CREATING A SYSTEMS ENGINEERING APPROACH FOR THE MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

A Thesis

by

HEATHER CHRISTINE MCNEAL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Civil Engineering

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Approved by:

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Committee Members,	Yunlong Zhang
	Abhijit Deshmukh
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ABSTRACT

Creating a Systems Engineering Approach for the Manual on Uniform Traffic Control Devices.

(May 2010)

Heather Christine McNeal, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Gene Hawkins

The Manual on Uniform Traffic Control Devices (MUTCD) establishes the basic principles for the design, selection, installation, operation, maintenance, and removal of traffic control devices (TCDs). The MUTCD indicates that some TCDs that are required and some are recommended, depending on the situation. However, most TCDs are not required and the decision to use a given TCD in a given situation is typically made by an engineer (or an individual working under engineering supervision) based on a variety of information. Not all engineers have the same degree of experience in making TCD decisions, and not all engineers that make these decisions have traffic engineering expertise. There are many other factors not addressed by the MUTCD that can lead to differences in the decision-making process. To assist engineers with evaluating these factors, this research developed a decision analysis process to assist engineers with making TCD decisions.

The value of this research is the idea that the decision analysis process for TCD can be modeled and analyzed using appropriate factors. The developed factors include need,

impact, influence, and cost. The process developed in this research applies two elements to each factor. One element compares the importance of each factor among all the other factors, and the other incorporates the engineer's judgment into the TCD decision. The first element described uses a decision analysis method, analytic hierarchy process, to determine the weights for each factor, or coefficients, as applied generally to a TCD. The second uses a mixture of quantitative and qualitative engineering judgment to determine the degree to which the factor applies to the TCD situation, or situational variable. The output of this process was a utility value that can be compared to a scale and determine the installation value of the device. This process will contribute to more uniform decisions amongst all levels of experience in TCD decision-making. Additional research that could expand on this developed process would include data collection on typical importance values for each factor as applied to a TCD and on decision scales for specific TCD situations.

When applying this research, it is important to remember that it is not the intent of this process to remove engineering judgment. This is an important part of the process and should remain as such.

DEDICATION

This thesis is dedicated to my parents, Patrick and Janet McNeal. Their support, confidence, and understanding have helped me to achieve my success.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Gene Hawkins, and my committee members, Dr. Yunlong Zhang, and Dr. Abhijit Deshmukh, for their guidance and support throughout the course of this research.

Thanks also to the professionals that provided their expertise to my data collection for the research. Your contributions were extremely helpful and appreciated.

NOMENCLATURE

AASHTO	American Association of State and Highway Transportation Officials
AHP	Analytic Hierarchy Process
DOT	Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NCUTCD	National Committee on Uniform Traffic Control Devices
PDP	Project Development Process
TCD	Traffic Control Device
TX MUTCD	Texas Manual on Uniform Traffic Control Devices
a	Relationship between factors or coefficients
c	Cost factor
i	Influence factor
f	Impact factor
n	Need factor
U_m	Utility model
x	Individual factor consideration or situational variable

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CHAPTER I

INTRODUCTION

The *Manual on Uniform Traffic Control Devices* (MUTCD) is a national document that assists engineers in making decisions about selecting, designing, installing, operating, maintaining, and removing signs, signals, markings, and other traffic control devices (TCDs) (1). Although thorough in addressing selection, design, installation, operation, maintenance, and removal of each TCD, there is no explanation of the reason for this decision or consider factors beyond the MUTCD. This can lead to differences between engineers in deciding which TCD treatment, if any, is the most appropriate. The purpose of this research is to devise a process that would guide practitioners towards making a more thorough and consistent TCD decision. To reach this goal, a thorough understanding of the experienced traffic engineer's TCD decision process is needed. Although there have been many revisions to the MUTCD since its first publication, its application to the general decision-making process has remained the same. In the past few decades, however, fields such as engineering systems, decision theory, and probability theory have been growing in development. The application of these tools to the MUTCD would allow for a more formalized, unified decision-making process. The results of this research would be a TCD decision-making process that would have direct implementation into everyday practice. The development of case studies, using input from professional traffic engineers, tests the accuracy of this proposed process.

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This thesis follows the style and format of *Transportation Research Board*.

PROBLEM STATEMENT

Knowledge of, training on, and experience with the MUTCD differ from engineer to engineer. Professionals tend to make TCD decisions using their engineering judgment on a case-by-case basis. Not all engineers have the same amount of experience in TCD decisions, and not all engineers that make TCD decisions have traffic engineering expertise. There are many other influences outside of the MUTCD that need to be considered when making TCD decisions. An engineering system handles these other influences, which experienced traffic engineers understand and frequently apply. Lack of experience in this specialization may not lead to the most appropriate decision. These engineers follow the MUTCD guidelines to the best of their ability, but the MUTCD does not explain the reasoning for certain requirements, how to make a particular decision, or other considerations included in the decisions. A decision analysis process is needed that would assist engineers with these TCD decision limitations. The knowledge from experienced traffic engineers of how they approach TCD decisions would assist in the development of the process. The common factors and issues that are considered with these decisions would be addressed and put into a formal process that outlines these practitioners' thought process for TCD decisions.

RESEARCH OBJECTIVES

The goal of this research is to develop a process that will assist practicing traffic engineers in making more thorough TCD decisions that result in greater uniformity in application. To accomplish this, three objectives are outlined:

- Understand concepts of systems engineering, decision analysis, and probability theory that may be applicable to the project,
- Identify different factors that are considered in the selection, design, installation, operation, maintenance, and removal of TCDs, and
- Develop a general process towards device selection, installation, operation, maintenance, or removal decisions using the tools addressed in the background and the data collected.

THESIS ORGANIZATION

There are seven primary tasks conducted in the research for this thesis: 1) identify background information related to the MUTCD and options for modeling the decision-making process, 2) identify the current practice for TCD decisions, 3) develop and distribute surveys to verify state-of-practice, 4) identify and develop models for general process, 5) select best model for general process, 6) create and apply TCD decision case studies, and 7) revise and recommend a final process. Item 1 is addressed in Chapter II, items 2 through 5 are addressed in Chapter III, and item 6 is addressed in Chapter IV. Item 7 is addressed in a draft form in Chapter III, and revised into the final form in

Chapter IV. The following paragraphs describe the organization of the tasks as well as the organization for this thesis.

Chapter II Background

Chapter II presents the background for the research including information about the MUTCD, transportation decision making, systems engineering, and statistics. Transportation decision making includes decision-making methods used in different transportation specialties including traffic engineering and TCD decisions. The statistics background includes probability theory and decision analysis. Utility theory and Analytic Hierarchy Process are tools of decision analysis that are also outline in this research. The most applicable process selected for this research is the Analytic Hierarchy Process.

Chapter III Process Development

Chapter III outlines the development of the general process for this research. It includes the initial investigation, common factors currently used for TCD decisions, and the development of a general process. The investigation resulted in a comprehensive list of all considerations used for the process development and TCD decisions and outlined the state-of-practice for TCD decisions. Grouping these considerations together created four main factors: need, impact, influence, and cost, which are used as the basis for the decision analysis. A survey of professionals verified the validity of these factors. The development and application of different decision models led to the selection of the Analytic Hierarchy Process for the proposed general process.

Chapter IV Process Application

Chapter IV applies the general process to specific decision cases. Four case studies were developed for individual TCD applications including a Traffic Generator sign, a marked crosswalk, a Stop Ahead sign, and an Intersection control beacon. A fifth case study was also developed as a TCD system. A turn-prohibited system that includes pavement markings, signs, and channelizing devices tested the process as a more complicated situation. After initial development, applying the process to the test cases helped to refine the process.

Chapter V Conclusions and Future Research

Chapter V summarizes the research efforts and presents the conclusion for the final recommended process. It also outlines future research suggestions that are beyond the scope of this research.

SUMMARY OF PROPOSED GENERAL PROCESS

The result of this thesis was a general process that models the decision making process for selecting TCDs. The process includes four main factors for every decision analysis:

need, impact, influences, and cost. The total utility for the decision, U_m, is a summation of the product of each of the factor's coefficient, or weight, *a*, and a situational variable, *x*, as seen in the equation below.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

The subscripts *n*, *f*, *i*, and *c* denote the need, impact, influences, and cost, respectively. The coefficients, *a*, are determined using a partial Analytic Hierarchy Process and will be the same for all similar TCDs. This means that all advanced traffic control decisions will use the same coefficients within a particular agency. The situational variables, *x*, evaluates the engineer's opinion of the device's applicability to the situation. Comparing the total utility to a range of values indicates the level of benefit if the device is installed.

CHAPTER II

BACKGROUND

Before this new process can be developed, some background information on the current process used by practicing engineers is examined. The MUTCD is a basic engineering document used to guide engineers with installation, maintenance, and removal of TCD, but there are other tools that may help apply these guidelines such as engineering systems, decision analysis, or statistical methods.

MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

The MUTCD contains basic principles for TCDs (1). This document is the starting point for considering the installation benefits of a device. There are three types of statements used to classify the necessity of the traffic control device:

- A standard describes a mandatory practice. It describes when a device is required to be installed or how it is required to be installed. If the device is not required by the standard, it does not have to be used, but that does not mean that it cannot be used.
- A guidance describes a practice that is recommended but not mandatory. This classification can be modified according to engineering judgment or study. It allows a device to be installed, but does not require it.
- An option describes a "permissive condition". It generally describes "allowable modifications" to the previous two classifications.

If a device is not required or recommended by the MUTCD, it does not necessarily mean that it cannot be installed. It simply means that an engineer is not required to install one, unless an engineering study or judgment suggests otherwise. As previously stated, the MUTCD provides guidelines of how to select, install, maintain, and remove TCD, but does not always explain the reasoning or other considerations that could be included in the decision process.

In addition to the MUTCD, other factors also determine the installation benefits of a device. Defining these factors and their application to TCD will be determined in this research.

ENGINEERING SYSTEMS

Systems engineering looks at the "big picture" (2). It considers everything and everyone to come up with potential solutions. This system emphasizes that there can be many correct solutions to a problem. Along with many other things, systems engineering is used to develop processes such as the one included in this research. Sage and Armstrong claim that systems engineering can be accomplished through formulation, analysis, and interpretation of each solution and the impacts of the different perspectives (engineer, politician, laypeople) (2). These actions are also applicable to each individual step within the systems process. The formulation step defines the problem, sets the goals and objectives, and selects the sufficient alternatives for evaluation. The analysis step determines the impacts or consequences of each alternative. These alternatives are also refined to meet the system's objectives and goals better. The interpretation step involves making the decision and creating a plan for implementation.

Sage and Armstrong also define phases of systems engineering as the "definition, design, development, production, and maintenance of functional, reliable, and trustworthy systems within cost and time constraints" (2). The system definition phase determines the inputs required for the system, by evaluating the stakeholder's needs, objectives, and activities. It also develops several concepts that would satisfy the goals and objectives of this phase. The system design and development phase specifies the content and detail required for the system product. It also established the detailed design specifications of the system product. In the systems operation and maintenance phase, the system is implemented, tested, refined, and accepted. Figure 1 shows the interrelated matrix of flow between the steps and phases for the engineering system.

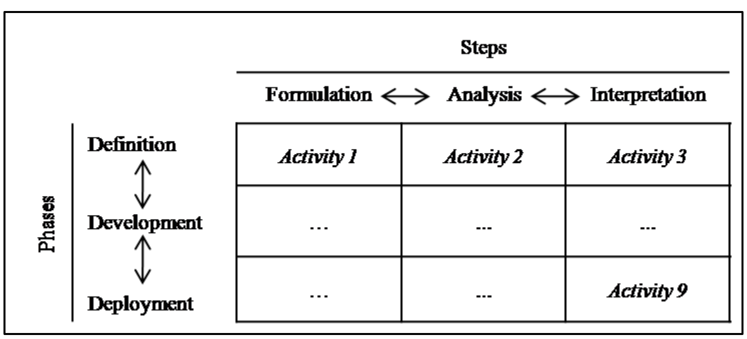

Figure 1. Framework work systems engineering processes (2)

The directional arrows indicate that the process is constantly updating to meet the objectives and goals.

The decisions in systems engineering are dynamic and constantly updating. Ken Hammond outlines three features in his theory of dynamic decision-making (3):

1. Decisions are varied in a continuum from analytical to intuition.
2. Judgments are more valid when there is a stronger relationship between the decision-maker and the task information
3. As more task information becomes more defined, the decision process will change.

These tasks are “dynamic decision making tasks” and are characterized by requiring a series of decisions that are interrelated and made in real time. “The decision situation changes, both autonomously and as a consequence of the decision maker’s actions over time” (4).

Engineering Systems in Transportation

There are many examples of applied engineering systems. NASA has a thorough handbook on the systems engineering engine that is used for the organization (5). In the transportation field, California Department of Transportation developed a guidebook for intelligent transportation system (ITS) implementation that uses the systems engineering practice (6).

For the purposes of this project, systems engineering is applied by taking the transportation system users, designers, and policy makers' opinions and issues into consideration in the TCD decision-making process. Time constraints, budget limitations, and user safety are just examples of factors that need to be balanced in the decision-making process using systems engineering. The application of systems engineering will be the foundation for development of the process in this research.

In this thesis, all of the decisions are dynamic. A more effective decision can be made as more information of the site or device evaluation becomes available. The process devised in this thesis is also dynamic, in that, if implemented it will begin to generate data which will in turn assist in updating the process and making it more effective.

STATISTICS BACKGROUND

The branches of statistics that will be integrated in this research are inferential statistics and statistical decision theory. Inferential statistics is "the process of drawing conclusions or making predictions on the basis of limited information," i.e. using information from a small sample of the population and applying it to the entire population (7). Statistical decision theory uses this inferred information to make choices from "alternative actions." The underlying issue with these branches is uncertainty of outcomes. Inferences, made from incomplete information, add a degree of uncertainty, and then decisions are made based on these inferences.

