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Developing Guidelines for Including Mobility-Based Performance Specifications in Highway Construction Contracts

Shawn J. Larson
Brigham Young University - Provo

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Specifications in Highway Construction Contracts

Shawn Jonas Larson

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Mitsuru Saito, Chair
Grant G. Schultz
W. Spencer Guthrie

Department of Civil and Environmental Engineering

Brigham Young University

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ABSTRACT

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Shawn Jonas Larson
Department of Civil and Environmental Engineering, BYU
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Construction zones can greatly affect the traffic flow on roadways, especially when lane closures are required. Traditionally, the Utah Department of Transportation (UDOT) has used traffic management specifications that only allow lane closures and road work to be done during predetermined hours or specifications that require a certain number of lanes to be open at all times. Recently, mobility-based work-zone traffic flow maintenance has been considered. This method requires continuous monitoring of mobility-based performance data and a mechanism to send alerts to the contractors when the mobility data does not meet the standards set by the specifications. UDOT recently tested mobility-based performance specifications at an urban arterial work zone and studied issues related to implementation of mobility-based performance specifications. Parallel to this experiment, UDOT funded a study to develop guidelines for implementing mobility-based performance specifications to manage traffic flow in work zones. Dynamically collecting mobility-based data such as travel time and speed is now feasible using technologies such as Bluetooth and microwave sensors. The core benefit of using mobility-based performance specifications is that they can give the contractor more flexibility in construction work scheduling while maintaining an acceptable level of traffic flow. If the level of traffic flow is not maintained, then the contractor is assessed a financial penalty. The penalty is determined by the amount of time where the flow is not maintained at a predetermined condition. To discuss issues and develop guidelines, a task force consisting of UDOT representatives, several representatives from the construction industry, and researchers from Brigham Young University was formed. Through three task force meetings, a set of 12 guidelines were developed, including guidelines about when mobility-based performance specifications should be used and which mobility data should be used. Some of the issues were difficult for the task force members to agree on, and a decision-making theory called the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was used to find best approaches to deal with some of the difficult issues associated with the implementation of mobility-based performance specifications in highway construction contracts. These guidelines should be reviewed as appropriate in the future as UDOT accumulates experience in using these types of specifications.

Keywords: Shawn Larson, construction, mobility-based performance, specification, incentive, disincentive, work zone, TOPSIS, task force

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1 INTRODUCTION

Roadway construction is necessary for maintaining the roadway system. Without construction the roads would eventually become impassable. However, the roadway system is relied upon every day and closing or limiting the amount of access due to construction will cause congestion and increased delay. Lane closures severely limit the capacity of a roadway but are often necessary for construction.

Traditionally, to limit the amount of delay caused by construction projects, a specification for the construction will include a schedule for when lanes can be closed, or the specification will require the contractor to keep a predetermined number of lanes open at all times. Often, to avoid any possible chance that daytime closures could cause unacceptable traffic conditions, daytime hours that could be available for construction are limited, even though there might be periods where construction work would not cause substantial amount of delay. These requirements can limit the amount of construction work that can be completed in a day by allowing work to be done only during certain hours. However, if the traffic conditions were to be monitored continuously, more work could be done during the daylight hours while still requiring that an acceptable level of traffic flow be maintained.

Mobility-based performance specifications can be used to help decrease delay caused by congestion and increase the number of hours that contractors are allowed to work. However, there are a number of concerns with how mobility-based performance specifications would distribute the risk from a construction project. With these types of specifications, the contractors would be asked to take more of the risk from the project. There are also concerns with how mobility-based performance specifications would add financial penalties to the project without giving an incentive for the contractor to use this type of specification. To deal with these issues, a task force was created as a part of this project to discuss and develop guidelines on how mobility-based performance specifications should be written and used for future construction projects. The objective and scope of the research project as well as the organization of this thesis are discussed below.

1.1 Research Objective and Scope

The purpose of this report is to record the results of the second phase of a study that was conducted to review the feasibility of mobility-based performance specifications in roadway construction contracts where the contractor is required to maintain a predetermined level of mobility in the work zone.

The scope of the first phase of this study was to determine if there was technology available to continuously monitor the mobility data selected for use in the specification and to research the background of incentive/disincentive specifications, in particular, mobility-based specifications. The results from this phase can be found in a report written by Saito et al (2012).

The objective of the second phase of the study is to develop a task force that will help recommend a set of guidelines for what to include in mobility-based performance specifications. These guidelines will be used for future projects that will employ mobility-based performance specifications. The task force was composed of members of the Utah Department of Transportation (UDOT), the Association of General Contractors (AGC), and Brigham Young University (BYU) researchers. The purpose of the task force was to discuss the issues with mobility-based performance specifications and create guidelines for future projects with mobility-based performance specifications. This purpose was accomplished through a series of group meetings along with other analysis, including a Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) analysis of several different topics.

1.2 Thesis Organization

This report is organized into the following chapters: 1) Introduction, 2) Literature Review, 3) Task Force, 4) TOPSIS Analysis Results, 5) Recommended Guidelines, and 6) Conclusion and Recommendations. Following these chapters is a list of references and appendices.

Chapter 1 presents the background, the objectives and the scope of the research. Chapter 2, Literature Review, presents a brief summary of findings of a search into decision-making methods and techniques. Included in the methods researched are a number of multi-criteria decision-making methods. Chapter 3 describes the formation of a task force that was created to develop guidelines for mobility-based performance specifications and the results of three task force meetings. Chapter 4 presents a TOPSIS analysis conducted as part of the research. Three topics required a TOPSIS analysis: risk management, penalty-tier calculations, and incentives. Chapter 5 presents the recommended 12 guidelines developed from the task force meetings and the TOPSIS analysis. Finally, Chapter 6 presents the conclusion and recommendations from this research. Appendix A contains an example of the TOPSIS spreadsheet distributed to each of the task force members as part of this study. Appendix B presents TOPSIS worksheets completed by task force members.

