.5	8	11
Chi-square test statistic:		10.3
Degrees-of-freedom:		6
P-value:		0.1115

[a] Expected count values are based upon a normal distribution with a mean of 47 and standard deviation of 17.5 and total count of 115.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 67. Chi-Square Test Statistic for Number of Points Allocated to Reliability and Efficiency Given More than Zero Points Were Allocated to the Objective.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 12.5	9	6
12.5 to 22.5	20	24
22.5 to 32.5	33	26
32.5 to 42.5	30	28
> 42.5	21	14
Chi-square test statistic:		5.4
Degrees-of-freedom:		4
P-value:		0.2449

[a] Expected count values are based upon a normal distribution with a mean of 31 and standard deviation of 12.9 and total count of 113.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 68. Chi-Square Test Statistic for Number of Points Allocated to Economic Activity Given More than Zero Points Were Allocated to the Objective.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 7.5	21	24
7.5 to 12.5	27	33
12.5 to 17.5	22	12
> 17.5	10	12
Chi-square test statistic:		6.4
Degrees-of-freedom:		3
P-value:		0.0925

[a] Expected count values are based upon a normal distribution with a mean of 11 and standard deviation of 5.6 and total count of 80.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 69. Chi-Square Test Statistic for Number of Points Allocated to Environmental Sustainability Given More than Zero Points Were Allocated to the Objective.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 7.5	21	20
7.5 to 12.5	20	27
12.5 to 17.5	19	15
> 17.5	18	15
Chi-square test statistic:		3.9
Degrees-of-freedom:		3
P-value:		0.2683

[a] Expected count values are based upon a normal distribution with a mean of 12 and standard deviation of 7.4 and total count of 77.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 70. Chi-Square Test Statistic for Number of Points Allocated to Other Expectations and Preferences Given More than Zero Points Were Allocated to the Objective.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 7.5	25	29
7.5 to 12.5	27	35
12.5 to 17.5	22	10
> 17.5	13	12
Chi-square test statistic:		10.1
Degrees-of-freedom:		3
P-value:		0.0177

[a] Expected count values are based upon a normal distribution with a mean of 11 and standard deviation of 6.2 and total count of 86.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

APPENDIX G

Table 71. Probability of a Participant Including an Objective by Employer Type.

Safety						
Employer Type	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
City	33	33	100	0.0	87	100
State	17	16	94	5.7	71	100
Private Consultant	41	41	100	0.0	90	100
University or College	14	14	100	0.0	74	100
Reliability and Efficiency						
Employer Type	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
City	33	33	100	0.0	100	100
State	17	16	94	5.7	83	100
Private Consultant	41	39	95	3.4	89	100
University or College	14	14	100	0.0	100	100
Environmental Sustainability						
Employer Type	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
City	33	27	82	6.7	69	95
State	17	11	65	11.6	42	87
Private Consultant	41	22	54	7.8	38	69
University or College	14	11	79	11.0	57	100
Economic Activity						
Employer Type	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
City	33	28	85	6.2	73	97
State	17	9	53	12.1	29	77
Private Consultant	41	24	59	7.7	43	74
University or College	14	11	79	11.0	57	100
Other Expectations and Preferences						
Employer Type	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
City	33	28	85	6.2	73	97
State	17	11	65	11.6	42	87
Private Consultant	41	27	66	7.4	51	80
University or College	14	12	86	9.4	67	104

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Table 72. Average Number of Points Allocated to each Objective by Employer Type Given the Participant Allocated More than Zero Points to the Objective.