The Bayesian approach to statistics tries to reduce the amount of uncertainty by applying all available information (7). The addition of this information to previously acquired data reduces uncertainty. The procedure of combining this information as a formal method is called Bayes' theorem. This method enables the information to be constantly updated.

Probability Theory

Uncertainty can be mathematically quantified using the theory of probability (7). Basic probability theory used in statistical inference and decision can be found in most beginning statistics textbooks. Some concepts of probability that apply to this research include unique events, degree of belief, and subjective interpretation. Although there may be similar TCD situations, each TCD decision will not be identical which makes this a unique event. Since the events do not have observed frequencies, the probability of an event is the degree of belief for the situation. This subjective interpretation of probability is an individual's judgment. In the proposed process, the situational variable is determined using the decision maker's interpretation of the device installation benefits.

Decision Analysis

"We can define a generic decision making problem as consisting of the following activities:

- Studying the situation
- Organizing multiple criteria
- Assessing multiple criteria
- Evaluating alternatives on the basis of the assessed criteria
- Ranking the alternatives
- Incorporating the judgments of multiple experts" (8).

While most decisions are intuitive and require little thought, some are more complex and need to apply a formal decision-making process, or decision theory (7). Since the decisions made in this research have conditional events and unknown outcomes, there is a degree of uncertainty in the process. The major influence on decisions in this research is the expected payoffs versus losses and how significantly the consequences affect them. The value for these payoffs or losses can be positive or negative and applied to a decision tree or tree diagram. Payoffs and losses are usually associated with monetary values. To measure the relative value of the payoffs or losses, the decision maker will apply the theory of utility. After this application, the terms payoffs and losses are no longer strictly monetary rewards, but a general number. Once there is a utility for a series of choices that all have a likelihood probability, the multiplication of the utility and probability will enable the decision maker to rank the events and make the corresponding decision.

Utility

A common application of utility theory in transportation is in mode choice modeling (9). The modeling uses the multimodal logit (MNL) model. A traveler deciding which mode of transportation to use (walk, bike, motor vehicle, etc.) will choose the travel mode that has the greatest utility to them. However, it is difficult for a modeler to measure this utility, and each individual may have a different perception of each mode choice. The utility function derived for this application is shown below (9).

$$U_m = a_{0,m} + a_{1,m}x_{1,m} + \cdots + a_{n,m}x_{n,m} + \varepsilon$$

The situational variable $x_{i,m}$ indicates the likelihood “that a traveler in category i would choose mode m.” The situational variable could be total travel time for a specific income taking the bus. The product of this variable with $a_{i,m}$ equates to the situational utility for that mode factor. “The random variable ε accounts for the factors that are not easily measured or observed” (9).

Analytic Hierarchy Process

A basic issue with decision theory is determining the importance weights of the activities (10). Multiple criteria decision making considers the many different criteria included in the decision. The Analytic Hierarchy Process, developed by Dr. Thomas L. Saaty, is a process that determines the relative strength or priority of an activity or objective. AHP is a “multiobjective multicriteria decision-making approach which employs a pairwise comparison procedure to arrive at a scale of preferences among a set of alternatives” (10). These comparisons can “reflect the relative strength of preferences and feelings” (11). It considers several factors simultaneously and allows for feedback. The basic procedure, as applied to this thesis, for the AHP is in Appendix A

TRANSPORTATION DECISION MAKING

Many, if not all, aspects of transportation engineering require some type of decision analysis. The next subsection describes general decision-making techniques used primarily in transportation planning, but has application to many areas within the transportation field. The second subsection describes state-of-practice for decision-making techniques within traffic engineering and the analysis of TCDs.

Principles of Transportation Decision Making

Sinha and Labi wrote a textbook about transportation decision-making (4). The book highlights the many considerations involved in the transportation design, planning, and management decisions. It does not cover traffic engineering decisions explicitly, but it does describe concepts that can be applied to the process being developed in this research.

A transportation decision can be as simple as a single project or as complex as an entire network (4). At the project level, the project development process (PDP) involves "design, construction, management, operation, and post-implementation evaluation" (4). Programs developments rank, prioritize, and optimize projects to maximize the network-level utility. Due to differences in requirements and conditions, this process is different for each agency. It considers "sensitive social, economic, environmental, cultural, and public policy issues (4)."

Considerations for the development of the transportation system include technical, environmental, economic efficiency, economic development, legal, and sociocultural impacts (4, 12). Although the technical impacts are a large portion of the development process, the other impacts are significant in maintaining a complete and suitable system to the population. The technical impacts include all sight conditions, safety, accessibility, mobility, congestion, risk and vulnerability, and intermodal movement efficiency. Environmental impacts include air quality, water, noise, and aesthetics. Economic efficiency includes the initial and life cycle costs and benefit to cost ratio. Economic development considers the growth of the population, employment, and economy. The legal impact includes tort liability exposure. Sociocultural impacts describe the quality of life of the population.

Other ways of categorizing impacts can be direct versus indirect, tangible versus intangible, real versus pecuniary, internal versus external, cumulative versus incremental, and other categories that can be found in Sinha and Labi (4). Table 1 defines each impact.

Table 1. Definition of impact types

Impact Type	Definition
Direct	Impact related directly to the goals and objectives
Indirect	"By-products of the actions, experienced by society as a whole"
Tangible	Benefits and costs that can be measured in monetary terms
Intangible	Cannot be measured monetarily e.g. increased aesthetics do to rehabilitation of roadway
Real	Money that is lost or gained
Pecuniary	Money that is moved around in the economy
Internal	Impacts that affect the study area or analysis period
External	Impacts that occur outside the study area or analysis period
Cumulative	Initial costs and benefits
Incremental	Costs and benefits that occur due to the change minus the existing cost and benefits

Sinha and Labi agree with the professionals interviewed in this thesis research in that the evaluation process should "identify the most optimal course of action" and investigate alternative scenarios (4). The basis for evaluation of each project is its efficiency, effectiveness, and equity (13). Efficiency is the relative return of the investment. Effectiveness is the degree to which the alternative will meet the objectives. Equity evaluates the distribution of the cost and benefits of the alternative. Procedures for evaluating transportation alternatives are established at most agencies (4). There may or may not be documentation of these, and therefore, they can vary from one decision maker to another. This agrees with the results of the initial investigations seen in Appendix B. "Formally documented evaluation procedures enable rational, consistent, and defensible decision-making" (4). Sinha and Labi have outlined ten general steps below for their evaluation procedure (4):

1. Identify the evaluation subject
2. Identify the concerns of the decision makers and other stakeholders
3. Identify the goals and objectives of transportation improvement
4. Establish the performance measure for assessing objectives

5. Establish the dimensions for analysis (evaluation scopes)
6. Recognize the legal and administrative requirements
7. Identify possible courses of action and develop feasible alternatives
8. Estimate the agency and user cost
9. Estimate other benefits and costs
10. Compare alternatives

Hierarchy of Outcomes

Sinha and Labi outline a hierarchy of outcomes for the transportation system as seen in Figure 2 (4). Overall goals are the basis for evaluation. As previously stated these include efficiency, effectiveness, and equity. In this thesis, the overall goals are the need, impact, influences, and cost.

General goals include "system preservation, economic development, environmental quality protection, and so on" (4, 12). Each general goal has a set of objectives to establish performance measures. "Identification of goals and objectives is a key prerequisite to the establishment of performance measures and therefore influences the evaluation and decision outcome" (4). In this thesis, the general goal is the coefficients and the objectives are the measurable variables

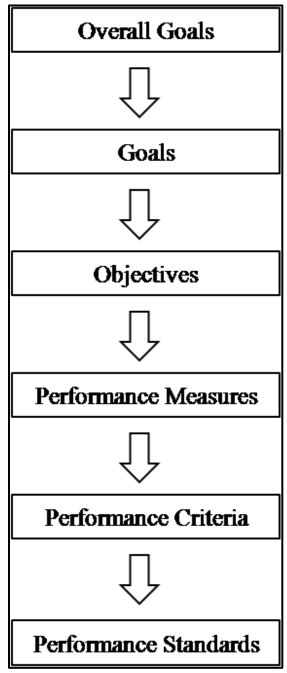

Figure 2. Hierarchy of desired outcomes for transportation system projects and programs (4)

"Performance measures represent, in quantitative or qualitative terms, the extents to which a specific function is executed" (4). There can be performance measures at both the network and project levels (4). For this thesis, the network level would be the coefficients and the project level would be the measurable variables. Performance criteria are the entities of the performance measure, and performance standards are the values associated with these criteria. Sinha and Labi also outline properties of a good performance measure (4). These properties include appropriateness, measurability, dimensionality, realistic, defensible, and forecastable.

In evaluating the transportation system, there are different dimensions that assist in the identification of the types of performance measures involved (4, 12). Those dimensions include entities affected (the users, community, agency, facility operator, and government), geographical scope of impacts (project, corridor, regional, national, and global), and temporal scope of impacts (short, medium, and long term). These dimensions are also applicable to traffic engineering decisions.

The multiple entities and stakeholders may all have a different perspective and expectation (14). The level of agency responsibility may require different performance measures. Local governments may be very concerned about a corridor improvement whereas at the state level it may not be as beneficial. Sinha and Labi also outline the current outcome oriented performance measures of state agencies. By monitoring performance measures, an agency can benefit from "clarity and transparency of decisions, attainment of policy goals, internal and external agency communications, and monitoring and improvement of agency business processes" (4).

Agencies have different ways to evaluate types of cost (initial, life cycle, etc) (4). The application of cost in this research is more generally applied, but agencies can include their cost analysis procedures in this process easily. That is one benefit of the design of this decision process in this thesis.

Evaluation Using Multi-Criteria

Many decisions try to maximize one criterion by evaluating performance (4). In many transportation situations, however, there needs to be an analysis of multiple criteria. There are two basic steps to evaluate multiple criteria. The first is to determine the important relationships between the different criteria. The second is to convert all the criteria from their original dimensions to a uniform dimension. The first step gives weights to the criterion, and the second gives a scale. Next, the level of "desirability" is determined through the combination of the impacts of each alternative. There may not be a clear "dominate" alternative, but by evaluating using the multiple criteria method, the performance measures will identify good alternatives.

To establish weights for the criterion, Sinha and Labi outline several different methods such as equal weighting, direct weighting, regression-based observer-derived weighting, Delphi technique, gamble method, pairwise comparison of performance criteria, and value swinging method (4). Table 2 defines each of these.

Table 2. Weighting method definitions

Weighting Method	**Definition**
Equal weighting	Assigns same weight to all criteria
Direct weighting	Assigns different weights directly to criteria
Regression-bases observer-derived weighting	Uses statistical regression to assign weights to criteria
Delphi technique	Assigns weights to criteria as a decision making group
Gamble method	Assigns weights based on the outcome of risk
Pairwise comparison	Develops weight based on experience
Value swinging	Assigns weight to criteria at minimum accepted value

This research evaluated methods such as equal weighting, the direct weighting, regression-based weighting, and pairwise comparison. The Delphi technique was not evaluated because it would be too difficult to get a diverse group of transportation professionals together to determine the weights, although it may be useful in further research. The gamble method generally assigns weights based on the outcome of risk. Not all criteria in this research are risk based; therefore, this method was not evaluated. Value swinging would be too difficult to determine, as well, because of the limited professional resources of this project, but it may also prove useful in further research.

There are typically two approaches when scaling criteria, the value function approach and the utility function approach (4). The value function is assigns a value on a scale, for example 0 to 100, for all criteria based on the decision maker's preference. The utility function applies a value to each level of a specific criterion. Again, this is based on the decision maker's preference, but the utility function is generally linear, concave, convex, or S-shaped based on the decision maker's risk taking behavior.

Once the performance criteria are weighted and scaled, they need to be combined to determine the overall outcome and priority of the alternative (4). The alternative with the highest rank, value, or utility is the chosen alternative, or priority. Table 3 shows the common tools and definitions used to combine the criteria.

Table 3. Common tools to evaluate performance criteria

Tool	**Definition**
Mathematical function	Uses either the difference or ratio of all benefit to all costs
Ranking and rating	Assigns rating to criteria and ranks all alternatives
Maxmin approach	Determines max and min desirability of alternatives
Impact index method	Considers error in the ranking and rating method
Pairwise comparison	Compares all alternatives to develop ranking
Mathematical programming	Finds optimal combination of criteria the maximizes objectives
Outranking method	Compares alternative two at a time to determine which is superior

Mathematical functions would not be applicable to this research because it attempts to present all performance measures in terms of cost, which cannot be done for all decision factors. The rank and rate method was a starting point for the factor evaluation, but it primarily uses only the decision maker's judgment for all weights and rates. The maxmin method is not applicable to this process because it assumes that there is a maximum or minimum value for each factor, and that is the case in this research. The impact index method considers error in the ranking and rating method. It is not feasible to determine the error for these values in this process, so this method is not applicable. The pairwise comparison method used the AHP to compare the factors. This is a valid method to use in evaluating the factors. The mathematical programming method is similar to utility theory in that it tries to maximize the objectives. This method is not applicable to the process due to insufficient data. After implementation of the process, agencies will generate and eventually this method may become useful. The outranking method is a more complicated alternative to the AHP, so it was not a useful method. From the presented methods, the rating and ranking and pairwise comparison seemed to be the most useful for the purposes of this thesis.

Every needed project would be implemented if funds were always available. Since this is not the case, Sinha and Labi present three types of systems to determine which projects are selected: priority setting, heuristic, and mathematical programming (4). The priority setting system selects the project with the "highest desirability, in terms of overall utility," that does not exceed the budget (4, 15). A heuristic approach tries to maximize the return of several selected projects, not necessarily in priority order.