2 LITERATURE REVIEW

To help facilitate the discussion for the task force and reach a consensus on the guidelines for mobility-based performance specifications, a literature review was conducted with a focus on reviewing group decision-making methods and tools. Many decisions made by companies have very important ramifications and can include a number of different variables or criteria. To help with these decisions, a number of multi-criteria decision-making methods and other group decision methods have been developed by researchers and private organizations.

Multi-criteria decision-making methods help to rank different alternatives when there is a large amount of information that needs to be included in the decision. These methods rely on mathematical formulations and numerical values assigned to different criteria to determine the best alternative. They also require discussion and input from all of the stakeholders in the decision-making process to assign numerical values and weights to the criteria and alternatives.

Many other decision-making methods are based on group meetings and discussions. One of the other methods for group decision-making that was reviewed was Value Engineering. Value Engineering is a process that helps to increase the value of projects and it has been used in a number of different applications. There are a number of steps in Value Engineering that include group meetings and discussions. Group decision-making tools that were reviewed included the Functional Performance Specifications, which are used in conjunction with Value Engineering, and Gradients of Agreement. These tools and previous experiences with incentive/disincentive clauses in highway construction contracts are also summarized in this chapter.

2.1 Multi-criteria Decision-making Methods

Multi-criteria decision-making methods have been developed to help make a decision while taking into account a number of different criteria. Four different inputs are required for multi-criteria decision-making methods. The first two inputs are a set of criteria and a set of alternatives. The criteria are a set of variables upon which the alternatives will be ranked, which may include cost, manpower, and other important characteristics of the alternatives. The set of alternatives consists of all the possible outcomes that are being reviewed. The other two inputs in a multi-criteria decision-making method are two sets of numerical values. Multi-criteria decision-making methods employ numerical values that are given to a set of criteria; these values are then used to rank the alternatives. Different multi-criteria decision-making methods use different mathematical processes to take the numerical values and develop ranks for the alternatives.

There are several multi-criteria decision-making methods that have been developed and are used in a variety of industries including the Analytic Hierarchy Process (AHP), the Elimination Et Choix Tranduisant La REalité or Elimination and Choice Expressing the Reality (ELECTRE), and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Figueira et al. 2004, Opricovic and Tzeng 2004, Saaty 1994). These methods were selected because they have been widely used, and they were evaluated for their possible use in this research and summarized in this subsection. A number of other multi-criteria decision-making methods were also initially considered, including the Preference Ranking Organization Method for Enrichment and Evaluation (PROMETHEE), the Operational Competitiveness Rating

Analysis (OCRA), and Višekriterijumsko Kompromisno Rangiranje, or, in English, multicriteria Optimization and Compromise Solution (VIKOR) (Brans and Vincke 1985, Opricovic and Tzeng 2004, Wang 2006). The AHP, ELECTRE, and TOPSIS methods are discussed in the following subsections.

2.1.1 AHP

One of the more commonly used multi-criteria decision-making methods is the AHP. AHP was created by T. L. Saaty and introduced in 1977 (Triantaphyllou and Mann 1995). This method has been used in many different fields including medicine, planning and development, forecasting, and resource allocation (Vaidya and Kumar 2006). AHP is based on using a pair-wise comparison to determine a preferred alternative or solution. AHP is started by creating a hierarchy for the decision. The hierarchy starts with the goal of the decision at the top, with the objectives starting from a broad perspective down through different levels until the lowest level objectives are reached, which have the most detail. Numerical values are then given to the objectives to give them weights for comparison. These values are assigned through judgments or comparisons of items that share a common parent or that are on the same level. All of these comparisons can be represented in a matrix in which each alternative is compared to each of the other alternatives (Saaty 1990). To compare each of the criteria and alternatives, a scale from 1 to 9 is used as illustrated in Table 2-1; these values are then put into a matrix (Saaty 1990). The eigenvalue of the matrix is then used to provide a ranking to each of the alternatives. One journal article discusses how an eigenvalue can be the only plausible method for determining which alternative is preferred when a positive reciprocal matrix is used (Saaty 2003).

Table 2-1: Explanation of Ranking Values 1 to 9 (Saaty 1990)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value, but, when compared with other contrasting activities the size of the small numbers would not be too noticeable; however, they can still indicate the relative importance of the activities

An example of the AHP process is shown in Figure 2-1. This example illustrates a decision to purchase a house and was obtained from a paper by Saaty (1990). In the case outlined in Figure 2-1, there are eight criteria that need to be taken into account for three different alternatives, or different houses A, B, and C. In this example the criteria are the size of the house, transportation, neighborhood, age of the house, yard space, modern facilities, general condition, and financing. For the next step in the analysis, a matrix is created for the criteria, and comparisons are made using the 1 to 9 scale. In this scale the values represent the relationships between the different alternatives. For example, if the cell that represents two of the alternatives is given a value of 1, the alternatives would be considered equally important.