Employer Type	N_Yes	Average Points	STDEV	Lower Bound	Upper Bound
Safety					
City Government	33	43	15.1	37.5	47.8
State Government	16	47	22.7	36.1	58.3
Private Consultant	41	52	17.6	46.5	57.3
University or College	14	48	17.3	38.7	56.8
Reliability and Efficiency					
Employer Type	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
City Government	33	31	11.8	27.0	35.0
State Government	16	41	19.7	31.3	50.6
Private Consultant	39	27	8.8	24.6	30.2
University or College	14	26	10.5	20.9	31.8
Environmental Sustainability					
Employer Type	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
City Government	27	11	5.5	8.5	12.7
State Government	11	9	5.0	6.0	11.9
Private Consultant	22	14	6.8	10.8	16.5
University or College	11	12	5.9	8.1	15.0
Economic Activity					
Employer Type	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
City Government	28	11	5.9	9.1	13.5
State Government	9	10	7.3	4.9	14.4
Private Consultant	24	12	5.5	9.5	13.8
University or College	11	9	4.8	6.5	12.2
Other Expectations and Preferences					
Employer Type	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
City Government	28	10	5.4	7.6	11.6
State Government	11	10	10.6	3.3	15.8
Private Consultant	27	12	6.1	9.7	14.3
University or College	12	11	3.6	9.0	13.0

N_Yes = Total number including the specific factor.
STDEV = Standard deviation
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Table 73. Probability of a Participant Including an Objective Given the Participant's Area of Practice is Planning or Not Planning.

Area of Practice	N_total	N_Yes	%_Yes	STDEV	Lower Bound	Upper Bound
Safety						
Transportation Planning	32	32	100	0.0	100	100
Not Planning	84	83	99	1.2	96	100
Reliability and Efficiency						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	32	30	94	4.3	85	100
Not Planning	84	83	99	1.2	96	100
Environmental Sustainability						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	32	24	75	7.7	60	90
Not Planning	84	53	63	5.3	53	73
Economic Activity						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	32	23	72	7.9	56	87
Not Planning	84	57	68	5.1	58	78
Other Expectations and Preferences						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	32	23	72	7.9	56	87
Not Planning	84	63	75	4.7	66	84

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Table 74. Average Number of Points Allocated by Planners and Not Planner to Each Objective (With Allocations of Zero Points Removed).

Safety					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	32	46	18.6	39.6	52.4
Not Planning	83	48	17.1	44.3	51.7
Reliability and Efficiency					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	30	29	9.6	25.6	32.4
Not Planning	83	31	14.0	28.0	34.0
Environmental Sustainability					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	24	14	9.2	10.3	17.7
Not Planning	53	11	6.3	9.3	12.7
Economic Activity					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	23	12	6.4	9.4	14.6
Not Planning	57	10	5.3	8.6	11.4
Other Expectations and Preferences					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Transportation Planning	23	11	5.6	8.7	13.3
Not Planning	63	10	6.5	8.4	11.6

N_Yes = Total number including the specific factor.
STDEV = Standard deviation
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval

Table 75. Probability of a Participant Including an Objective Given the Participant's Area of Practice is Engineering or Not Engineering.

Area of Practice	N_total	N_Yes	%_Yes	STDEV	Lower Bound	Upper Bound
Safety						
Engineering	109	108	99	0.9	97	100
Not Engineering	7	7	100	0.0	100	100
Reliability and Efficiency						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	109	106	97	1.6	94	100
Not Engineering	7	7	100	0.0	100	100
Environmental Sustainability						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	109	74	68	4.5	59	77
Not Engineering	7	3	43	18.7	6	80
Economic Competitiveness						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	109	75	69	4.4	60	78
Not Engineering	7	5	71	17.1	38	100
Other Expectations and Preferences						
Area of Practice	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	109	82	75	4.1	67	83
Not Engineering	7	4	57	18.7	20	94

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 90 percent confidence interval.
Upper Bound = Upper value of 90 percent confidence interval.

Table 76. Average Number of Points Allocated by Engineers and Not Engineers to Each Objective (With Allocations of Zero Points Removed).

Safety					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	108	47	17.2	43.8	50.2
Not Engineering	7	55	21.6	39.0	71.0
Reliability and Efficiency					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	106	31	13.2	28.5	33.5
Not Engineering	7	26	7.9	20.1	31.9
Environmental Sustainability					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	74	12	7.3	10.3	13.7
Not Engineering	3	14	11.0	1.6	26.4
Economic Competitiveness					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	75	11	5.6	9.7	12.3
Not Engineering	5	12	7.6	5.3	18.7
Other Expectations and Preferences					
Area of Practice	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Engineering	82	11	6.4	9.6	12.4
Not Engineering	4	9	2.5	6.6	11.5

N_Yes = Total number including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 90 percent confidence interval.
Upper Bound = Upper value of 90 percent confidence interval.