Mathematical programming can include a linear analysis of variable, integer programming in which all values are integers and a project will either be entirely selected or rejected, goal programming where each goal is evaluated separately and then the sum of these goal deviations are minimized, or dynamic programming where a large number of interrelated decision variables can be used to find a solution.

Transportation decision making is a broad subject and is applicable to many transportation specialties. Sinha and Labi primarily outline transportation design and planning uses, but these ideas are also applicable to traffic engineering and TCD decisions. The state-of-practice for TCD decision making was determined in the initial investigation in Chapter III

CHAPTER III

PROCESS DEVELOPMENT

The goal of this research is to develop a process that will assist practicing traffic engineers in their TCD decisions. The initial investigation with experienced traffic engineers determined the current state of practice with TCD decisions. It also outlined several considerations for TCD decisions that were grouped into four factors: need, impacts, influences, and cost. A survey, sent out to experienced professionals, helped determine how these factors applied to TCD situations and how each factor affects another. This enabled the researcher to develop a general global process that has application for different types of TCDs and is able to be refined. This process assigns a coefficient to each factor based only on the TCD and a situational variable based on the TCD application to the specific situation. An analysis of several case studies validated the design of the decision making general process.

INITIAL INVESTIGATION

The initial investigation for this research had several objectives. It needed to establish the typical process used in TCD decisions, where the variations in this process occur and why, and how to familiarize the researcher with the issues that arise in TCD decisions. The target audience for this investigation was practitioners who had expertise in using the MUTCD. Subjects were selected from the membership of the National Committee on Uniform Traffic Control Devices (NCUTCD). This committee develops and forwards recommendations to the FHWA for changes and updates to the MUTCD (16). These respondents are the "experienced traffic engineers" throughout the report. A request for an interview was distributed to a large list of engineers in different agencies, and five engineers agreed to participate in the investigation. The variety of agencies included state, county and local government employees and consultants.

The investigation, conducted via phone conversations, used open-ended questions. A list of questions asked to get the respondent talking included:

- How often have you dealt with decision based on the MUTCD,
- What are the major considerations or factors when making decisions,
- Discuss each factor (safety, cost, political influences, etc), and
- What is the hierarchy of factors and are they on a case-by-case basis.

Detailed summaries of these conversations are in Appendix B. The overall gain from this initial investigation was to determine what the typical issues and processes are in traffic engineering when applying the MUTCD. The above questions guided the conversations and generated discussion about other issues, such as:

- Quid pro quo
- Signs as a panacea
- Budget is not increasing but requests for signs are
- Level in which political factors actually influence decisions
- Risks engineers are willing to accept
- Public satisfaction versus use good engineering design

- Request origination for devices
- Budget types to pay for devices
- Engineers that lack traffic engineering

It also showed how these engineers use systems engineering as part of their decisions process by including more than just the MUTCD in the process, such as local policies, political pressures, etc. Table 4 shows a list of all considerations discussed in this investigation of TCD decision making and the process development.

Table 4. List of considerations in the TCD decision process

Agency types that use MUTCD	Over use of TCD (i.e. sign clutter)
Types of devices process would affect	Driver expectancy
Request initiation (by who, and why)	Impact on system
Challenging or difficult TCD decisions	Presence
Process usefulness to inexperienced engineer in traffic application	Other agencies, besides engineer, that affect decision making
Process priority or hierarchy method	Extenuating circumstances
Maintain engineering judgment in process	Quid pro quo
Need	Tort liability
Safety	Land development influences
Operations	New technology
Constraints	Changes in standards or policies
MUTCD	Political influences
Device importance	Initial cost
Engineering study and results	Life cycle cost
Evaluation data needed	Maintenance cost
Uniformity	Benefit to cost ratio
Risk assessment	Funding sources
Effectiveness	Budget
Consistency in application	

State-of-Practice for Traffic Control Device Decision Making

The state-of practice for TCD decision making was determined from this initial investigation. Traffic engineers make TCD decisions for various agencies at various levels. Examples of agencies are state, county, and local departments of transportation, but this is not an all-inclusive list. Consultants may also make TCD decisions for agencies. Each agency has a unique perspective, and therefore, yields different decisions with each TCD. A practicing engineer pointed out that at the city level, especially in medium sized cities; the engineers are not trained traffic engineers (Appendix B). This emphasizes the need for a process to guide these types of engineers.

For most TCDs, there is a general approach to assist with decision-making. Either the public or the Department of Transportation (DOT) will make a request for a TCD. Then an engineering evaluation determines the installation benefit for a device. This is the typical approach. After this, the decision will either be accepted or rejected. The rejection could lead to further study if someone strongly opposes the outcome of the initial evaluation. The procedures that occur after the initial engineering evaluation are the focus of this project. This information, gained through initial investigations with experienced traffic engineers, will help to determine what should be included in the formal survey of professionals as well as which direction the process should go.

FACTORS

The information obtained from the initial investigation determined that there were four factors that are inclusive of all considerations in the decision making process. These factors were need, impacts, influences, and costs. The considerations could apply to one or more of these factors. The TCD decision will be a function of these factors,

$$Decision = f(need, impacts, influences, cost)$$

The need factor includes all evaluations of the site for the TCD. Considerations that incorporated the future or assumed affects of the device on the system were included in the impacts factor. The influence factor contained all external and internal entities that would affect the decision process for the device. The cost factor analyzes the initial and life cycle costs of a TCD. The combination of these factors will result in the installation benefits of the device.

Need

Need is be expressed in terms of the degree to which a device would increase the safety and/or operations of the system. The list below shows items from Table 4 that are considered as part of the need factor:

- Need
- Safety

- Operations
- Constraints
- MUTCD
- Device importance
- Engineering study and results
- Evaluation data needed

The need factor includes the device evaluation, improved safety, and improved operations of existing conditions. It requires the decision maker to evaluate the situation based on policies or accepted practice. The decision maker has a choice of four levels of evaluation criteria to analyze this part of the process:

- MUTCD warrant criteria,
- Evaluations based on published or documented criteria,
- Engineering study, or
- Engineering judgment.

The MUTCD provides warrant criteria for a few TCDs, but not all. Some TCD that have warrant studies are traffic signals and advance warning signs (1). Indication that a device satisfies a warrant does not mean that the device has to be installed; only that it has met the minimum requirements to be installed. Evaluation of other factors will assist in determining that decision to install. There are also proposed updates to the MUTCD (17) and ongoing research that may contain an analysis not published in the current Manual. These evaluations include published or documented criteria. Examples of these evaluations are the horizontal alignment change proposal to the MUTCD (17) and the crosswalk installation evaluation (18).

Some devices require an engineering study to evaluate the need for an installation such as a new Speed Limit sign. Agency policy is also included in engineering study. Agency policies are in-house guidelines for device installation decisions. For all other TCDs, engineering judgment is the basis for establishing need. Engineering judgment may be used for devices such as a Traffic Generator sign.

The safety and operations of the existing conditions are often included in the evaluations for this factor, but may also be a separate consideration. The safety aspect can include crash history and the operations can include roadway conditions, i.e., width, curbs, speed, rural, objects on the side of the road, etc. These considerations use the current existing condition and history that would affect the TCD decision.

Impact

The impact factor outlines the expected effectiveness of that device. It identifies the future effects of the device from a safety and operations perspective. The list below shows items from Table 4 that are considered as part of the impact factor:

- Safety
- Operations
- Uniformity
- Risk assessment
- Effectiveness
- Consistency in application
- Over use of TCD

- Driver expectancy
- Impact on system
- Presence

In terms of safety, this factor considers the reduction of crashes. Operations determine if the sign would command attention if installed or if the driver perceives and responds in ample time. The factor also considers adequate site distance, driver compliance, and driver expectancy of the device. Essentially, this factor determines if the device will have the intended effects on the transportation system (reduce crashes, improve operations, etc.).

Influences

Engineering systems include all parties affected by a device or contribute to the installation decision. The next factor includes these influences, external or internal. The list below shows items from Table 4 that are considered as part of the influences factor:

- Other agencies that affect decision-making
- Extenuating circumstances
- Quid pro quo
- Tort liability
- Land development influences
- New technology
- Changes in standards or policies
- Political influences

Some examples of external influences could be political pressure to install a device, a school district that requires a device, or future development that may affect traffic operations. In addition, an agency may try to be uniform with a neighboring jurisdiction. Internal influences could be the threat of a lawsuit if the device is or is not installed, expected changes in standards, or device novelty.

Cost

The cost of the device is a comparison of the cost to install and maintain the device and the funds available for this device. The list below shows items from Table 4 that are considered as part of the cost factor:

- Initial cost
- Life cycle cost
- Maintenance cost
- Benefit to cost ratio
- Funding sources
- Budget

Cost does not have an effect on the need for a device but will have an effect on the installation process.

There are several ways to consider cost. It could be the installation costs alone or it could be a variation of installation costs, maintenance cost, or other life cycles costs. Each agency will evaluate the costs differently within the cost factor. Different methods of securing the funds for the device are also considered. There would be a difference if this were a budgeted device versus having to secure bonds or grants for the device.

Available funds affect the decision to install the treatment. Although cost does not affect the requirement to install, it may delay the actual action to install the treatment. If there are no funds, the device simply cannot be installed. Depending on the outcomes from the other factors, if the decision is to install, but the budget does not allow for the installation of the device, this factor may also be useful in prioritizing projects. Most agencies already have a system like this in place, which can be included in this part of the process.

SURVEY

Information gathered through the initial investigation and the developed factors contributed to the creation of the survey on TCD decision making. A blank survey is in Appendix C. This survey began with background questions about the respondent to make sure they had the appropriate experience on the subject. Next, it determined the overall current process. These questions were derived from the initial investigations and the resulting factors. Questions 4 through 13 in Appendix C inquired about the current process.

The next section determines the weaknesses of the MUTCD as seen in questions 14 and 15 in Appendix C. The final survey question, Question 16, assisted with the development of the case studies by determining the level of difficulty for certain TCD decision processes.

Survey Results

The survey respondents consisted of city, county, and state government engineers, as well as consultants, all with more than ten years of experience as an engineer responsible for making TCD decisions. They had different levels of responsibilities including, but not limited to:

- Establishing policy for TCDs in the agency,
- Supervising others that make TCD installation decisions,
- Deciding to install or not to install a TCD,
- Making recommendations to supervisor about installation of a TCD, and/or
- Providing, collecting, processing, or analyzing the data or input for supervisor to make decision.

The typical process outlined in the survey was:

1. Request/determine need
2. Outline choice of alternatives
3. Conduct study for alternatives
4. Analyze results
5. Evaluate applicability
6. Make selection
7. Implement

The changes that can occur to this typical process, caused by political pressures or lack of funding, can either expedite or halt the installation of a device. The survey asked key questions including: major challenges with TCD decisions, lack of traffic experience with engineers, and the strengths and weaknesses of the MUTCD. The results are presented below and the number in the parentheses indicates that number of respondents that reported that result.

The major challenges that engineers face when making TCD decisions are listed below:

- Lack of funds/resources (4)
- Public perception of what should/should not be installed (3)
- Lack of studies (2)
- Backlog of projects (2)
- Lack of information (1)
- Local governments support for maintenance (1)

Inexperienced engineers lack:

- Knowledge of what has worked in the past (1)
- Consideration of maintenance issues (1)
- Ability to handle public opinion on project versus alternative, better solutions (2)
- Individual or a whole community request differentiation (2)
- Training with MUTCD (1)

MUTCD strengths:

- Good listing of typical applications (1)
- Good application to highways (1)

- Clear as to what is required versus recommended versus optional (1)
- Good sign size tables (1)
- Adequate warrant studies (1)
- Ample leeway allowed to engineer (1)

MUTCD weaknesses:

- Not always applicable to city or residential streets (1)
- Too vague (1)
- Too much dictation (2)

This results obtained from this survey strengthen the factors concept used in this thesis. The respondents believe the MUTCD to be a useful manual. The additional factors, especially influences and cost, help to strengthen the decision analysis where the MUTCD cannot. The goal of this process is to help engineers that do not have an expertise in traffic engineering. The weaknesses hi-lighted by the respondents of these types of engineers will be minimized in this process by including influences and cost in analysis. This will assist these engineers on how to deal with these factors.

GENERAL PROCESS

The survey analyzed the previously defined factors and the results helped to form a general process for TCD decisions. There were two models studied to determine applicability to the TCD decision-making process: the utility theory analyzed as a linear model and the AHP model. Both models have two elements for each factor that equate to the utility for that decision.

$$Utility = f(relationship\ between\ factors, individual\ factor\ considerations)$$

The relationship between factors is known as the coefficient, a, and determines how each factor affects the others. The decision maker evaluates the extent to which each individual factor affects the installation decision. This situational variable, x, is unique for each TCD situation. For each element, the subscripts n, f, i, and c denotes the need, impact, influence, and cost factors, respectively. Therefore, the general utility model, U_m, follows the form below.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

Coefficients

There were three models discussed in Chapter II that would yield the coefficients for the factors. The first was the decision maker picking the values. The second was using the linear risk-taking model to determine the values of the factor. The third was using the AHP to determine the coefficients. The first method is not discussed in depth because a quantitative approach needed to be a part of this process. The other two methods are discussed below, and the AHP is chosen as the method for determining the coefficients for this decision model.

Utility as a Linear Model

Typical applications of utility are linear models, as discussed in Chapter II. The coefficients are determined from past decisions by the agency. These coefficients are the likelihood that factor will affect the decision, or its importance. These values require on data that does not currently exist which would create the decision maker's risk taking behavior, also covered in Chapter II.