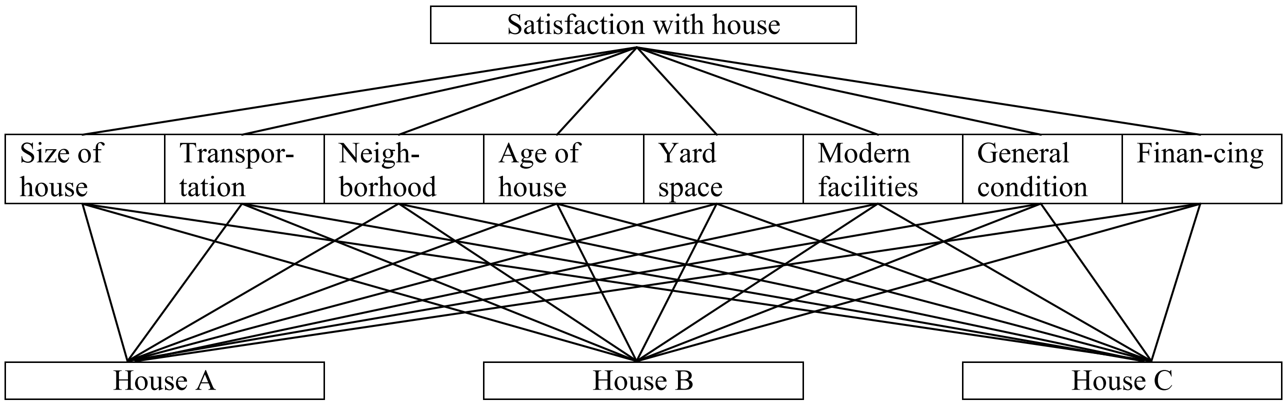


Figure 2-1: Decision Hierarchy (Saaty 1990)

The eigenvalue from the alternatives-criteria matrix is then used as the weights for the criteria when the preferred alternative is determined. The matrix can be seen in Table 2-2. The priority vector is the result of the eigenvector calculations and is used to determine the preferred alternative. The alternative with a higher eigenvalue is preferred. In the table λ_{max} is the principal eigenvalue, CI is the consistency index, and CR is the consistency ratio. The CI is calculated using Equation 2-1, where n is the order of the square alternatives-criteria matrix. This is an index to assess how much the consistency of pairwise comparisons is away from the perfect consistency. The consistency ratio is calculated by taking the consistency index of the alternatives criteria matrix over the consistency index of matrices filled with random values. A consistency ratio of 0.10 or less can be considered acceptable.

$$CI = (\lambda_{max} - n)/(n - 1) \qquad (2\text{-}1)$$

where:

λ_{max} = the principle eigenvalue

n = the order of the square alternatives-criteria matrix

Table 2-2: Criteria Matrix (Saaty 1990)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Priority vector**
1	1	5	3	7	6	6	1/3	1/4	0.173
2	1/5	1	1/3	5	3	3	1/5	1/7	0.054
3	1/3	3	1	6	3	4	6	1/5	0.188
4	1/7	1/5	1/6	1	1/3	1/4	1/7	1/8	0.018
5	1/6	1/3	1/3	3	1	1/2	1/5	1/6	0.031
6	1/6	1/3	1/4	4	2	1	1/5	1/6	0.036
7	3	5	1/6	7	5	5	1	1/2	0.167
8	4	7	5	8	6	6	2	1	0.333

$\lambda_{max} = 9.669, CI = 0.238, CR = 0.169$

Eight different matrices are then created, one for each of the criteria for the sample problem. Again, the values 1 to 9 are used to represent the relationship between the each of the alternatives. One matrix is created for each criterion to allow for comparison between each of the alternatives based on the criteria. Table 2-3 shows each of the matrices created for this analysis. In the table λ_{max} is the principal eigenvalue, CI is the consistency index, and CR is the consistency ratio, as explained previously.

The eigenvalues from each of the matrices are then weighted using the values from the first matrix comparing the criteria. Next, these values are used to create a matrix of the alternatives and the criteria as can be seen in Table 2-4. The eigenvalue of this matrix is then used to determine the priority of each alternative. The formula for an eigenvalue is provided in Equation 2-2. Also shown in Table 2-4 is the priority vector for the three houses; these values were calculated by taking the sum of the priority vectors from each of the criteria multiplied by the weights. From this analysis it is determined that House A is preferred, as it has the largest value in the priority vector as shown in Table 2-4.

Table 2-3: Alternative Matrix for Each Criterion (Saaty 1990)

Size of house	**A**	**B**	**C**	**Priority vector**	**Yard space**	**A**	**B**	**C**	**Priority vector**
A	1	6	8	0.754	A	1	5	4	0.674
B	1/6	1	4	0.181	B	1/5	1	1/3	0.101
C	1/8	1/4	1	0.065	C	1/4	3	1	0.226

λ_{max} = 3.136, CI = 0.068, CR = 0.117 λ_{max} = 3.086, CI = 0.043, CR = 0.074

Transportation	**A**	**B**	**C**	**Priority vector**	**Modern facilities**	**A**	**B**	**C**	**Priority vector**
A	1	7	1/5	0.233	A	1	8	6	0.747
B	1/7	1	1/8	0.005	B	1/8	1	1/5	0.060
C	5	8	1	0.713	C	1/6	5	1	0.193

λ_{max} = 3.247, CI = 0.124, CR = 0.213 λ_{max} = 3.197, CI = 0.099, CR = 0.170

Neighborhood	**A**	**B**	**C**	**Priority vector**	**General Condition**	**A**	**B**	**C**	**Priority vector**
A	1	8	6	0.745	A	1	1/2	½	0.200
B	1/8	1	1/4	0.064	B	2	1	1	0.400
C	1/6	4	1	0.181	C	2	1	1	0.400

λ_{max} = 3.130, CI = 0.068, CR = 0.117 λ_{max} = 3.000, CI = 0.000, CR = 0.000

Age of house	**A**	**B**	**C**	**Priority vector**	**Financing**	**A**	**B**	**C**	**Priority vector**
A	1	1	1	0.333	A	1	1/7	1/5	0.072
B	1	1	1	0.333	B	7	1	3	0.650
C	1	1	1	0.333	C	5	1/3	1	0.278

λ_{max} = 3.000, CI = 0.000, CR = 0.000 λ_{max} = 3.065, CI = 0.032, CR = 0.056

Table 2-4: Alternative and Criteria Matrix (Saaty 1990)