Table 77. Probability of a Participant Including an Objective Given the Participant Has or Does Not Have a PE License.

Safety						
License	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	96	95	99	1.0	97	100
No PE License	20	20	100	0.0	100	100
Reliability and Efficiency						
License	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	96	94	98	1.5	95	100
No PE License	20	19	95	4.9	85	100
Environmental Sustainability						
License	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	96	60	63	4.9	53	72
No PE License	20	17	85	8.0	69	100
Economic Activity						
License	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	96	62	65	4.9	55	74
No PE License	20	18	90	6.7	77	100
Other Expectations and Preferences						
License	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	96	69	72	4.6	63	81
No PE License	20	17	85	8.0	69	100

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 78. Average Number of Points Allocated by Participants with and without PE Licenses (With Allocations of Zero Points Removed).

Safety					
License	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	95	48	18.4	44.3	51.7
No PE License	20	43	11.3	38.0	48.0
Reliability and Efficiency					
License	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	94	31	13.4	28.3	33.7
No PE License	19	28	10.2	23.4	32.6
Environmental Sustainability					
License	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	60	12	7.7	10.1	13.9
No PE License	17	13	6.1	10.1	15.9
Economic Activity					
License	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	62	11	5.6	9.6	12.4
No PE License	18	11	6.0	8.2	13.8
Other Expectations and Preferences					
License	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
PE License	69	11	6.6	9.4	12.6
No PE License	17	11	4.5	8.9	13.1

N_Yes = Total number including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 79. Probability of a Participant Including an Objective Based Upon Years of Experience.

Safety						
Experience	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	21	21	100	0.0	100	100
11 to 20 years	27	27	100	0.0	100	100
21 to 30 years	29	29	100	0.0	100	100
31 years or more	39	38	97	2.5	92	100
Reliability and Efficiency						
Experience	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	21	20	95	4.6	86	100
11 to 20 years	27	26	96	3.6	89	100
21 to 30 years	29	28	97	3.4	90	100
31 years or more	39	39	100	0.0	100	100
Environmental Sustainability						
Experience	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	21	19	90	6.4	78	100
11 to 20 years	27	17	63	9.3	45	81
21 to 30 years	29	17	59	9.1	41	77
31 years or more	39	24	62	7.8	46	77
Economic Activity						
Experience	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	21	17	81	8.6	64	98
11 to 20 years	27	18	67	9.1	49	84
21 to 30 years	29	19	66	8.8	48	83
31 years or more	39	26	67	7.5	52	81
Other Expectations and Preferences						
Experience	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	21	19	90	6.4	78	100
11 to 20 years	27	21	78	8.0	62	93
21 to 30 years	29	20	69	8.6	52	86
31 years or more	39	26	67	7.5	52	81

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 80. Average Number of Points Allocated by Participants Based Upon Years of Experience (With Allocations of Zero Points Removed).

Safety					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	21	43	13.3	37.0	48.4
11 to 20 years	27	46	16.2	39.5	51.7
21 to 30 years	29	42	17.1	35.7	48.2
31 years or more	38	43	20.7	36.1	49.3
Reliability and Efficiency					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	20	24	9.4	19.7	27.9
11 to 20 years	26	29	11.3	24.8	33.5
21 to 30 years	28	29	13.7	24.4	34.5
31 years or more	39	32	12.2	28.3	36.0
Environmental Sustainability					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	19	13	6.1	10.0	15.4
11 to 20 years	17	7	5.7	3.9	9.3
21 to 30 years	17	8	8.2	4.5	12.4
31 years or more	24	8	10.1	3.9	12.0
Economic Activity					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	17	9	6.5	5.5	11.7
11 to 20 years	18	8	7.1	4.7	11.2
21 to 30 years	19	9	7.8	5.2	12.3
31 years or more	26	9	6.4	6.1	11.0
Other Expectations and Preferences					
Experience	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
1 to 10 years	19	12	6.4	9.3	15.1
11 to 20 years	21	11	6.7	7.8	13.5
21 to 30 years	20	11	9.1	7.4	15.4
31 years or more	26	9	5.4	6.6	10.8

N_Yes = Total number including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 81. Probability of a Participant Including Safety or Reliability and Efficiency Based Upon ITE District.