Original thought believed utility theory was the best way to apply the factors quantitatively, but it quickly became apparent that this model would not be applicable at this time. Another alternative was needed for a quantitative approach this decision process. With the implementation of this decision process, however, agencies can collect and incorporate data into a model that could determine which coefficients are appropriate for different TCD decision processes.

Utility as an AHP Model

A different approach was investigated as a decision model. For this model, the coefficients of each factor enable the user to compare the importance between each factor. These coefficients can be a range for each factor that an agency or individual can adjust for their applications. Although these values can vary, there should be a set range for this variance.

There should be sets of coefficients that are applicable to different types of situations where the factors have different relationships, i.e., traffic signals, warning signs, modal conflicts, etc. These relationships are determined through the AHP discussed in Chapter II to yield parameters that are applicable to each type of decision.

The range of values for the coefficients should be determined through a partial application of the AHP. Although a complete AHP is applicable to this process, it would eliminate a large amount of judgment that is crucial in these decisions. The decision maker would use the global priority percentages of the factors as the coefficients. Appendix A outlines the AHP for general and specific TCD applications.

For general TCD a pairwise comparison compares the factors to each other. First, the importance between each individual factor was determined by an experienced traffic engineer. These intensities were then expanded into a matrix, seen in Table 5, showing the intensity value of the important factor as well as the reciprocal of the less important factor in the comparison.

Table 5. Factor importance comparison matrix

Criteria	Need	Impact	Influence	Cost
Need	1	1	8	1
Impact	1	1	7	1
Influence	1/8	1/7	1	1/6
Cost	1	1	6	1
Sum	3.125	3.143	22.000	3.167

These intensities are then normalized by dividing each cell in a column by the sum of that column. These normalized values are then summed across each row to determine the priority for each factor. Table 6 shows the factor priorities associated with general TCDs. A more detailed description of this process is in Appendix A.

Table 6. Priority values for general TCDs

Criteria	Priority	Coefficient
Need	32.94%	a_n
Impact	31.80%	a_f
Influence	4.59%	a_i
Cost	30.67%	a_c
Sum	100.00%	-

These values are determined through the decision maker's or agency's opinion of the pairwise comparison of each factor. Therefore, these values will be different for each agency, but should be the same for all applications of this process.

Situational Variable

The situational variables are the values assigned to each factor by the decision maker based on their interpretation of the factor's application to the situation. This application is not an observed frequency, but is the degree of belief that the device will accomplish the overall goal. This judgment is to remain a large part of the process.

The values for the situational variables generally range from 0 to 1. Essentially, this value describes the degree to which the situation meets the specific factor. This value can be less than zero as well as greater than one. When this occurs, it implies that the significance of that factor is such that it should increase its weight in the total utility or have a negative effect on the overall utility. The factors that are designed to allow for this deviance are need and impact and are addressed below.

Need

The situational variable for the need factor is a function of the evaluation, safety issues, and operational issues with the existing conditions. There are four levels of evaluation, as previously explained. Only one determines the influence on the decision. From most influential to least, the levels are MUTCD warrants, evaluation of published or documented criteria, engineering study, and engineering judgment. The addition of the evaluation level to the degree in which the situation meets that level of evaluation equates to the situation variable for the need, as seen below.

$$x_n = f(Evaluation\ Level, Degree\ Evaluation\ Criteria\ Met)$$

The product of the evaluation level and the degree the situation meets the evaluation criteria equates to a significance value that is normalized to get the situational variable for the need, x_n. Table 7 shows the need significance values. The values for the evaluation level vary from 1 to 1.5 with the MUTCD being the most significant evaluation level. The degree to which the situation meets the evaluation is divided into objective and subjective evaluations. Objective evaluations include MUTCD, published or documented criteria, and engineering studies where data can be obtained from more than just engineering judgment. Subjective evaluations include all evaluations that use engineering judgment as the basis for the evaluation criteria.

Table 7. Need significance value

	Values	MUTCD 1.5	Published or Documented Criteria 1.35	Engineering Study 1.2	Engineering Judgment 1.0
Objective					
Exceeds warrant criteria	3	4.5	4.1	3.6	--
Equals warrant criteria	2	3.0	2.7	2.4	--
Almost meets warrant criteria	1	1.5	1.4	1.2	--
Warrant not met	0	0.0	0.0	0.0	--
Subjective					
Exceeds need	3	--	--	3.6	3.0
Meets need	2	--	--	2.4	2.0
Potential value	1	--	--	1.2	1.0
Little value	0	--	--	0.0	0.0

Normalization of the significance value yields the equation below.

$$x_n = \frac{(Evaluation\ Level + \ Degree\ Evaluation\ Criteria\ Met)}{3}$$

The denominator of this equation is chosen as the normalizing factor. A value of 3 represents a device decision that is evaluated using the MUTCD and equals the warrant criteria. This would allow all the priority value to be used in the total utility. This device would meet the need evaluation criteria 100%, or 3 out of 3. A significance value greater than 3 results in a situational variable value that is greater than 1, indicating the significance of the evaluation method and results for the situation. A situational variable value greater than 1 increases the weighting associated with the need. This indicates that the need for the device is strong enough to justify a higher utility relative to the other factors.

An application of variable is a traffic sign that does not quite meet an engineering study's objective criteria. This corresponds to a value of 1.2 from the top row in Table 7 and a value of 1 from the first column in Table 7, which equals a total value of 1.2 out of 3, or 0.4, for x_n.

There is a minimal threshold value, 1 or greater, for the need significance or an x_n value of 0.33 that, if not met, there is no need for further evaluation of the TCD. There is no reason to install the device if does not meet a certain level of need.

Impact

Since the impact factor considers events that have not happened, this situational variable is more interpretive. The decision maker can interpret each function on a scale basis.

Table 8 shows the values that are associated with the impact judgments.

Table 8. Impact values

Value	Significance
5	High positive impact
3	Positive impact
0	No impact
-3	Negative impact
-5	High negative impact

The equation below shows the situational variable for the impacts.

$$x_f = \frac{Impact\ Value}{5}$$

The impact values are designed to range from 1 to -1. Impact values less than 0 are provided to allow for the negative effects that a device could have after installation. Although it is rare that a device would be installed if it were believed to have negative effects, the factor is designed to alert an engineer to the possibility and the effects of that decision.

An example of the variable for this factor is an intersection with a high crash rate has a TCD system proposed that is believed to reduce crashes significantly. This high positive impact would equate to a value of 5 out of 5, or 1, for x_f. Another example is an advanced warning sign for a speed zone. A study show there is no indication that traffic is violating the speed limit in this zone. Therefore, the installation of this warning device would have no impact. This equates to an impact value of 0, which in turn is a 0 out of 5, or 0, for x_f.

Influences

Similar to the impact factor, the interpretation of the situational variable depends on how influential the user thinks the entities are on the decision. Table 9 shows the values associated with the influence significance.

Table 9. Influence values

Value	**Significance**
3	Strong influence
2	Some influence
1	Little influence
0	No influence

The equation below shows the situational variable for the influences.

$$x_i = \frac{Influence\ Value}{3}$$

For example, there are plans for construction of a future development near an intersection where an agency is conducting a traffic signal study. The traffic from this development will increase the traffic through this intersection. This is a strong influence on the device installation and is allocated a 3 out of 3 for x_i. Another example is of a citizen request to put a stop sign at an intersection in their neighborhood. There are no other influences for this device. Although the citizen's request caused the evaluation of the intersection, there is no influence factor to be applied in this situation. The result is a 0 out of 3 for x_i.

Cost

The difficulty in evaluation cost comes from the different sources of funds that an agency uses for devices. Devices are paid for under maintenance budgets, bonds, capital improvement programs, etc. A series of steps that determine whether the sources can be secured or if there are sufficient funds from these sources. The results of these steps are the situational variable for this cost factor. The steps are listed below:

1. Is there a special budget category or stand alone budget source? (i.e., bonds, capital improvement programs, safety enhancement funds)
    a. Yes, then $x_c = 1$.
    b. No, then go to 2.
2. Are the funds in the maintenance budget sufficient to cover the cost of the device?
    a. Yes, then $x_c = 1$.
    b. No, then $x_c = 0$.

This factor is not intended to prioritize internally the device benefits. Rather, the purpose of this process is to identify the decision benefits and then possible prioritization between other devices. Therefore, the cost factor does not compare this device to the other competing costs.

Total Utility

A higher total utility value, U_m, indicates a higher likelihood for decision to install. The range of total utility values in Table 10 reflects the installation value of the decision.

Table 10. Utility decision values

Total Utility Value, U_m	**Suggested Decision**
$U_m \geq 80$	the treatment has probable installation value.
$80 > U_m \geq 50$	the treatment has possible installation value.
$50 > U_m \geq 20$	the treatment has questionable or uncertain installation value
$20 > U_m$	the treatment has little to no installation value.

These values, arbitrarily chosen for the purposes of this research, can be on any scale that an agency feels applicable to their process. The suggested installation values are not finite answers. If a mid range utility is the decision result, then other alternatives should be analyzed to determine if a higher utility would result. The final decision is made by the decision maker despite what the utility results indicate.

This utility value process could eventually determine what level of alternatives could satisfy the decision. For example, if there is a crash history at an intersection with a two-way Stop, there are multiple alternatives to consider, such as: larger Stop sign, Stop Ahead sign, Stop Ahead pavement markings, rumble strips, flashing Stop beacons on the Stop sign, flashing warning beacons on the advance warning sign, or flashing Stop beacon above the intersection. Although the data is currently not available, this process could determine which level of device would be most cost effective at reducing the crash rate at this intersection.

Process of Expressed Need

The need for a device is essential for all TCD decisions. As stated earlier. A minimum threshold value for x_n is required to continue the evaluation of the device. An x_n value of

0.33 or greater expresses a minimum level of need for a device with the value system chosen for this thesis. Therefore, the process is defined below.

$$If\ x_n \geq 0.33, then\ evaluate\ U_m,$$

$$Else, TCD\ does\ not\ express\ sufficient\ need\ for\ installation\ value.$$

Global versus Individual Process

The general process is global to all TCD decision situations and can be applied to groups of similar devices or a system of devices. It is beyond the scope of this research to develop these specific group processes, but individual process applications in the case studies this research analyzes. Table 11 shows an example of the difference between global and individual TCD decision. The individual TCD coefficients are for the installation of a marked crosswalk case study in Chapter IV.

Table 11. Comparison of priority values of general and individual TCD situations

	Priority		
Criteria	**General**	**Crosswalk**	**Coefficient**
Need	32.94%	59.50%	a_n
Impact	31.80%	21.69%	a_f
Influence	4.59%	5.87%	a_i
Cost	30.67%	12.94%	a_c
Sum	100.00%	100.00%	-

As seen in, the priority values for the overall TCD system may not be the same as each individual TCD situation. This suggests that there should be different priority values either for all individual TCDs or for groups of similar TCDs. This is beyond the scope of this thesis, but would be further application of the developed process. The next step for this research is to evaluate individual case studies of TCD scenarios to determine the validity of the general process.

CHAPTER IV

PROCESS APPLICATION

To verify that the general process developed in the previous chapter will apply to TCD decisions, five case studies have been created: 1) Traffic Generator sign, 2) marked crosswalk, 3) Stop Ahead sign, 4) Intersection control beacon, and 5) turn prohibited TCD system. The first four cases are of individual TCDs. The fifth case studies the effect of the process on a TCD system, which includes pavement markings, signs, and channelizing devices.

The considerations listed for each factor are for the purposes of this case study. From these considerations, the decision maker, using engineering judgment, will give the treatment a rating based on the scale presented in Chapter III. The judgment decision from these criteria is for example purposes only and not intended to reflect an actual practitioner's judgment.

EVALUATION TO INSTALL TRAFFIC GENERATOR

This case study evaluated the installation of a traffic generator sign. There are many considerations for this decision, and the values of these considerations vary for each jurisdiction. Table 12 contains a list of some of the considerations used to evaluate the treatment.

Table 12. Traffic generator installation considerations

Considerations	
Type of generator	Installation site sign density (sign clutter)
Location area (metro, urban, rural)	Sufficient space to install sign
Generator size- type and amount (students, attendees, etc.)	New or old generator (future development vs. existing)
Distance from interchange	Elected official opinion
Traffic type (local, commuter, tourist)	Community opinion
Number of trips	Traffic generator opinion
Location from highway (not more than two highways)	Cost to install and maintain

Determining Coefficients

The AHP application determines the coefficients for this type of case study. This process is in Appendix A. Table 13 shows the resulting priorities, or coefficients, for the factors in the total utility equation.

Table 13. Priority values of traffic generator sign

Criteria	Priority	Coefficient
Need	21.46%	a_n
Impact	12.95%	a_f
Influence	15.41%	a_i
Cost	50.17%	a_c
Sum	100.00%	-

Determining Situational Variables

The next part of the process is to determine the situational variables for the specific scenario.

Scenario

A community college would like to have a traffic generator sign installed on the freeway alerting drivers to the exit for the school. The college is located in a medium sized city about half a mile from the freeway. The college attracts a fair amount of trips, but most of the traffic is familiar with the area. There are no dorms in the school, and the enrollment is estimated at 8,000 students.

Need

The first step in the process is to determine the need for the device by conducting an engineering evaluation. The MUTCD does not have warrants for this device, but it does include a reference to "Guidelines for the Selection of Supplemental Guide Signs for Traffic Generators Adjacent to Freeways" published by American Association of State and Highway Transportation Officials, AASHTO (1, 19). Other states, such as Texas, have incorporated these guidelines into their state MUTCD (20). This research uses the national MUTCD. The need evaluation criteria will be at the same level as a published or documented criteria. However, if the Texas MUTCD were being applied to this process, it would be at the MUTCD warrant level. Additional requirements for traffic generators are at the discretion of the governing state or local agency.