	1 (0.173)	**2** (0.054)	**3** (0.188)	**4** (0.018)	**5** (0.031)	**6** (0.036)	**7** (0.167)	**8** (0.333)	**Priority vector**
A	0.754	0.233	0.754	0.333	0.674	0.747	0.200	0.072	0.396
B	0.181	0.055	0.065	0.333	0.101	0.060	0.400	0.650	0.341
C	0.065	0.713	0.181	0.333	0.226	0.193	0.400	0.278	0.263

$$\boldsymbol{Av = \lambda v} \tag{2-2}$$

where:

A = the alternatives-criteria matrix

λ = the eigenvalue of the alternative-criteria matrix

v = a non-zero vector of the criteria weights

Past research has shown that the AHP has a problem with rank reversal (Millet and Saaty 2000). Rank reversal occurs when new information is added to an alternative and the order of the rankings changes for the alternatives that are not influenced by this new information. It can also occur when a new alternative is added to the matrix and the previous order of the alternatives is not the same with and without this new alternative. There has been some debate about whether this invalidates the whole process or if it is just part of natural decision-making. It has been shown that for AHP the number of criteria used has little effect on the number of rank reversals but that rank reversals are affected by the weight distribution of the criteria (Zanakis et al. 1998). Some modifications have been made to AHP to remove the rank reversal problem. The modifications have led to the creation of the Ideal AHP, where each alternative is compared to the ideal instead of to each other (Millet and Saaty 2000). Comparing alternatives to the Ideal AHP removes rank reversal from this multi-criteria decision-making method.

A study that compared AHP, SMART (another multi-criteria decision-making method) and TOPSIS concluded that the revised AHP was the best decision-making method for the two evaluative criteria used. The first evaluation criterion was that a decision-making method that works in multiple dimensions must also work in a single dimension decision. The second evaluation criterion was that the decision-making method must yield the same outcome when a non-optimal alternative was replaced with a worse alternative (Lootsma and Schuijt 1997).

2.1.2 ELECTRE

The ELECTRE multi-criteria decision-making method has been commonly used throughout Europe. This method was first introduced in 1965 by a European company called Specialty Equipment Market Association (Figueira et al. 2004). ELECTRE is based on outranking alternatives. Each of these alternatives has criteria that are given numerical values in a predetermined range. In this method the same range is used for each of the criteria in the different alternatives. These numbers represent how the decision makers feel, using any available data and their judgment, about how the criteria relate to the alternatives. To find the best alternative, this method uses these values as well as two conditions. The first condition is that the strength of the concordant coalition must be powerful enough to support the conclusion of one alternative outranking another. The concordant coalition is that a majority of the criteria should be in favor of the assertion that this alternative is the preferred alternative. The other condition that must be met to determine that an alternative is preferred to the others is that the discordant coalition must not pass a certain level, or none of the criteria should too strongly oppose this alternative being the preferred alternative. If both of these conditions are met then one alterative outranks the other alternative and is preferred. The first ELECTRE method did not have a set way to determine which alternatives met these two conditions; hence, it did not have significant practical application, which required more development (Figueira et al. 2004). The limited practical application of the first ELECTRE method has led to the creation of different versions of ELECTRE. Each version has its own method for determining if an alternative meets both the concordant and the discordant coalitions.

In the late 1960s the ELECTRE II method was developed. This method is focused on ranking the options from the best to the worst option. To accomplish this, the ELECTRE II method uses a technique based on the construction of an embedded outranking relations sequence. There are two embedded relations in this method; the first one is a strong outranking relation, and the second is a weak outranking relation; that is, an alternative can either strongly or weakly outrank another alternative depending on the set boundaries determined by the decision maker. For a simpler method, these can be simply combined into an outranking relationship, which is the basis of the ELECTRE I method (Figueira et al. 2004). Once the concordance and discordance coalitions are calculated, they can be displayed in a matrix that shows the relationship between all alternatives. For simple analysis this can be the final step, as the preferred alternative can be seen in the matrix by which alternative has a value of 0.5 or above towards the other alternatives. However, for more complex problems, the matrix can be confusing, and creating a graph, called a preference graph, which shows the relationship between the alternatives, is helpful. These graphs visually illustrate if an alternative is preferred to another by either placing alternatives in bubbles and connecting them with arrows or using other visual techniques (Raj and Kumar 2013).

To present a basic concept, an example of the ELECTRE method is shown using three criteria and three alternatives. The criteria are accuracy, margin of error, and ease of calculation. The three alternatives in this example are travel time, queue, and speed. Weights are also assigned to each of the criteria. These weights are given so that if one criterion is more important to the decision it can be taken into account in the analysis. The weights in this example can be seen in Table 2-5.

Using the alternatives and criteria, a matrix is created as shown in Table 2-6. The values in this matrix are from a predetermined set of the numbers, which in this case range from 1 to 10. These numbers are assigned subjectively by the decision makers. In the example, a cell that contains the number 10 means that the decision maker feels, based on any data or information available, that the alternative is the best it can be according to the criteria. A value of 1 in the cell represents that the alternative is the worst according to the criteria. These numbers represent how each of the alternatives relates to each of the criteria.

Table 2-5: Criteria Weights

Accuracy	Margin of Error	Ease of Calculation
0.25	0.45	0.30

Table 2-6: Alternative and Criteria Matrix

Alternatives	Criteria		
	Accuracy	Margin of Error	Ease of Calculation
Travel Time	7	8	2
Queue	5	3	5
Speed	4	5	6

Using the original matrix a concordance matrix can be created that shows the concordance coalition that was calculated to show the relationship between each of the alternatives. Table 2-7 presents the concordance matrix and Table 2-8 presents the discordance matrix. The formula for the concordance coalition can be seen in Equation 2-3, where w is the aggregate of the weights. In this example the concordance index is 0.70 when travel time is compared to queue; this is the sum of the weights for accuracy and margin of error. This value is used because the values in the alternative criteria matrix are larger for the alternative travel time for the accuracy and margin of error. The discordance coalition formula is shown in Equation 2-4. This calculation is used to determine if any of the values given to the criteria by the decision makers object too strongly against one of the alternatives being preferred.