ITE District(s)	N_total	N_Yes	%_Yes	STDEV	Lower Bound	Upper Bound
Safety						
Western District	32	32	100	0.0	100	100
Texas District	27	27	100	0.0	100	100
Northeastern District & Mid-Colonial District	15	14	93	6.4	81	100
Great Lakes District & Midwestern District	22	22	100	0.0	100	100
Southern District & Florida District	15	15	100	0.0	100	100
Canadian District & International District	5	5	100	0.0	100	100
Reliability and Efficiency						
ITE District(s)	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	32	32	100	0.0	100	100
Texas District	27	26	96	3.6	89	100
Northeastern District & Mid-Colonial District	15	14	93	6.4	81	100
Great Lakes District & Midwestern District	22	22	100	0.0	100	100
Southern District & Florida District	15	14	93	6.4	81	100
Canadian District & International District	5	5	100	0.0	100	100

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 82. Probability of a Participant Including Environmental Sustainability, Economic Activity, or Other Expectations and Preferences Based Upon ITE District.

Environmental Sustainability						
ITE District(s)	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	32	25	78	7.3	64	92
Texas District	27	19	70	8.8	53	88
Northeastern District & Mid-Colonial District	15	8	53	12.9	28	79
Great Lakes District & Midwestern District	22	12	55	10.6	34	75
Southern District & Florida District	15	9	60	12.6	35	85
Canadian District & International District	5	4	80	17.9	45	100
Economic Activity						
ITE District(s)	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	32	21	66	8.4	49	82
Texas District	27	22	81	7.5	67	96
Northeastern District & Mid-Colonial District	15	10	67	12.2	43	91
Great Lakes District & Midwestern District	22	13	59	10.5	39	80
Southern District & Florida District	15	10	67	12.2	43	91
Canadian District & International District	5	4	80	17.9	45	100
Other Expectations and Preferences						
ITE District(s)	**N_total**	**N_Yes**	**%_Yes**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	32	23	72	7.9	56	87
Texas District	27	23	85	6.8	72	99
Northeastern District & Mid-Colonial District	15	10	67	12.2	43	91
Great Lakes District & Midwestern District	22	17	77	8.9	60	95
Southern District & Florida District	15	9	60	12.6	35	85
Canadian District & International District	5	4	80	17.9	45	100

N_total = Total number of respondents.
N_Yes = Total number including the specific factor.
%_Yes = Percent of respondents including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 83. Average Number of Points Allocated to Safety or Reliability and Efficiency Based Upon ITE District (With Allocations of Zero Points Removed).

Safety					
ITE District(s)	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	32	45	18.0	38.8	51.2
Texas District	27	46	17.4	39.4	52.6
Northeastern District & Mid-Colonial District	14	49	11.8	42.8	55.2
Great Lakes District & Midwestern District	22	49	16.2	42.2	55.8
Southern District & Florida District	15	49	23.1	37.3	60.7
Canadian District & International District	5	44	20.4	26.1	61.9
Reliability and Efficiency					
ITE District(s)	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	32	30	11.8	25.9	34.1
Texas District	26	30	10.6	25.9	34.1
Northeastern District & Mid-Colonial District	14	36	21.7	24.6	47.4
Great Lakes District & Midwestern District	22	29	12.5	23.8	34.2
Southern District & Florida District	14	33	10.1	27.7	38.3
Canadian District & International District	5	29	8.2	21.8	36.2

N_Yes = Total number including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

Table 84. Average Number of Points Allocated to Environmental Sustainability, Economic Activity, or Other Expectations and Preferences Based Upon ITE District (With Allocations of Zero Points Removed).