For this type of sign, data, such as the local population size, the amount of trips generated by the school, and the distance and location from the highway or directness of travel, are all considerations of the decision. Table 14 compares the case study data to the AASHTO guideline criteria for a Traffic Generator sign on a freeway (19).

Table 14. Minimum criteria for traffic generator

Specific Criteria	**AASHTO Criteria (pop. < 50,000)**	**Community College Data**
Total enrollment	4,000	8,000
Number of trips generated annually	900,000 (without dorms)	1,800,000[1]
Max. distance from interchange (mi)	3	0.5

[1] Number of Annual Trips Generated = (Enrollment) X (1.5 trips/day/student) X (150 day/year) (19)

According to the AASHTO guidelines, the community college meets the need for a traffic generator sign. The device is evaluated using MUTCD criteria for a traffic generator, but these guidelines are not MUTCD warrants. This is equivalent to using published criteria and corresponds to a value of 1.35 from Table 7 for the evaluation level. The traffic generator criteria also exceed the values published in the AASHTO guidelines, which corresponds to a value of 3 from the first column in Table 7. The situational variable for the need factor, x_n, is a normalized product of these two values which is 4.1 out of 3. As stated earlier, satisfying MUTCD criteria does not indicate that the treatment has to be installed, only that it has met the minimum requirements to be installed (1, 19). Evaluation of the other factors will assist in determining the decision to install.

Impact

Impacts evaluated in the case study assess considerations such as driver familiarity, sign clutter, or type of traffic. The traffic that the site generates is familiar with the area. There may be commuter traffic, but they take similar routes daily. A few times a year, like the first week of the semester, unfamiliar drivers need to find the college, but this is not common.

The installation location for the proposed sign does have other adjacent signs. There is adequate spacing for the sign to be installed in both directions, but no other signs will be able to be installed in this stretch of roadway. If the installation of a more important sign were required, the removal of the Traffic Generator sign would be the first measure towards ensuring adequate space for the new sign. Since the proposed sign is a guide sign, a more important sign would be a regulatory or warning sign (1).

The device would alert drivers to the generator, but sign location would not be sufficient for visibility of the sign with other, more important signs taking priority. Due to the minimal impact of informing the driver of the location and the space constraints, the situational variable for this factor is given a 1 out of 5 based on Table 8.

Influence

Influences for this device can include elected officials or the entities that requested the traffic generator sign. They may emphasize a strong need for the sign, and they may indicate how thoroughly they believe an agency should sign the traffic generator. This factor reflects how strong the decision maker feels their influence is on the installation of the device.

This college has been at the location for approximately ten years. The school officials requested the sign because of the new enrollment levels they have just recently achieved. These officials also believe that the traffic generator would be good advertisement for the college. Although these reasons are not adequate from a traffic engineer's perspective, it is possible to experience this case study as an actual situation.

The influences listed here are not adequate to influence the installation of this device. According to Table 9, the situation variable for the influence factor, x_i, is a 0 out of 3. Additionally, Traffic Generator signs are not a form of advertisement (19), and therefore the influence loses credibility in their need for the device.

Cost

The sign installation or initial costs are minimal. There will probably be a sign installed in each direction on the highway, and currently the agency has many signs competing for the funds available. The college will not make any changes to the signs. Therefore, life cycle costs will also be minimal since the sign replacement will not more than once every ten to fifteen years. The Traffic Generator sign does not qualify for a special budget category, and there are insufficient funds in the maintenance budget to cover the cost of installation. According to the cost analysis steps in Chapter III, the situational variable for this factor, x_c, will be receive a 0.

Total Utility

With the variables previously determined, the utility equation from Chapter III is applied.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

$$U_m = (21.46)\left(\frac{4.1}{3}\right) + (12.95)\left(\frac{1}{5}\right) + (15.41)\left(\frac{0}{3}\right) + (50.17)(0)$$

$$U_m = 20.19$$

The decision scale presented in Table 10 indicates that since $50 \geq U_m < 20$, there is questionable or uncertain installation value for the treatment. The decision is not to install the traffic generator. Although there is an indicated need for the device, there is no significant positive impact, no place in the budget for this device, and no other influences that would encourage the installation of the device. If this treatment had received a higher utility, then there may have been a greater benefit to the sign's installation. The situational variable for the cost, x_c, is 0 for this case study because of the lack of funds in the budget. However, if the device had a specialized budget or there were more funds in the maintenance budget, then it would have received a value of 1 for x_c and U_m would have been70.36 indicating that there is some installation value to the device. This change emphasizes the importance of cost in this device installation decision.

EVALUATION TO INSTALL MARKED CROSSWALK

This case study evaluates a crosswalk pavement marking installation. To make this process applicable to all types of situations, the decision can use readily available data or data collected specifically for the study. A list of considerations is in Table 15. This list is not exhaustive, but does try to include most considerations. This case study applies these considerations.

Table 15. Crosswalk installation considerations

Readily Available Data	Data to be Collected
Sidewalks or beaten dirt path Posted speed Roadway width Number and types of lanes Median Walking speed Motorist compliance Driver awareness of pedestrians Crosswalk location (midblock, controlled, uncontrolled) Cost to install and maintain Elected official opinion School district opinion Accessibility Horizontal and vertical alignment Sight distance Visibility of crosswalk and pedestrian Alternative installations	Pedestrian volume Vehicular volume 85% speed Crash history

Determining Coefficients

The AHP application determines the coefficients for this type of case study. This process is in Appendix A. Table 16 shows the resulting priorities, or coefficients, for the factors in the total utility equation.

Table 16. Priority values of crosswalk

Criteria	Priority	Coefficient
Need	59.50%	a_n
Impact	21.69%	a_f
Influence	5.87%	a_i
Cost	12.94%	a_c
Sum	100.00%	-

Determining Situational Variables

The next part of the process is to determine the situational variables for the specific scenario.

Scenario

There is a request for a crosswalk installation at an intersection. The minor road is a two-lane 30 mph residential street with Stop control at the intersection. The major road is a two-lane 35 mph collector with no control at the intersection. The data provided for the site is in Table 17.

Table 17. Variables and values for crosswalk case study

Input Variables (18)	**Term (18)**	**Value**
Speed on major road (mph)	S_{maj}	35
Peak hour pedestrian volume (ped/hr)	V_p	35
Major road peak hour vehicle volume (veh/hr)	V_{maj}	1000
Signal warrant check (ped/hr)	SC	271.21
Pedestrian crossing distance (ft)	L	28
Pedestrian walking speed (ft/s)	S_p	3.5
Pedestrian start up time and end clearance time (s)	t_s	3
Critical gap (s)	T_c	11
Major road flow rate (veh/s)	v	0.278
Average pedestrian delay (s/person)	d_p	61.97
Total pedestrian delay (ped-hr)	D_p	0.602
Motorist compliance	Comp	low

Need

There are no explicit MUTCD warrants for crosswalks (1). The next level of evaluation considers other published criteria that are not in the MUTCD. For crosswalks, NCHRP Report 562 by Fitzpatrick, et al. outlines an evaluation process for this situation (18). This report is the basis for evaluation of the crosswalk and uses the criteria from the existing conditions. The variables in Table 17 correspond with the labels in the study by Fitzpatrick, et al. The evaluation process follows the worksheet guidelines created by Fitzpatrick, et al. in Figure 3 (18). The values from this case study are in the worksheet.

The first step is to determine if the site meets the minimum pedestrian volume of 20 ped/hr. Since this study has 35 ped/hr it meets this criteria, and further evaluation is needed.

The next step checks the traffic signal warrant for pedestrians. Using the vehicular volume, the minimum pedestrian volume that could warrant a signal is 271 ped/hr. The pedestrian volumes are less than that, therefore, the site does not warrant a traffic signal.

WORKSHEET 1: PEAK-HOUR, 35 MPH (55 KM/H) OR LESS

Analyst and Site Information

Analyst: Analysis Date: Data Collection Date:	Major Street: Minor Street or Location: Peak Hour:

Step 1: Select worksheet (speed reflects posted or statutory speed limit or 85th percentile speed on the major street):

a) Worksheet 1 – 35 mph (55 km/h) or less

b) Worksheet 2 – exceeds 35 mph (55 km/h), communities with less than 10,000, or where major transit stop exists

Step 2: Does the crossing meet minimum pedestrian volumes to be considered for a TCD type of treatment?		
Peak-hour pedestrian volume (ped/h), V_p	*2a*	**35**
If *2a* ≥ 20 ped/h, then go to Step 3.		
If *2a* < 20 ped/h, then consider median refuge islands, curb extensions, traffic calming, etc. as feasible.		
Step 3: Does the crossing meet the pedestrian volume warrant for a traffic signal?		
Major road volume, total of both approaches during peak hour (veh/h), $V_{maj\text{-}s}$	*3a*	**1000**
Minimum signal warrant volume for peak hour (use *3a* for $V_{maj\text{-}s}$), SC $SC = (0.00021\ V_{maj\text{-}s}^2 - 0.74072\ V_{maj\text{-}s} + 734.125)/0.75$ OR $[(0.00021\ 3a^2 - 0.74072\ 3a + 734.125)/0.75]$	*3b*	**271**
If *3b* < 133, then enter 133. If *3b* ≥ 133, then enter *3b*.	*3c*	**271**
If 15th percentile crossing speed of pedestrians is less than 3.5 ft/s (1.1 m/s), then reduce *3c* by up to 50 percent; otherwise enter *3c*.	*3d*	**271**
If *2a* ≥ *3d*, then the warrant has been met and a traffic signal should be considered if not within 300 ft (91 m) of another traffic signal. Otherwise, the warrant has not been met. Go to Step 4.		
Step 4: Estimate pedestrian delay.		
Pedestrian crossing distance, curb to curb (ft), L	*4a*	**28**
Pedestrian walking speed (ft/s), S_p	*4b*	**3.5**
Pedestrian start-up time and end clearance time (s), t_s	*4c*	**3**
Critical gap required for crossing pedestrian (s), $t_c = (L/S_p) + t_s$ OR $[(4a/4b) + 4c)]$	*4d*	**11**
Major road volume, total both approaches or approach being crossed if median refuge island is present during peak hour (veh/h), $V_{maj\text{-}d}$	*4e*	**1000**
Major road flow rate (veh/s), $v = V_{maj\text{-}d}/3600$ OR $[4e/3600]$	*4f*	**0.278**
Average pedestrian delay (s/person), $d_p = (e^{v\,t_c} - v\,t_c - 1)/v$ OR $[(e^{4f \times 4d} - 4f \times 4d - 1)/4f]$	*4g*	**61.97**
Total pedestrian delay (h), $D_p = (d_p \times V_p)/3{,}600$ OR $[(4g \times 2a)/3600]$ (this is estimated delay for all pedestrians crossing the major roadway without a crossing treatment – assumes 0% compliance). This calculated value can be replaced with the actual total pedestrian delay measured at the site.	*4h*	**0.602**
Step 5: Select treatment based upon total pedestrian delay and expected motorist compliance.		
Expected motorist compliance at pedestrian crossings in region, Comp = high or low	*5a*	**Low**

Total Pedestrian Delay, D_p (from *4h*) and Motorist Compliance, Comp (from *5a*)	Treatment Category (see Descriptions of Sample Treatments for examples)
$D_p \geq 21.3$ h (Comp = high or low) OR $5.3\text{ h} \leq D_p < 21.3$ h and Comp = low	RED
$1.3\text{ h} \leq D_p < 5.3$ h (Comp = high or low) OR $5.3\text{ h} \leq D_p < 21.3$ h and Comp = high	ACTIVE OR ENHANCED
$D_p < 1.3$ h (Comp = high or low)	CROSSWALK

Figure 3. Worksheet for crosswalk warrant (18)

The third step estimates pedestrian delay. The critical gap that a pedestrian requires to cross the road determines delay. Using the equations from the worksheet in Figure 3, the total pedestrian delay is determined to be 0.602 ped-hr.

The fourth step is to determine driver compliance. The driver compliance for this site is unknown, and therefore chosen to have a low driver compliance to yield a conservative answer.

The total pedestrian delay corresponds to a pavement marking crosswalk as the treatment for this case study. The site uses a published study as the evaluation criteria which Table 7 indicates a value of 1.35 for the evaluation level. This study meets the study criteria but is not considered to exceed the criteria. This indicates a value of 2 from Table 7 for the study criteria. The product of these two values equals a situational variable, x_n, of 2.7 out of 3.

Impact

The factor evaluates the expected impact of the treatment installation. A list of considerations for this factor is in Table 18, as well as how they apply to this case study.

Table 18. Impact factor considerations and resulting application

Consideration	Application to Case Study
Will there be driver compliance?	Low
Will the drivers see the signage for the crosswalk?	There will be a crosswalk warning ahead sign as a warning sign at the crosswalk
Is there visibility of the pedestrian on the curb and in the crosswalk?	Yes
Will pedestrians use the crosswalk and feel safe doing so?	Yes and possibly
Does the crosswalk give a false sense of security to the pedestrian?	Probably not because of above answer
Is the driver expecting a crosswalk at this location?	Yes, it is near a park

This device installation will have a positive impact on the system based on the "Application to Case Study" in Table 18. Table 8 indicates that for a positive impact for the pedestrians and the drivers, the situation variable for the impact, x_f, will be a 3 out of 5.

Influences

There are many external and internal influences that affect the treatment decision, such as future development in the area, which would increase pedestrian or traffic volumes. External influences, such as political officials or school districts, could be pushing for this installation as well, but there is no indication of this in this scenario. As stated in Chapter III, these influences are also largely related to the considerations that have been included in the need and impact factors, but are emphasized here as part of the reasoning within the decision-making process.