Table 2-7: Concordance Matrix

Concordance Index	Travel Time	Queue	Speed
Travel Time	--	0.70	0.70
Queue	0.30	--	0.25
Speed	0.30	0.75	--

Table 2-8: Discordance Matrix

Discordance Index	Travel Time	Queue	Speed
Travel Time	--	0.60	0.67
Queue	0.63	--	0.33
Speed	0.38	0.20	--

$$C(h,k) = \frac{W^{+}}{W^{+}+W^{=}+W^{-}} \qquad (2\text{-}3)$$

where:

w^{+} = the sum of the weights for the criteria of the alternatives being compared if the difference in criteria is positive

w^{-} = the sum of the weights for the criteria of the alternatives being compared if the difference in criteria is negative

$w^{=}$ = the sum of the weights for the criteria of the alternatives being compared if the difference in criteria is zero

h = the alternative for which the concordance matrix is being calculated

k = the alternative being compared against

$$D(h,k) = \sum_{j=1} \frac{g_j(A_h) - g_j(A_k)}{g_j(A_h)} \qquad (2\text{-}4)$$

where:

$g_j(A_h)$ = the alternatives-criteria relationship value for the alternative for which the discordance coalition is being calculated

$g_j(A_k)$ = the alternatives-criteria relationship value for the alternative that is being compared against in the calculation

h = the alternative for which the concordance matrix is being calculated

k = the alternative being compared against

From the concordance and discordance coalitions, the preferred alternative can be identified. In the example described above, the preferred alternative is travel time. It is preferred because its concordance coalition is larger than the discordance coalition for each comparison that was made. In other words, the travel time alternative outranked the other alternatives in each comparison. For the preferred alternative, which in this case is travel time, the comparison value in the concordance matrix is 0.7, which means that the majority of the criteria are in support of this alternative, as 0.7 is greater than 0.5 or 50 percent, and no discordance index is larger than the concordance index.

The ELECTRE III method was developed to improve how ELECTRE II deals with inaccurate, imprecise and uncertain data. This method introduces pseudo-criteria instead of true-criteria. In this method the outranking relationships can be interpreted as a fuzzy relationship. To construct this relationship the definition of a credibility index is required; this index uses both the concordance and discordance coalitions. The credibility index then characterizes the credibility of the assertion that one alternative outranks another. This credibility index is based on three ideas. The first idea is that if there is no discordance criterion, then the credibility index is equal to the concordance index. If the discordance criterion objects too much to one alternative outranking another, or if it is above the threshold level determined by the decision maker, then the credibility index is null. Otherwise, the credibility index is calculated and can be used to determine if one alternative outranking another is credible (Figueira et al. 2004).

The ELECTRE IV method is also based on the construction of a set of embedded outranking relations. The main difference in this method is that this method is used when weights are not assigned to the criteria. However, this does not necessarily mean that the criteria are assumed to be weighted equally (Hokkanen and Salminen 1997).

In addition to these ELECTRE methods, there is the ELECTRE TRI method, which was made to assign a set of actions, objects, or items to categories. Each of these categories is ordered and characterized by a lower and upper profile. This process is meant to show the preference as the upper profile is preferred to the lower profile. There are also a number of other ELECTRE methods that that are not widely used (Figueira et al. 2004).

The ELECTRE multi-criteria decision-making method has some problems with rank reversal like AHP. This is where ranking already set will change when new alternatives or information are added. The ELECTRE method is more susceptible to rank reversal in problems with a high number of criteria and a lower number of alternatives (Wang and Triantaphyllou 2008). This susceptibility is confirmed in another study that showed the ELECTRE is more robust or resistant to rank reversal in studies with fewer criteria (Zanakis et al. 1998). This study also shows that in ELECTRE equal weights tend to produce more rank reversals and that the distribution of criteria weights also has an effect on the number of rank reversals (Zanakis et al. 1998).

2.1.3 TOPSIS

TOPSIS was developed in 1981 by Hwang and Yoon (1981). Hwang and Yoon proposed TOPSIS as a means to select the best alternative with a finite set of criteria. This multi-criteria decision-making method is based on identifying how close the alternative is to the ideal solution and how far the alternative is from the negative-ideal solution. There are five steps that need to be taken in this process to determine the preferred alternative. The five steps in this report are taken from paper written by Lofti et al. (2011), as well as some input from a paper written by Behzadian et al. (2012). While the basis of TOPSIS analysis is the same, some users change the order of the first two steps. The end rankings derived from the analysis will be the same, but the numerical values will differ. An example structure for the matrix can be seen in Table 2-9, where x_{ij} is the rating of alternative i with respect to criterion j, and w_j is the weight of criterion j.

Table 2-9: Structure of Alternative Performance Matrix

	Criterion 1	**Criterion 2**	**…**	**Criterion n**
Alternative 1	x_{11}	x_{12}		x_{1n}
Alternative 2	x_{21}	x_{22}		x_{2n}
. .				
Alternative m	x_{m1}	x_{m2}		x_{mn}
	w_1	w_2	…	w_n

The first step of TOPSIS's five-step process is to construct a normalized decision matrix. This matrix represents the relationship between each alternative and criterion based on decision makers' subjective judgment. The rating values are assigned using a predetermined set of values, often a set of integer values. The normalized matrix is created using Equation 2-5.

$$n_{ij} = \frac{x_{ij}}{\sqrt{\left(\sum_{j=1}^{m} x^2{}_{ij}\right)}}, i = 1, \dots, m, j = 1, \dots, n \qquad (2\text{-}5)$$

where:

n_{ij} = normalized matrix values

x_{ij} = rating of alternative i with respect to criterion j

i = alternative number

j = criterion number

m = number of alternatives

n = number of criteria

The second step is to multiply all values in the normalized matrix (n_{ij}) by the weight (w_j) for each of the criteria to create the weighted normalized decision matrix; this is done using Equation 2-6. The key to accuracy in the TOPSIS method is to obtain as accurate weights for the criteria as possible (Olson 2004). The weights are used to represent how important each of the criteria is in determining the preferred alternative.

$$v_{ij} = n_{ij} w_j, i = 1, \dots, m, j = 1, \dots, n \qquad (2\text{-}6)$$

where:

v_{ij} = weighted normalized matrix values

i = alternative number

j = criterion number

m = number of alternatives

n = number of criteria

The third step in the TOPSIS method is to determine the positive (v_i^+) and negative (v_i^-) ideal solutions. The positive ideal solution is determined by taking the highest number assigned to a criterion from all of the alternatives. This is done for each of the criteria. Then the negative ideal solution is determined by taking the lowest number assigned to each of the criteria from the alternatives.

