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

Heather McNeal
Graduate Assistant
Texas Transportation Institute
September 22, 2011
INTRODUCTION

The Manual on Uniform Traffic Control Devices (MUTCD) is a national document that assists engineers in making decisions about designing, installing, operating, maintaining, and removing signs, signals, markings, and other traffic control devices (TCDs) (1). Although thorough, this document addresses design, installation, maintenance, and removal of each TCD individually and not as a coordinated system. It explains where and how to install devices, but not why. 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 consistent TCD decision. To reach this goal, a thorough understanding of the experienced traffic engineer’s TCD decision process is needed, as well as how tools such as engineering systems, decision analysis, and probability theory can be applied to create a more formalized, unified process. To test the accuracy of this process, case studies would be developed and tested using professional traffic engineers. The results of this research would be a TCD process that can be directly implemented into everyday practice.

PROBLEM STATEMENT

Experience, training, and knowledge of 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, but the engineers that make TCD decisions generally do not spend their whole career in traffic. Therefore, they may not make the best possible decisions due to their lack of experience in this specialization. These engineers follow the MUTCD guidelines to the best of their ability, but the MUTCD does not explain the reasoning for certain requirements, nor does it explain how to make a particular decision. Despite the thoroughness of the MUTCD, the engineering judgment used to make these TCD decisions varies from engineer to engineer. To assist engineers with these inconsistencies, a process should be developed that would assist with TCD decisions. 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.

BACKGROUND

Before this process can be developed, some background information on the current process used
by practicing engineers needs to be determined. 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,
probability theory, or Bayesian analysis.

Manual on Uniform Traffic Control Devices

The MUTCD has basic principles for traffic control devices (1). This document is the starting
point for considering whether or not a device should be used. There are three types of statements
that are 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 for 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 legally an engineer is not required to install one, unless
an engineering study or judgment shows otherwise. As previously stated, the MUTCD provides
guidelines of how to install, maintain and remove TCD, but does not explain why this is done or
give background on the development of these policies.
Other factors besides the MUTCD are also used to determine if a device needs to be installed. These factors are generally considered when the requirements in the MUTCD are not necessarily met. What the factors are and how they are used towards TCD decisions will be determined during the research.

**Traffic Control Device Decision Making (surveyed practitioners)**

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. It was pointed out by one practicing engineer that at the city level, especially medium sized cities, the engineers are not trained traffic engineers (practitioner interview). 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. A request is made either from the public or from the Department of Transportation (DOT) for a TCD. Then an engineering evaluation is conducted to determine if a device is needed. This is the typical approach. After this, the decision can either be accepted or will need further study because someone strongly opposes the outcome of the initial evaluation. The procedures that occur after the initial engineering evaluation are the main focus of this project. This information, gained through informal conversations with experienced traffic engineers, will help to determine what should be included in the formal survey of professionals as well as the direction the process should go.

**Engineering Systems**

Systems engineering takes a look at the “big picture” (2). It takes into account everything and everyone that needs to be considered 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 how it impacts the different perspectives (engineer, politician, laypeople). These actions can also be applied to each individual step within the development. They also define systems engineering as the “definition, design, development, production, and maintenance of functional, reliable, and trustworthy systems within cost and time constraints.”

There are many examples of applied engineering systems. NASA has a thorough handbook on the systems engineering engine that is used for the organization (3). In the transportation field, California Department of Transportation developed a guidebook for intelligent transportation system (ITS) implementation that uses the systems engineering practice (4).

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.

**Statistics Background**

The branches of statistics that will be integrated in this research are inferential statistics and statistically decision theory. Inferential statistics is “the process of drawing conclusions or making predictions on the basis of limited information,” i.e. using information from small sample of the population and applying it to the entire population (5). Statistical decision theory uses this inferred information to make choices from “alternative actions.” The underlying issue with these branches is uncertainty of outcomes. Inferences must be made from incomplete information which adds 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. This information can be added to previously acquired data to reduce
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 (5). 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. Each TCD decision will not be identical, although similar situations can be observed which makes this a unique event. Since the events do not have observed frequencies, the probability of an event is based off the degree of belief for the situation. This subjective interpretation of probability is an individual’s judgment.

Another concept of probability that will be included in this research is conditional probability, “the probability that one event will occur given that a second event has already or will occur.” This condition is easily represented with tree diagrams and depicts the relationships between events. Bayes’ theorem provides a formula for the probability of a conditional event. It describes the conditional events in terms of prior probabilities, likelihoods, and posterior probabilities.

**Decision Analysis**

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 (5). 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 important the consequences affect them. The value for these payoffs or losses can be positive or negative, and can be 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 a utility is assigned to 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.
GOAL

The goal of this research is to develop a process that will assist practicing traffic engineers in making more consistent TCD decisions.

OBJECTIVES

- 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 design, installation, maintenance, and removal of TCDs
- Develop a general approach towards device installation, maintenance, or removal using the tools addressed in the background and the data collected

WORK PLAN

To begin this research, the current state of practice for TCD decisions will be established. The researcher will understand how current decisions are made in real-world situations by surveys and interviews. From this information, a general process will be developed that will be applied to different TCD decisions to develop a process for each individual decision. Finally, case studies will be developed to test this process and determine if it is applicable to real-world situations. The final process will be implemented into everyday practice.