In this case study, the city requested that an evaluation of this location be conducted. This could have stemmed from either an elected official or a citizen's request. The location area is fully developed, so this is not future planning, and there is no known crash history due to pedestrians.

Engineering judgment allocates a 0 out of 3 for the situational variable of the influence factor, x_i, because there is not adequate influences for the installation of the device. Again, this judgment does not reflect an actual practitioner's evaluation, but is for demonstration purposes only.

Cost

The initial cost of installation for a pavement marking is not significant, but it is more costly that regular longitudinal pavement marking because Crosswalk pavement marking lines are installed by hand. In addition, if other treatments are included, such as signing or a warning or overhead signal, then the cost of the installation will increase greatly. If the decision maker is running the scenarios for different treatments, they need to be sure to specify which treatment they are analyzing.

Initial installation requires two Crossing Ahead signs, two Pedestrian Crossing Here signs, and two Stop for Pedestrian plaques, one for each direction, as well as the pavement marking crosswalk of two parallel lines. These are simple installations, and do not require additional significant cost. Life cycle costs apply the same concept as initial costs. A typical pavement marking or sign may not have a high life cycle cost, but if signals are needed, then it will be more costly to supply the electricity to run the devices as well as to replace the parts that break. Crosswalk pavement markings, however, cross the wheel path of vehicles and therefore required more maintenance than a typical longitudinal pavement marking.

The pavement marking for this installation will need the most frequent maintenance. This regular maintenance of the pavement marking may be in a maintenance cycle that the agency uses to renew all pavement markings on a rotational schedule. This would have a less significant cost than maintaining the treatment by itself because the agency is maintaining the system as a whole.

The funds for the crosswalk installation and life cycle costs would come from the maintenance budget, but there are no funds available in the budget. Therefore, the situational variable, x_c, for the cost facto is 0.

Total Utility

With the variables previously determined, the utility equation from Chapter III is applied.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

$$U_m = (59.50)\left(\frac{2.7}{3}\right) + (21.69)\left(\frac{3}{5}\right) + (5.87)\left(\frac{0}{3}\right) + (12.94)(0)$$

$$U_m = 66.56$$

The decision scale presented in Table 10 suggests that since $80 > U_m \geq 50$, the device has some installation value.

The decision is to install a crosswalk with two parallel pavement markings treatment. If this treatment had received a lower utility, or a different suggested treatment from the analysis, then the next step would be to conduct investigations of alternative treatments. This could change the affects that the impact of the treatment's visibility to the driver, the initial and life cycle costs, or consistency and uniformity within this particular jurisdiction or neighboring jurisdictions have on the process.

EVALUATION TO INSTALL AN ADVANCED WARNING SIGN

This case study evaluated advanced warning signs such as a Yield Ahead, Stop Ahead, or Signal Ahead signs. These signs warn the driver of a TCD ahead that may not be expected. A list of considerations is seen in Table 19. This table may not include all possible considerations. This case study applied some of these considerations the scenario.

Table 19. Advanced warning sign installation considerations

Considerations	
Type of sign for advanced warning Sight distance Driver expectancy Crash history Uniformity of signing system	Elected official opinions School district opinions Citizen requests Cost to install and maintain

Determining Coefficients

The AHP application determines the coefficients for this type of case study. This process is in Appendix A. Table 20 shows the resulting priorities, or coefficients, for the factors in the total utility equation.

Table 20. Priority values of advance warning sign

Criteria	Priority	Coefficient
Need	64.55%	a_n
Impact	23.30%	a_f
Influence	5.74%	a_i
Cost	6.41%	a_c
Sum	100.00%	-

Determining Situational Variables

The next part of the process is to determine the situational variables for this specific scenario.

Scenario

On a rural highway, there is a four-way Stop at the intersection with another rural highway. These are both high speed, low volume roads. There is adequate sight distance according to the MUTCD tables (1). Recently, there was a reported vehicle collision.

There were no fatalities, only property damage, but the agency requested an evaluation of the site for the installation of a Stop Ahead sign.

Need

The MUTCD primarily requires advance warning of traffic control signs based on inadequate sight distance (1). MUTCD Tables 2C-4 or 4D-1 determine if there is adequate sight distance for signs and signals, respectively (1). With little change in alignment of these roadways, there is adequate sight distance. Therefore, the warrant is not met. However, the MUTCD also states as an option that states, "An Advance Traffic Control sign may be used for additional emphasis of the primary traffic control device, even when the visibility distance to the device is satisfactory" (1). Therefore, an engineering study or engineering judgment determines the need for the Stop Ahead sign.

Some other considerations that would influence this decision are the site crash history or driver expectancy of the TCD. Crash history can be difficult to obtain because not all crashes are reported. If there are records for the sight crash history, that should be taken into account in this part of the analysis. The collision that started this evaluation is the only reported crash. Although there were no fatalities, this collision may indicate inadequate intersection signing. However, one crash in the history of this intersection is not significant.

Driver expectancy is defined as a driver that has expectations of the condition of the road and is ready to react accordingly (21). Transportation engineers try to minimize violations of driver expectancy to improve the safety of the driving task. For this scenario, the drivers are on high-speed rural highways that do not have a significant amount of stops or traffic. This intersection is unexpected to the driver and could cause the driver to brake at the last minute or miss the Stop sign all together. To avoid or minimize this situation, a Stop Ahead sign is the suggested treatment. This would warn the driver of the maneuver that they are about to encounter and reduce last second realization of the device or intersection. Since this study uses engineering judgment, Table 7 indicates a value of 1 be used for this evaluation level. Similarly, engineering judgment suggests that the device be installed at a value of 2 from Table 7. The product of the values sets the situational need, x_n, at a 2 out of 3.

Impact

To evaluate the impacts of this Stop Ahead sign, judgment is needs on the effectiveness of the device installation. Table 21 suggests questions that evaluate the impact of the advance warning sign.

Table 21. Impact considerations for an advance warning sign

Although minimum sight distance has been met, should a larger distance be allotted in situations? (vehicle queue at device, etc.)
Will the installation of the advance warning sign reduce the types of crashes that are occurring?
Will the installation of the advance warning sign increase a different type of crashes at the TCD?
Will the advance warning increase driver awareness of the TCD?

For this case study, a Stop Ahead sign is believed to be an effective solution to warn drivers of the Stop sign at the intersection they are about to encounter. This device would have a positive impact on the scenario. This corresponds to an x_f value of 3 out of 5 from Table 8.

Influences

Influences such as elected officials, school districts, citizens, and communities could all request the advance warning sign. In addition, a new development could be constructed somewhere along the route causing traffic to increase while causing driver familiarity to decrease.

Since there was a collision, an elected official, the media, or the agency has requested to make this intersection safer. This is typical process for a site evaluation, but there is believed to be a little external influence for a device at this intersection to increase the safety of this intersection due to the collision. Table 9 indicates the situational value for influence is given a 1 out 3.

Cost

The sign installation costs are minimal for this device. Only four signs need to be installed, one at each approach. The maintenance costs are also to be minimal, but will need periodic evaluation for the sign quality. Since initial and life cycle costs are relatively low, the maintenance budget has sufficient funds to install the device. This yields a situational variable, x_c, of 1.

Total Utility

With the variables previously determined, the utility equation from Chapter III is applied.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

$$U_m = (64.55)\left(\frac{2}{3}\right) + (23.30)\left(\frac{3}{5}\right) + (5.74)\left(\frac{1}{3}\right) + (6.41)(1)$$

$$U_m = 65.34$$

The decision scale presented in Table 10 suggests that since $80 > U_m \geq 50$, this device has some installation value.

The decision is to install a Stop Ahead sign as that specified distance in the MUTCD. If there is another collision or the effectiveness is relatively low, this process can evaluate pavement markings as well or other alternatives, such as an alignment change, may be considered.

EVALUATION TO INSTALL AN INTERSECTION CONTROL BEACON

This case study evaluates an intersection control beacon. The MUTCD limits these beacons to a flashing yellow on the major route with a flashing red on the minor route or flashing red on all approaches (1). Table 22 lists the considerations for the installation decision process.

Table 22. Intersection control beacon installation considerations

Considerations	
Driver expectancy	Operations cost
Stopping sight distance	Alternative devices
Speed differential required	Adequate visibility
Crash history	Elected official opinion
Installation cost	Citizen or community request
Maintenance cost	Loss of significance in over application

Determining Coefficients

The AHP application determines the coefficients for this type of case study. This process is in Appendix A. Table 23 shows the resulting priorities, or coefficients, for the factors in the total utility equation.

Table 23. Priority values of intersection control beacon

Criteria	Priority	Coefficient
Need	30.55%	a_n
Impact	31.94%	a_f
Influence	5.58%	a_i
Cost	31.94%	a_c
Sum	100.00%	-

Determining Situational Variables

The next part of the process is to determine the situational variables for this specific scenario.

Scenario

On a rural highway, there is a four-way Stop at the intersection with another rural highway. These are both high speed, low volume roads. There is adequate sight distance according to the MUTCD tables (1). There was one reported vehicle collision resulting in property damage, but the agency had installed a Stop Ahead sign in response. There have not been any more collisions since the installation of that device. Shortly after the installation of the Stop Ahead sign, there was another request for more emphasis at the intersection, specifically an Intersection control beacon.

Need

The MUTCD does not give criteria to conduct a warrant study for intersection control beacons. It does suggest options for the use of beacons to increase visibility of an intersection or to help to reduce crash rates at an intersection (1). In addition to the MUTCD, there was a research paper by Pant, et al. about rural beacon-controlled intersections (22). This study suggests guidelines for the installation of an Intersection control beacon at rural, low volume intersections. The recommendations are as follows:

- Use intersection control beacons sparingly to increase respect for device from drivers.
- Do not use intersection control beacons to increase effectiveness at intersections with adequate sight distance.
- Use intersection control beacons to reduce speed slightly on the major approaches.
- Do not use intersection control beacons to reduce Stop sign violations or accidents due to these violations.

This case study has adequate intersection sight distance. There has been only one collision, and that occurred before the installation of the advance warning treatment. The request may be to try to reduce Stop sign violations, but the exact reasons for the request are unknown. The evaluation level is a published study, which Table 7 indicates is a value of 1.35. Application of the guidelines from both the MUTCD and the Pant, et al. study to the intersection suggest that the device not be installed. Whether this case evaluation uses MUTCD standards or evaluation criteria, it does not meet any requirements for an Intersection control beacon. This corresponds to a value of 0 from Table 7. The product of these values will set the situational variable to a 0 out of 3.

This low value for the need of the device should be enough to end the process here. No further evaluation is needed. However, this research will conduct a full process evaluation.

Impact

There are two main considerations for the impact factor for the decision to install an Intersection control beacon. These include the potential to increase driver visibility of the intersection control and the potential to reduce intersection crash rates. Neither one of these considerations is currently an issue with the intersection. Therefore, Table 8 indicates that the situational variable, x_f, be a 0 out of 5.

Influences

Influences are the cause for this intersection evaluation. It is unclear as to whether a citizen or an elected official has made the request for the evaluation, but no further pressure has come from the agency about this intersection evaluation other than the initial request. There are no additional influences on the evaluation of the device. Therefore, the situational variable for influence, x_i, from Table 9 is a 0 out of 3.

Cost

The initial costs for an Intersection control beacon are significant due to the poles, electrical system, other equipment, and labor used for installation. There are also significant life cycle costs associated with this device. Power will need to be provided for the device, as well as occasional maintenance. This device does not qualify for any special budgets nor are there sufficient funds in the maintenance budget to install the device. For these reasons, the situational variable for the cost factor, x_c, from is 0. This is due to the significant cost and lack of funds.

Total Utility

With the variables previously determined, the utility equation from Chapter III is applied.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

$$U_m = (30.55)\left(\frac{0}{3}\right) + (31.94)\left(\frac{0}{5}\right) + (5.58)\left(\frac{0}{3}\right) + (31.94)(0)$$

$$U_m = 0$$

The decision scale presented in Table 10 suggests that since $U_m < 20$, the treatment has little to no installation value.

As stated earlier, the evaluation should have ended when it was determined that there was no need for the device. At the end of the full process evaluation, it was clear that the decision for this device is not to install. The total utility was a negative value. This is to be expected, and demonstrates the limited value of the device.

EVALUATION TO INSTALL A LEFT-TURN PROHIBITED SYSTEM

This case study evaluated a left-turn prohibited system. There are two main types of applications of this system. The first is a minor road or a driveway approaching a major road. The second is a major road prohibited from turning left onto a minor road or driveway. This case study evaluates the whole system of TCDs involved including pavement markings, signs, and channelizing devices. Table 24 shows a list of specific TCD that could be included in the system as well as the criteria that for the installation.

Table 24. TCDs involved and consideration for turn prohibited system installation

TCDs Involved	**Considerations**
Directional arrow pavement marking	Volume on major road
No Left-turn sign	Volume of left-turn out of driveway or minor road
Right Turn Only sign	Delay on minor road or driveway
Channelizing island	Critical gap
Tubular marker - longitudinal on major road	Available gap on major road
Tubular marker - to channel right turn on minor road	Crash history
Solid double yellow line approaching major intersection	Number of lanes on minor road approaching major road
	Number of lanes on major road
	Speed on major road
	Median on major road (TWLTL or left-turn bay)
	Distance to nearest major intersection

This table may not include all possible devices or considerations. This case study applies some of these devices and considerations in the scenario.

Determining Coefficients

The AHP application determines the coefficients for this type of case study. This process is in Appendix A. Table 25 shows the resulting priorities, or coefficients, for the factors in the total utility equation.