Environmental Sustainability					
ITE District(s)	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	25	13	9.6	9.2	16.8
Texas District	19	12	5.7	9.4	14.6
Northeastern District & Mid-Colonial District	8	15	10.2	7.9	22.1
Great Lakes District & Midwestern District	12	11	4.8	8.3	13.7
Southern District & Florida District	9	9	3.0	7.0	11.0
Canadian District & International District	4	11	6.6	4.5	17.5
Economic Activity					
ITE District(s)	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	21	12	5.9	9.5	14.5
Texas District	22	10	5.6	7.7	12.3
Northeastern District & Mid-Colonial District	10	9	6.6	4.9	13.1
Great Lakes District & Midwestern District	13	12	5.4	9.1	14.9
Southern District & Florida District	10	11	5.7	7.5	14.5
Canadian District & International District	4	12	3.5	8.6	15.4
Other Expectations and Preferences					
ITE District(s)	**N_Yes**	**Average Points**	**STDEV**	**Lower Bound**	**Upper Bound**
Western District	23	10	5.3	7.8	12.2
Texas District	23	10	5.2	7.9	12.1
Northeastern District & Mid-Colonial District	10	10	6.3	6.1	13.9
Great Lakes District & Midwestern District	17	12	5.9	9.2	14.8
Southern District & Florida District	9	11	11.1	3.7	18.3
Canadian District & International District	4	11	6.6	4.5	17.5

N_Yes = Total number including the specific factor.
STDEV = Standard deviation.
Lower Bound = Lower value of 95 percent confidence interval.
Upper Bound = Upper value of 95 percent confidence interval.

APPENDIX H

Table 85. Chi-Square Test Statistic for Number of Points Allocated to Mobility by State Employees for the Confidence Interval in Table 17.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 32.5	6	6
32.5 to 47.5	5	6
> 47.5	6	5
Chi-square test statistic:		0.47
Degrees-of-freedom:		2
P-value:		0.7890

[a] Expected count values are based upon a normal distribution with a mean of 41 and standard deviation of 19.7 and total count of 17.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 86. Chi-Square Test Statistic for Number of Points Allocated to Mobility by Private Consultants for the Confidence Interval in Table 17.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 22.5	5	3
22.5 to 32.5	15	17
32.5 to 42.5	14	14
> 42.5	5	5
Chi-square test statistic:		1.5
Degrees-of-freedom:		3
P-value:		0.6936

[a] Expected count values are based upon a normal distribution with a mean of 27 and standard deviation of 8.8 and total count of 39.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 87. Chi-Square Test Statistic for Number of Points Allocated to Mobility by Professionals with 0 to 10 Years of Experience for the Confidence Interval in Table 21.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 22.5	9	6
22.5 to 27.5	4	5
> 27.5	7	9
Chi-square test statistic:		1.5
Degrees-of-freedom:		2
P-value:		0.4653

[a] Expected count values are based upon a normal distribution with a mean of 24 and standard deviation of 9.4 and total count of 20.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 88. Chi-Square Test Statistic for Number of Points Allocated to Mobility by Professionals with 31 Years of Experience or More for the Confidence Interval in Table 21.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 22.5	9	11
22.5 to 32.5	12	11
32.5 to 42.5	11	13
> 42.5	8	4
Chi-square test statistic:		2.7
Degrees-of-freedom:		3
P-value:		0.2550

[a] Expected count values are based upon a normal distribution with a mean of 32 and standard deviation of 12.2 and total count of 39.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 89. Chi-Square Test Statistic for Number of Points Allocated to Environmental Sustainability by Professionals with 0 to 10 Years of Experience for the Confidence Interval in Table 21.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 12.5	9	8
12.5 to 17.5	6	6
> 17.5	4	5
Chi-square test statistic:		0.1873
Degrees-of-freedom:		2
P-value:		0.9106

[a] Expected count values are based upon a normal distribution with a mean of 13 and standard deviation of 6.1 and total count of 19.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.

Table 90. Chi-Square Test Statistic for Number of Points Allocated to Environmental Sustainability by Professionals with 11 to 20 Years of Experience for the Confidence Interval in Table 21.

Cell Data Range	Expected Count[a]	Actual Count[b]
< 12.5	9	6
12.5 to 17.5	5	8
> 17.5	3	3
Chi-square test statistic:		2.7
Degrees-of-freedom:		2
P-value:		0.2507

[a] Expected count values are based upon a normal distribution with a mean of 7 and standard deviation of 5.7 and total count of 17.
[b] Actual count does not include observations of zero since confidence intervals were calculated without these data.