The fourth step in the TOPSIS method is to compare the weighted alternatives to the ideal solutions. This is done by calculating the separation between the alternative and the ideal. This separation is calculated using Equations 2-7 and 2-8. In these equations, s represents the separation and v_j and v_{ij} are the values in the ideal solution and in the alternative, respectively.

$$s_i^+ = [\sum_{j=1}^{n}(v_{ij} - v_j^+)^2]^{\frac{1}{2}}, i = 1, \dots, m \quad (2\text{-}7)$$

where:

s_i^+ = separation of the alternative from the positive ideal solution

v_{ij} = weighted normalized matrix values

v_j^+ = positive ideal solution values

m = number of alternatives

n = number of criteria

$$s_i^- = [\sum_{j=1}^{n}(v_{ij} - v_j^-)^2]^{\frac{1}{2}}, i = 1, \dots, m \qquad (2\text{-}8)$$

where:

s_i^+ = separation of the alternative from the negative ideal solution

v_{ij} = weighted normalized matrix values

v_j^- = negative ideal solution values

m = number of alternatives

n = number of criteria

The fifth step in the TOPSIS method is to determine the relative closeness of the alternatives being evaluated and to rank the alternatives. The relative closeness of each alternative is calculated using Equation 2-9. The closer the value of c_i is to 1, the higher the priority of the ith alternative. The alternative with the highest relative closeness value is the best alternative (Behzadian et al. 2012).

$$C_i = {s_i^-}/{(s_i^- + s_i^+)} \qquad (2\text{-}9)$$

where:

C_i = relative closeness of alternative being evaluated

s_i^- = negative separation of alternative being evaluated

s_i^+ = positive separation of alternative being evaluated

A sample TOPSIS analysis is shown in the following paragraphs using three alternatives and three criteria. The three alternatives in this sample problem are travel time, queue, and speed. The criteria are accuracy, margin of error, and ease of calculation. In TOPSIS the weight for each criterion is determined by the analyst. In this example the weights are represented by percentage values in decimal form; however, the weights could be represented by other methods. The weights used in the example are shown in Table 2-10. The sum of the weights must equal one.

Table 2-10: Criteria Weights

	Criteria		
	Accuracy	**Margin of Error**	**Ease of Calculation**
Weights	0.70	0.25	0.05

Using these criteria and alternatives, a matrix is created. This matrix can be seen in Table 2-11, where the values given to each cell of the matrix used a range from 1 to 10 in this example. The range used should be customized to the situation in question. The number assigned to each of the matrix cells are subjectively based on available data and the rating range selected for evaluation.

Table 2-11: Alternative and Criteria Matrix

	Criteria		
Alternatives	**Accuracy**	**Margin of Error**	**Ease of Calculation**
Travel Time	7	4	6
Queue	2	4	8
Speed	6	5	7

The values from the original alternative and criteria matrix seen in Table 2-11 are then normalized, using Equation 2-5, and multiplied by the criteria weights. The values in the new weighted normalized matrix can be seen in Table 2-12. In this computation, weights are expressed in percentages such as 70 for 70 percent, not in decimal value such as 0.70.

The next step is the creation of the positive and the negative ideal solutions. This is accomplished by taking the largest values assigned to the three alternatives for each criterion for the positive ideal solution and the lowest for the negative ideal solution. For this example these values can be seen in Table 2-13.

Table 2-12: Weighted Normalized Matrix

	Criteria		
Alternatives	**Accuracy**	**Margin of Error**	**Ease of Calculation**
Travel Time	51.9	13.3	2.5
Queue	14.8	13.3	3.3
Speed	44.5	16.6	2.9

Table 2-13: Positive and Negative Ideal Solutions

	Criteria		
	Accuracy	**Margin of Error**	**Ease of Calculation**
Positive Ideal	51.9	16.6	3.3
Negative Ideal	14.8	13.3	2.5

After determining the positive and negative ideal solutions, the separation of each alternative to these solutions is determined, and the closeness is calculated using Equation 2-7, 2-8, and 2-9. From the closeness values, the priority of the alternatives is determined. The highest relative closeness value is preferred because the highest value represents the alternative closest to the positive ideal solution and furthest from the negative ideal solution as expressed in Equation 2-9. These values can be seen in Table 2-14.

Table 2-14: Separation, Closeness, and Ranking of Alternatives

Alternatives	**Separation From Positive Ideal**	**Separation from Negative Ideal**	**Closeness**	**Ranking**
Travel Time	3.4	37.1	0.92	1
Queue	37.3	0.8	0.02	3
Speed	7.4	29.9	0.80	2

A state-of-the-art survey conducted by Behzadian et al. (2012) on applications of TOPSIS found that there were at least 266 research papers that used the TOPSIS method. These papers were separated into nine categories: supply chain management and logistics; design, engineering, and manufacturing systems; business and marketing management; health, safety and environment management; human resources management; energy management; chemical engineering; water resources management; and others including medicine, agriculture, and education. Twenty percent of the papers came from Taiwan, the largest source of these papers. The next three largest sources of TOPSIS-related papers were China, Iran, and Turkey (Behzadian et al. 2012).