Table 25. Priority values of left-turn prohibited system

Criteria	Priority	Coefficient
Need	45.33%	a_n
Impact	27.89%	a_f
Influence	5.78%	a_i
Cost	20.99%	a_c
Sum	100.00%	-

Determining Situational Variables

The next part of the process is to determine the situational variables for this specific scenario.

Scenario

A driveway to an office building connects to a major 4 lane undivided arterial. During the PM peak hour, traffic on the major road is too heavy to allow a left-turn maneuver from this driveway, and there have been four collisions at this intersection in the past 10 years. This does not stop drivers from attempting this maneuver. The speed on the major road is 40 mph, and the traffic volume is growing as development expands on the arterial. The proposed mitigation includes a no left-turn sign, tubular markers to channel the exiting traffic through a right turn, and a right-turn directional arrow pavement marker.

Need

The MUTCD only provides information on the application of the devices, but presents no warrants. Engineering judgment will be the evaluation technique. Table 7 indicates a value of 1 be used for the evaluation level. There have been several collisions at this intersection, so there is a safety need for some type of mitigation. With the increase in volume on the major road, the gaps are getting smaller and delay on the driveway is increasing. This location exhibits an operational need for some type of mitigation. Safety and operations are the two major requirements for a TCD and this intersection exhibits poor performance in both areas. There is a clear need for mitigation at this intersection. This corresponds to a value of 3 from Table 7 for the evaluation criteria. The product of these values corresponds to a situational variable for need, x_n, of a 3 out of 3.

Impact

To evaluate the impacts of this left-turn prohibited system, judgment needs to be made on the effectiveness of the system once installed. Table 26 suggests questions to evaluate the impact of the turn prohibited system.

Table 26. Impact considerations for a turn prohibited system

Will drivers respect the devices installed in the system?
Will the devices reduce crash rate?
Will the device reduce delay at the driveway?
Will the device prevent the turning movement?

The proposed device system satisfies all of the consideration in the above table. Removal of any part of the system would result in a lack of driver respect for the turn prohibition, and the drivers would still attempt to make a left-turn, which would also result in the reduction of the safety and/or operations of the driveway intersection. Due to these conclusions and the high positive impact the device is believed to have on the site, the situational variable for the impact factor, x_f, is given a 4 out of 5 according to Table 8.

Influences

Influences such as elected officials, citizens, or the building owner could all request the investigation into a solution for the driveway intersection. Elected officials may want to reduce the crash rates, and make the intersection safer. Citizen or building owners may want to reduce the delay at the driveway exit. In this scenario, a citizen wanted to reduce delay. Reducing the crash rate would be a stronger influence than delay. Other than the initial request for the site evaluation, there are no influences for this scenario. This corresponds to a situational variable for the influence, x_i, of a 0 out of 3.

Cost

There are three main device parts in this system: a sign, a pavement marker, and a number of tubular channel markers. The initial cost of all these devices is minimal. The installation costs for tubular markers are more than the sign and pavement marker installation, but do not significantly increase the cost. There is some life cycle cost with this system because the tubular markers need frequent replacement (in terms of TCD life spans). The sign and pavement marker will have a lower life cycle cost. This device does not currently qualify for any special budgets nor are there sufficient funds in the maintenance budget to install the device. The situational variable of the cost, x_c, associated with this proposed system is therefore 0.

Total Utility

With the variables previously determined, the utility equation from Chapter III is applied.

$$U_m = a_n x_n + a_f x_f + a_i x_i + a_c x_c$$

$$U_m = (45.33)\left(\frac{3}{3}\right) + (27.89)\left(\frac{4}{5}\right) + (5.78)\left(\frac{0}{3}\right) + (20.99)(0)$$

$$U_m = 67.64$$

The decision scale presented in Table 10 suggests that since $80 > U_m \geq 50$, this device has some installation value.

The decision is to install the proposed left-turn prohibited system consisting of a no left-turn sign, a right turn directional arrow pavement marker, and tubular channel markers. Evaluation of other systems is encouraged and the utilities compared to determine which system would have the greatest utility for the driveway intersection. Due to the lower utility, the decision maker might evaluate a change, addition, or removal of device alternatives in the system.

CHAPTER V

CONCLUSIONS AND FUTURE RESEARCH

The MUTCD provides the guiding principles for the selection, design, installation, operation, maintenance, and removal of traffic control devices. Although it is the national standard for TCDs, it provides limited information to guide practitioners on the selection of TCDs that are not required. As a result, practitioners rely upon a combination of MUTCD information, results of research efforts and other practitioners' experiences, and their individual engineering judgment to determine whether it is appropriate to install a TCD in a given situation. The use of different sources of information can lead to inconsistencies in the TCD selection process. The purpose of this thesis was to devise a process that would guide practitioners towards making more thorough and consistent TCD decisions by applying all the factors into the decision process.

SUMMARY AND CONCLUSIONS

After evaluating the current state-of-practice of experienced traffic engineers, the combination of systems engineering and decision analysis concepts created a general process to assist traffic engineering practitioners in selecting TCDs to apply in a given situation. After the development of four factors for the process (need, impact, influences, and cost), the criteria was structured into an overall process that consisted of two elements for each factor. The first element used the decision analysis method, AHP, to determine the weights for each factor as applied generally to each TCD. The second element used a mixture of quantitative and qualitative engineering judgment to determine the factor specific application to TCD situation. The output of this process was a utility value that could be compared to a scale and determine the suggested installation decision. A comparison of the initial utility value to alternative utility values will determine which TCD has the greatest installation benefit. As emphasized throughout this thesis, it is not the intent of this process to remove engineering judgment. This is an important part of the process and should remain as such.

In recent years, the FHWA has made several changes to the MUTCD and its use to improve national uniformity of TCDs. While these steps have had a positive impact on the use of TCDs across the country, there can still be differences in the application of these devices because of how TCD decisions are made by individuals.

The concepts developed and presented in this thesis provide the foundation for a process that can be directly implemented into day-to-day decision-making for TCDs hereby furthering uniformity in application. Defining the four factors to analyze and guide the decision-making process, plus the creation of an overall utility value (as well as direct implementation of engineering evaluation) are the main ideas of the process and proved to be an effective tool for the TCD decision-making process. The proposed process appears to be the first effort to develop a decision-making procedure that has universal application to TCD and will be useful in making more uniform TCD decision no matter the engineers' level of traffic engineering experience.

FUTURE RESEARCH

The concepts presented in this thesis are only a starting point, as the scope of this thesis did not allow for a complete development of a process for all TCD situations. There are many aspects of this research that should be expanded upon. Some of the recommendations for future research include:

- Develop coefficient values, *a*, for all TCD situations or groups.
- Collect historical data of coefficient values used for linear utility application.
- Refine situational variable scale for each TCD situation.
- Refine utility scale for installation decision suggestion.
- Streamline decision process with computer program.

The addition of confidence bounds can be included with the different factors. For example, the *a* value may be multiplied by 1 if there is high confidence in *x* or subtract 1.25*a* from *a* if there is less confidence in *x*.

As this process is improved and implemented, more data will become available to better define and refine the process and the factors in the process. The application of this process would be similar to the *Highway Safety Manual*, which has not yet been finalized. This Manual will be a quantitative tool that will improve highway safety decisions in roadway planning, design, maintenance, construction, and operations (23).

Similarly to the *Highway Safety Manual*, the proposed process in this thesis will increase confidence in difficult decisions.

The inclusion of these ideas for future research would strengthen the proposed process and further assist engineers in TCD decisions.

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APPENDIX A

ANALYTIC HIERARCHY PROCESS APPLICATION

The Analytic Hierarchy Process, AHP, designed by Saaty, is used to determine the coefficients for each of the factors in each of the different case studies (11). The calculation tables are presented in this appendix.

To determine the coefficients, *a*, for the decision models, the AHP should be determined for the global priority of factors. Using the AHP fundamental scale a pairwise comparison can be made with the factors. Table A-1 explains the fundamental scale, and Table A-2 shows the pairwise comparison for all the different case studies. Table A-1 is the same scale and explanation that Saaty uses for his AHP.

Table A-1. Fundamental scale for pairwise comparison (11)

Intensity of Importance	Definition of Importance	Explanation
1	Equal Importance	Two elements contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one element over the other
5	Strong Importance	Experience and judgment strongly favor one element over the other
7	Very Strong Importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc., can be used for elements that are very close in importance.		

Table A-2 was created by comparing the criteria of each row to determine which was more important and the intensity of that importance. The importance and intensity values selected in this table are from one experienced traffic engineer. They are for demonstration purposes and may not reflect actual values that would be appropriate for the decision process.

Table A-2 Pairwise comparison of factors for all case studies

Criteria		General		Traffic Generator		Crosswalk	
A	B	More Important	Intensity	More Important	Intensity	More Important	Intensity
Need	Impact	A	1	A	1	A	6
Need	Influence	A	8	A	4	A	5
Need	Cost	A	1	B	5	A	6
Impact	Influence	A	7	B	2	A	7
Impact	Cost	A	1	B	3	A	2
Influence	Cost	B	6	B	3	B	4
Criteria		**Advanced Warning**		**Intersection Beacon**		**Turn Prohibited**	
A	B	More Important	Intensity	More Important	Intensity	More Important	Intensity
Need	Impact	A	7	A	1	A	3
Need	Influence	A	9	A	5	A	5
Need	Cost	A	7	A	1	A	2
Impact	Influence	A	6	A	6	A	6
Impact	Cost	A	5	A	1	A	2
Influence	Cost	A	1	B	6	B	5

The next step of the AHP is to expand these intensities into a matrix that compares all scenarios of factor comparison, as seen in Table A-3 for all cases studies. This matrix displays the intensity for the more important factor as well as the reciprocal for the less important factor.

Table A-3. Complete comparison matrix for all case studies

Criteria	Need	Impact	Influence	Cost
Need	1	1	8	1
Impact	1	1	7	1
Influence	1/8	1/7	1	1/6
Cost	1	1	6	1
Sum	3.125	3.143	22.000	3.167

(a) General

Criteria	Need	Impact	Influence	Cost
Need	1	1	4	1/5
Impact	1	1	1/2	1/3
Influence	1/4	2	1	1/3
Cost	5	3	3	1
Sum	7.250	7.000	8.500	1.867

(b) Traffic generator

Criteria	Need	Impact	Influence	Cost
Need	1	6	5	6
Impact	1/6	1	7	2
Influence	1/5	1/7	1	1/4
Cost	1/6	1/2	4	1
Sum	1.533	7.643	17.000	9.250

(c) Crosswalk

Criteria	Need	Impact	Influence	Cost
Need	1	7	9	7
Impact	1/7	1	6	5
Influence	1/9	1/6	1	1
Cost	1/7	1/5	1	1
Sum	1.397	8.367	17.000	14.000

(d) Advanced warning

Criteria	Need	Impact	Influence	Cost
Need	1	1	5	1
Impact	1	1	6	1
Influence	1/5	1/6	1	1/6
Cost	1	1	6	1
Sum	3.200	3.167	18.000	3.167

(e) Intersection beacon

Criteria	Need	Impact	Influence	Cost
Need	1	3	5	2
Impact	1/3	1	6	2
Influence	1/5	1/6	1	1/5
Cost	1/2	1/2	5	1
Sum	2.033	4.667	17.000	5.200

(f) Prohibited movement

These intensities are then normalized by dividing each cell in a column by the sum of the column. Table A-4 shows these normalized values as well as the priority ranking of each factor for all cases studies. This priority is derived by averaging the values across each row.

Table A-4. Normalized relative weight with priority values

Criteria	Need	Impact	Influence	Cost	Priority	Coefficient
Need	0.320	0.318	0.364	0.316	32.94%	a_n
Impact	0.320	0.318	0.318	0.316	31.80%	a_f
Influence	0.040	0.045	0.045	0.053	4.59%	a_i
Cost	0.320	0.318	0.273	0.316	30.67%	a_c
Sum	1.000	1.000	1.000	1.000	100.00%	

(a) General

Criteria	Need	Impact	Influence	Cost	Priority	Coefficient
Need	0.138	0.143	0.471	0.107	21.46%	a_n
Impact	0.138	0.143	0.059	0.179	12.95%	a_f
Influence	0.034	0.286	0.118	0.179	15.41%	a_i
Cost	0.690	0.429	0.353	0.536	50.17%	a_c
Sum	1.000	1.000	1.000	1.000	100.00%	

(b) Traffic generator

Criteria	Need	Impact	Influence	Cost	Priority	Coefficient
Need	0.652	0.785	0.294	0.649	59.50%	a_n
Impact	0.109	0.131	0.412	0.216	21.69%	a_f
Influence	0.130	0.019	0.059	0.027	5.87%	a_i
Cost	0.109	0.065	0.235	0.108	12.94%	a_c
Sum	1.000	1.000	1.000	1.000	100.00%	

(c) Crosswalk

Criteria	Need	Impact	Influence	Cost	Priority	Coefficient
Need	0.716	0.837	0.529	0.500	64.55%	a_n
Impact	0.102	0.120	0.353	0.357	23.30%	a_f
Influence	0.080	0.020	0.059	0.071	5.74%	a_i
Cost	0.102	0.024	0.059	0.071	6.41%	a_c
Sum	1.000	1.000	1.000	1.000	100.00%	

(d) Advanced warning

Criteria	Need	Impact	Influence	Cost	Priority	Coefficient
Need	0.313	0.316	0.278	0.316	30.55%	a_n
Impact	0.313	0.316	0.333	0.316	31.94%	a_f
Influence	0.063	0.053	0.056	0.053	5.58%	a_i
Cost	0.313	0.316	0.333	0.316	31.94%	a_c
Sum	1.000	1.000	1.000	1.000	100.00%	

(e) Intersection beacon

Criteria	Need	Impact	Influence	Cost	Priority	Coefficient
Need	0.492	0.643	0.294	0.385	45.33%	a_n
Impact	0.164	0.214	0.353	0.385	27.89%	a_f
Influence	0.098	0.036	0.059	0.038	5.78%	a_i
Cost	0.246	0.107	0.294	0.192	20.99%	a_c
Sum	1.000	1.000	1.000	1.000	100.00%	

(f) Prohibited movement

This part of the process does not require specific information from the installation scenario. Therefore, once these coefficient values from Table A-4 are obtained by an agency, they should be used for all similar TCD decisions.