Task 1: Identify current practice and pertinent information

This research will identify the current practice for TCD decisions, and the factors that are considered. An understanding of systems engineering, decision analysis, and probability theory will assist in the interpretation of the current practice.
Subtask 1.1: Identify current practice for TCD decisions
Current practices for TCD decisions can vary from professional to professional, but most engineers take a similar approach. This task requires the researcher to become familiar with the typical practice, or thought process that practitioners use to make their decisions on traffic control devices. This will be accomplished by informal interviews with different experienced traffic engineers that make these decisions every day. This information will give the research direction and focus when it comes to identifying different factors that affect TCD decisions.

Subtask 1.2: Identify different factors that are considered in the installation, operations, maintenance, and removal of TCDs
After talking to professionals, common factors used in TCD decisions will be identified. These can either be from direct conversations with professionals or through inference from their decision process. The major factors determined from this will help to shape the formal survey questions that will be distributed to other professionals. It will also determine the focus for the process development.

Subtask 1.3: Identify aspects of systems engineering that can be applied to the project
A literature review of what systems engineering is and how it is typically applied will be conducted. This will try to include specific examples in the transportation field. There are many systems processes that are already published that could help as a general outline to the development of the process. This will help to define how the process should be designed and the different considerations or viewpoints that should be analyzed or included in the process.

Subtask 1.4: Identify how probability theory and decision theory will be used in project
The data for this project will primarily be collected through surveys and interviews with practitioners. This data will be the opinions of the individuals. Therefore, theory of probability will help to analyze this data. The Bayesian approach to probability theory will be the most applicable to this research. A further application of probability theory will be to incorporate it into decision theory which will create a formal process for decision making in this research.
**Task 2: Develop and distribute surveys**

From the factors that have been identified and other comments from the informal interviews with practitioners, a survey will be developed that will try to narrow the general practice of how traffic engineers make TCD decisions. It will also determine what other things are considered in their decisions and how they handle more difficult situations. An exempt application will need to be submitted to Institutional Review Board (IRB) for approval of the survey protocol. The survey results will then be organized into usable data, such as factor weights and hierarchies.

**Task 3: Develop models**

A general process will be developed and refined. This global process can be used to develop the more specific TCD processes. Practitioners input will be used to verify the usefulness of the process. It will consider all factors that could influence TCD decisions, and be used to create case studies.

*Subtask 3.1: Develop general process*

With all the data collected, the TCD decision process will be developed. This general process, or global process, will define the steps traffic engineers use to make TCD decisions. Each step could also have another process, such as decision analysis, that will analyze the different factors that are considered for that decision. This process will be directly applicable to TCD decision making situations. It would be fine tuned for each decision process, to include or exclude steps that are necessary for that specific decision.

*Subtask 3.2: Determine utility and weights of different factors*

Applying decision theory will assist in organizing the results into a usable format, such as a decision tree, that will be used to create or organize the process. This will allow for different factors and utilities to be observed in the process. Utility theory can be used to analyze the relative importance of each factor. An additive utility model will be used to analyze the decision. Weights will be added to the utility. This will reflect the relative importance of that factor in that specific situation. This task will determine which factors are more important in certain situations and by how much.
Subtask 3.3: Solicit practitioners for advise on process

Once the process has been formalized, it will be distributed to a limited number of practitioners for comments and feedback. This could be done via email or phone conversations. These comments will help to determine if the current process is useful and what tweaks or additions are needed to make it more helpful to practitioners.

Subtask 3.4: Refine process

The developed process may need to be updated based on the practitioners’ feedback. This process may cycle through this task several times before finalized. The final process will be used to create case studies for TCD decisions.

Task 4: Create case study

The next task will be to devise test cases that can be studied using the developed process. Using various difficulty levels of TCD decisions determined from the professionals’ surveys, scenarios will be developed that practitioners can test using the finalized process. To develop these case studies the general process that was developed will be applied to the decision scenario. These scenarios will encompass a variety of TCDs such as pavement markers, signs, signals, and a combination of these devices. These case studies will be developed to test real-world decision situations. Each case will have individual issues that are included in each factor that will affect the utilities and weights of these factors. The studies will be designed so that practitioners can adjust the utilities and weights of the factors to the preferences of their agency. After the case studies are developed, they will be tested by experienced traffic engineers to determine their effectiveness.

Task 5: Test model

The sample scenarios will be sent out to experienced traffic engineers to test their response consistency using the process. The practitioners will explain what their decision would be with and without the process. The results from these test cases will serve as a validation test for the
process. It will also identify any other issues that may need to be addressed or changed with the developed process.

**Task 6: Revise and recommend**

If any inconsistencies are discovered in the previous task, they will be addressed. Final changes to the process will be made and tested. This task will result in a finalized process and results using the process.

Recommendations for the process will be made and a final report will be written. This process will be something that can be directly implemented into everyday practice and will be advertised as such.

**REFERENCES**