There are a number of advantages to TOPSIS. Some advantages of the TOPSIS system according to a study by Behzadian et al. (2012) are that the method represents sound logic, contains a scalar value that accounts for both the best and worst alternative, has a simple computational process, and can be visualized on a polyhedron. However, like many other multi-criteria decision-making methods, the TOPSIS method has an issue with rank reversal (Garcia-Cascales and Lamata 2012). It was found in a study by Zanakis et al. (1998), however, that of eight common multi-criteria decision-making methods, including four versions of AHP, ELECTRE, TOPSIS, Multiplicative Exponential Weighting (MEW), and Simple Additive Weighting (SAW), TOPSIS experienced the fewest rank reversals. It is still uncertain if rank reversal makes the method unreliable or if it should even be an issue, but this phenomenon has been noticed in TOPSIS. This issue was addressed in TOPSIS by changing the normalization formula and introducing the absolute mode, or a change in how the ideal solutions are calculated, which removes the presence of rank reversal (Garcia-Cascales and Lamata 2012). This study suggested that the given normalization formula, shown as Equation 2-4, be switched for a new formula that is shown in Equation 2-8.

$$n_{ij} = z_{ij}/Max_i(z_{ij}) \tag{2-8}$$

where:

n_{ij} = cell value from the normalized matrix

z_{ij} = cell value from the matrix being normalized

The absolute method, which is suggested to remove rank reversal, also changes how the ideal solutions, both positive and negative, are calculated. In the absolute method, two fictitious alternatives are created. Values of 1 to 10 are used in determining the value of each criterion for each alternative. Then the values for the positive ideal suggested by García-Cascales and Lamata (2012) would be 10 for each criteria and 1 for the negative ideal for each of the criteria. The absolute method with the new normalization formula has been shown to remove rank reversals from TOPSIS. However, what the presence of rank reversal actually means for the validity of the process is still highly debated (Garcia-Cascales and Lamata. 2012).

In a simulation comparison of the presence of rank reversals in different multi-criteria decision-making methods, it was shown that TOPSIS was the most robust, followed by AHP and then by ELECTRE (Zanakis et al. 1998). It was also shown that the number of criteria had little effect on rank reversals for TOPSIS but that the distribution of criteria weights did have an effect on rank reversal.

2.2 **Value Engineering**

Value Engineering, also known as Value Analysis, is a process that aims at increasing the value of projects through a series of group meetings and group discussion. Value Engineering was developed by General Electric during World War II. The original idea for Value Engineering was conceived in the early 1940s by Lawrence D. Miles, who worked for General Electric (SAVE International 2007). The idea originated because of the scarcity of strategic materials needed for producing products. Through the use of Value Engineering, General Electric gained a competitive advantage by having more direction in what products to produce and how to use the limited resources available. Soon this process was adopted by other companies and the U.S. Army and Navy. In 1959 the Society of American Value Engineers was established and since then Value Engineering has spread and become part of many industries, including transportation. Since 1995 the Federal Highway Administration (FHWA) has required Value Engineering studies on all projects that have an estimated cost of 25 million dollars or more (NCHRP 2005). During these studies, the project is reviewed using the Value Engineering process. Many projects in different states across the U.S. have had success using value engineering to improve the value of projects. The main idea behind Value Engineering is to focus on the function of the project or what the project must do, while reviewing other ways that the product or process can accomplish this function. The function is measured by the performance requirements of the customer and the resources that are available. The process of using Value Engineering to analyze a function, or how a project is to fulfill its purpose, is completed through six phases shown in Figure 2-2 and described in the following paragraph.

The first phase of the six phases of Value Engineering is the information phase where all the information about the project is gathered and distributed among the group members. This phase helps to increase the knowledge of the project background and create a common understanding of the purpose of the project. Some of the desired outcomes of this phase are a clear understanding of what needs to be addressed and what functions need to be considered. The second phase is the function analysis phase. During this phase, the functions, such as how a traffic signal retiming will improve traffic, are discussed. This helps all team members to establish the purpose of the project. The focus of this phase should be on making sure that the project being reviewed satisfies the needs and objectives of the customer or beneficiary of the project. After the team is updated on the project, the third phase is the creative phase, where new solutions are brainstormed. The team generates a number of new ideas that will fulfill the functions required by the project. To help with the brainstorming, it is recommended that rules that protect the creative environment are established.

The fourth step of Value Engineering is to reduce the number of ideas in the evaluation phase. This is called the evaluation phase because in this phase the ideas that were generated in the creative phase are evaluated. Some of these ideas are then selected for development. Following the evaluation phase is the fifth phase, which is the development phase where the alternatives selected are developed into a short list of alternatives. The last and sixth phase is the presentation phase. During the presentation phase, the different alternatives are presented to the stakeholders so that a decision on the different alternatives can be made. Some of the details for how the decision is to be made on which alternative to develop and present are left up to the decision makers (SAVE International 2007).

The Virginia Department of Transportation (VDOT) has been using Value Engineering since 1990 and has performed 1,101 studies on different projects. These Value Engineering studies have included highway projects as well as special projects such as optimizing snow removal operations, improving the building permit process and reviewing the utility relocation process. VDOT reports that through Value Engineering the value of these projects and processes has increased (VDOT 2012).