This thesis only uses a partial AHP. Additional steps in the AHP are described below, but not used in this thesis to maintain a large part of the engineering judgment. The next step in the AHP analyzes a sublevel of factors in the same process as presented in the tables above to determine their local priorities. Each sublevel can have multiple criteria to analyze. Sublevels for the need factor, for example, would be evaluations, safety, and operations. Next, the global priority of the sublevels is determined. These priorities are derived with the product of the maximum global priority of the factors by each individual local priority. Another pairwise comparison is then evaluated for each sublevel and the decision options, i.e., install or do not install, and the importance is decided. The local priorities and global priorities are then derived in the same manner as the previous derivations. Finally, a summation of the priorities for each decision (install and do not install) is calculated. The decision choice with the greatest priority summation is the decision choice. Saaty and Vargas offer more detail or in depth explanation of the process (10, 11).

APPENDIX B

INITIAL INVESTIGATION DETAILS

Five practitioners agreed to partake in the initial investigation to determine an approach towards traffic engineering decisions. They are all anonymous and will be referred to as Practitioners 1 through 5. Their agencies ranged from state, county and local government employees to consultants. A detailed summary of their conversation are below.

PRACTITIONER 1

Practitioner 1 works for a state department of transportation, but also has 5 years of experience working as a traffic engineer for a city.

This person wanted to express that every device should satisfy a need. This can be an engineering/operational need or a safety need.

A current issue within this practitioner's agency is citizens wanting to use signs as advertisement, whether it is for seat belts or for memorials, but this gets into an issue of selling the right of way (ROW).

Some typical political experiences deal with traffic signals, Stop signs, Children at Play signs, or Speed Limit change installations. This practitioner claims that at the state level, it is easier to avoid political pressures, but if a senator wants a device, they usually get it.

The quid pro quo that does go on happens in the background where the staff does not realize, know, or experience it. Maintenance is an issue when politicians get a sign installed. They do not always consider who is going to pay for the maintenance or replacement when needed.

Cost should not play a role in the decision to install a device. Signs, individually, are not that expensive to install, but a mass sign installation will be more expensive. Recently, the respondent's state has adopted the national MUTCD. It is costly to upgrade the system to meet the new standards, especially at the local level. The local level can get money through MPOs, grants, and pork barrels. There are budgets allocated for certain projects or parts of the transportation system. Cost is prioritized from immediate maintenance to installation. At the local level, when funding is tight, warning signs may be the first devices that are forgone. There are increasing numbers of request for signs, but no increase in the budget. Prioritization and cuts have to be made. For example, a Stop sign will be installed versus an Adopt a Highway sign. Just recently, they have tried to incorporate looking beyond the initial cost of installation to the life cycle costs of a device in the decision process.

This practitioner tries to minimize the risk to zero. Places where risks might be taken could be in sign compliance with the letter heights. Other risks include a false sense of security. The general population believes that signs are a panacea. For example, a request for an Autistic Child sign is not installed because there is no research supporting the effectiveness of that sign to the drivers.

Uniformity is an issue between the eastern to western sides of the country or even different regions in a state. For example, the use of a Stop Ahead sign may vary by each jurisdiction. Some may use more liberally while others are stricter in the use. At the state level, safety and engineering come first, but there is occasionally political influence (about 10 to 15% of the time).

The factor hierarchy will vary depending on the level of agency. Local agencies are not likely to have a traffic engineer, and therefore, political reasons have more importance. The decision to install will vary from level to level and situation to situation. There is not a one size fits all solution.

PRACTITIONER 2

Practitioner 2 works for a local agency, or a city, and has worked for local agencies for more than 10 years.

This practitioner believes that when evaluating a TCD, do not install unless absolutely necessary. Neighborhoods are starting to request All-way Stop signs at every intersection, which is not a necessary treatment. The MUTCD should be used for all TCD decisions, and if a device is not needed, try to avoid installation. There are devices that are warranted like signals that are not installed unless it is the absolute last resort. Alternative devices should always be considered, especially for devices such as a signal because of the capital and operational costs associated with them.

Political influences will dictate unnecessary installation such as the All-way Stop sign in the neighborhoods. Engineers should try to point out the operational risk of installing unnecessary devices to try to avoid installation. Sometimes governments are receptive and understanding to this reasoning, and other times they are not.

If there are multiple projects of equal importance, often time the project with the most citizen input will get installed to help build good will with the public.

Satisfying the warrants does not require a device to be installed. An agency is assuming more liability and risk by installing an unwarranted device than not installing a warranted device. One risk that the agency is currently undertaking is to try to sell and convince the public of the usefulness of roundabouts.

Signs and markings do not have significant costs. Signals, however, have significant cost and should be installed as a last resort. Cost-to-benefit ratio is used to compare projects to determine where to get the “biggest bang for the buck.”

Uniformity is important within the system. To meet the new standards in the MUTCD, all letter heights have been increased on the street markers. In addition, this city is trying the new flashing yellow indicator on traffic signals.

This practitioner states that their engineers have a good relationship with the government, but this is not always the case in other cities.

PRACTITIONER 3

Practitioner 3 was a consultant and has a unique perspective on the investigation.

Life cycle cost evaluation seemed to be a shortfall in the current process. In addition, investigating new technologies should be important in keeping the system up to date. Using a systems engineering approach to the decision process is a continuous system and will need to be designed as such.

The scope of the project changes depending on the agency level. Local agencies look at individual devices whereas state agencies look at the process.

If a systems engineering process is to be designed, then the FHWA report about ITS applications using systems engineering should be a reference for guidance.

The overall transportation process is to plan, design, build, operate, and maintain, and all should be considered in this research.

PRACTITIONER 4

Practitioner 4 is employed by a state department of transportation and is a regional traffic engineer.

Requests can come internally from an agency department or externally from private citizens. External requests are more common; especially for reduced speed zones or School Bus stop Ahead signs. It would be preferable if the request for the School Bus

Ahead sign came from the school districts. Other requests are for safety studies or highway reviews, but are still primarily generated by the public.

For a speed zone study, the site in question is evaluated on engineering terms and with the law enforcement to ensure that a speed zone is enforceable. If the zone is initially denied, the citizens may go to the elected officials to push for the zone. Sometimes officials accept the engineering decision. Other times the elected official will request a second study.

Political pressure may also get an unwarranted signal installed. If there is a lawsuit at this intersection, it is unknown how it is handled because it is outside the department.

In general, the elected officials will be receptive to the technical explanation of a TCD decision. Other times, not the majority but more than frequently, they do not accept the decision. It is understood that certain decisions made by the engineer may lead to political consequences, but engineers try to maintain the best engineering decision for all situations.

This practitioner tries to avoid quid pro quo to avoid setting precedence for devices to be installed and cites uniformity in application.

To avoid risk, only slip bolt poles are installed unless outside the clear zone and all warranted signs are installed.

Sign installation is funded through the maintenance engineer, and signals are funded through capital programs. Usually signals that are upgraded, replaced, or newly installed and are funded through federal aided programs. These programs usually cycle every two years, so if a new signals comes up after the contract it is generally put under another project contract. Rarely do they install signals with their own crew because it is usually contracted out. It is rare to remove signal. Flashing devices are occasionally taken out. In addition, signs such as school bus or handicapped area are commonly removed.

Some elected officials have requested bilingual signs, but to maintain uniformity, symbolic signs were installed.

One weakness this practitioner experiences with traffic engineering decision is that city engineers do not strictly adhere to the MUTCD.

PRACTITIONER 5

Practitioner 5 is a county traffic engineer.

A good decision process would guide practitioners to make good engineering decisions and minimize political pressures.

In house traffic expertise is a weakness of many medium sized cities. These cities typically have the city engineer make these types of decisions. This would be a good target group for applications of this research.

To minimize political influence this jurisdiction has many policies in place such as when to use directional signing, when to use a dead end signs, and where to put speed limit signs. These all help increase uniformity across the region. These policies also help reduce risk and liability.

A priority list, or project "to do" list helps with informing the political pressures of the order and priority of projects. This also helps with risk assessment and safety emphasis.

If an engineering study determines that a device is not needed, then an alternate device should be suggested, if needed. For example, a four-way Stop may not be warranted, but maybe a highway intersection warning sign would be helpful.

When politics get "real bad," however, an engineer needs to "pick their fights."

This practitioner's hierarchy of TCD factors is as follows:

- Uniformity--treat all devices in similar ways. Uniformity in using the MUTCD and augmenting with local policies
- Risk management/tort liability--this region has no sovereign immunity, no limits on damages, joint and severally liability law. All lawsuits have to be dealt with and can be costly. For consistency purpose they do not just settle, they fight the lawsuits that they can win. Good maintenance programs with thorough documentation help to reduce risk
- Cost--this is more significant in cases of signals or overhead signs, but this is also analyzed through a cost benefit ratio. Individual sign are not costly, but if a group of signs needs to be installed, it can be costly.
- Political--engineers have to be able to manage this factor

Other suggestions from this practitioner put emphasis on all MUTCD standards, and even guidelines. An agency should establish clear consistent policies.

APPENDIX C

SURVEY

PILOT SURVEY OF PROFESSIONALS

SYSTEMS ENGINEERING APPROACH FOR SELECTING TRAFFIC CONTROL DEVICES

Note to Participants: This survey is being conducted as part of research investigating the potential to develop a systems engineering approach for the selection and/or implementation of traffic control devices. Your responses will help the researcher identify critical factors that should be considered in selecting devices and the relative importance of those factors. Participation in this survey is voluntary. Individual survey responses will not be included in any reports and respondents will not be identified by name or organization in any reporting of the results.

Name:
Organization:
Phone:
Email:

1) What type of organization do you work for?
   a) ___ Government- federal
   b) ___ Government- state
   c) ___ Government- city
   d) ___ Government- county
   e) ___ Government- other (please specify):
   f) ___ Industry
   g) ___ Consultant
   h) ___ Research

i) ___ Other (please specify):

2) How many years of experience do you have as an engineer responsible for making traffic control decisions?
   a) ___ < 1 year
   b) ___ 1 - 5 years
   c) ___ >5 – 10 years
   d) ___ 10 + years

3) What is your responsibility for making traffic control device decisions? (Select all that apply.)
   a) ___ Establish policy for traffic control devices in agency
   b) ___ Supervising others that make traffic control device installation decision
   c) ___ Responsible for deciding to install or not to install traffic control device
   d) ___ Make recommendation to supervisor about installation of traffic control device
   e) ___ Provide/collect/process/analyze the data/input for supervisor to make decision

4) Please describe your typical process for deciding whether to install a traffic control device (from initial request to installation).

5) What influences might change or modify the typical process?

6) Based on your experience, please list all of the general factors that you normally consider when deciding whether to install a traffic control device (i.e. operational effectiveness, safety benefits, etc). Provide an importance value (1 to 5) for each factor with 5 being more important.

7) Please list other factors, beyond what were listed in Question 4, that could influence traffic control device decisions within your agency or at other agencies. These factors may not be normally considered by your agency or are rarely considered. Provide an importance value (1 to 5) for each factor with 5 being more important. Please be consistent with the previous question.

8) What are common considerations that an inexperienced engineer may not be familiar with that would improve their decision process for installing traffic control devices?

9) How does your agency assess the risk associated with the decision of whether to install or not install a traffic control device?

10) How does your agency assess the impacts of maintenance in the decision of whether to install or not install a traffic control device?

11) Please describe your process for deciding to remove a traffic control device.

12) Do you think your responses are typical to that of other jurisdictions or agencies? Explain.

13) What are the major challenges encountered in making traffic control device installation decisions (i.e. lack of data, competing priorities, etc.)?

14) What are the strengths of the MUTCD in terms of providing a process for making traffic control device installation decisions?

15) What are the weaknesses of the MUTCD in terms of providing a process for making traffic control device installation decisions?

16) Please rate the difficulty of each device decision in the following list as C- complicated or challenging, T- typical, or S- simple. Feel free to add and rate other items.

___ Install a STOP sign
___ Upgrade from YIELD control to STOP Control
___ Upgrade from a 2 way to a 4 way STOP
___ Upgrade an intersection from STOP control to signal control
___ Install flashing beacons at an intersection

___ Upgrade from flashing beacons to traffic signals
___ Install a pedestrian signal
___ Implement/change a speed limit
___ Implement/change a No Passing Zone
___ Implement/change School Zone
___ Install school crosswalk
___ Install a midblock crosswalk
___ Install a School Bus Stop sign
___ Install warning sign - i.e. curve, divided highway, STOP ahead etc.
___ Implement/change a one-way road
___ Implement/change a turn restriction at an intersection
___ Install additional route signs
___ Install lane control sign
___ Install pavement markings for lane control
___ Install a marked crosswalk
___ Install a guide sign
___ Other

17) The purpose of this research effort it to devise a process that would guide practitioners towards making a more consistent decisions about whether to install typical traffic control devices. In developing such a process, the research team hopes to identify the range of factors that should be considered and provide guidance on the relative importance of different factors. If such a tool can be developed, how would an improved decision making process for traffic control devices be helpful to your agency, if at all?

Please email or fax the survey back by June 5, 2009. Feel free to contact me if you have any questions or comments.

Thank you for your participation,

VITA

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