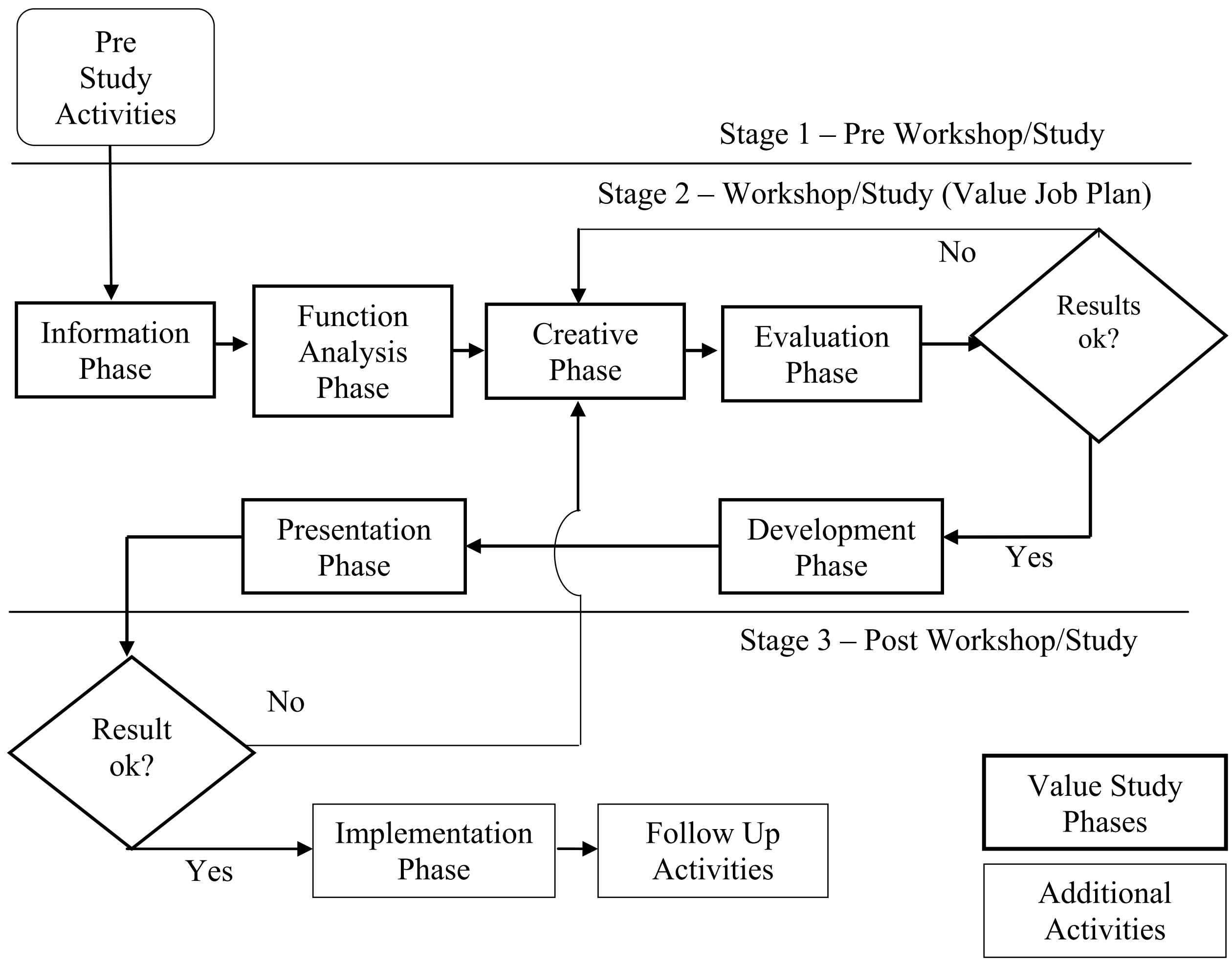


Figure 2-2: Value Engineering Flow Chart (SAVE International 2007)

The California Department of Transportation (Caltrans) has also been involved in using Value Engineering. Many of the projects on which Caltrans has used Value Engineering were highway construction projects; however, Caltrans also has studies called "process studies" that are Value Engineering projects that deal with increasing the value of the engineering and administrative processes. These projects include design-build document templates and construction and maintenance agreements (Caltrans 2011).

The process of Value Engineering is also used in many transportation authorities in Canada, including the Ministry of Transportation for Ontario (Ontario Ministry of Transportation

2006). However, in conjunction with Value Engineering, the Ontario Ministry of Transportation uses a Function Performance Specification (FPS). The FPS is a document that identifies the purpose of the project and describes the flexibility of each function. This document is then used as a tool to help in the decision-making process. Each FPS contains four components: function, criteria, level and flexibility. The function tells the need that is to be fulfilled by the project. The criteria section expresses what will be used to determine if the function is being met. The function, or what the project must do, must meet a predetermined level that is expressed in the level section. An example application involves selecting a vehicle. For the vehicle "a number of passengers" criterion is used and the level is set at five passengers. If a vehicle does not meet the level, meaning it cannot carry five passengers, it would not be considered. There are four different levels in the flexibility section of the FPS that show how negotiable the function, criteria, and level are for this project. The range of values used by the Ontario Ministry of Transportation to measure flexibility goes from F0 (not negotiable) to F3 (very flexible), and an example is shown in Table 2-15 (Ontario Ministry of Transportation 2006). This example is for someone looking for an sport utility vehicle using four criteria. In this example, the four criteria used are the number of passengers, style type, fuel efficiency, and price. For each of these criteria, a level is given. This level is the minimum standard required by the decision maker. A flexibility level is also given, which is used to show how flexible the decision maker is with the levels assigned. The functional specification is then used in the Value Engineering process to help guide the discussion.

Table 2-15: Sample Functional Specification for SUV Selection

Criteria	Level	Flexibility
Number of Passengers	5 Passengers	F0
Style Type	SUV	F3
Fuel Efficiency	12 liters/100 km	F1
Price	$15,000	F2

2.3 Gradients of Agreement

One important aspect of group decision-making is addressing how the decision will be made. There are many different ways for a group to determine what decision to make. Some of these different ways include voting, group consensus, or the group leader making the decision after discussion. In the book "A Facilitator Guide to Participatory Decision-Making" by Kaner et al. (2007), the Gradients of Agreement are given as a tool to determine where the group is at in the process of coming to an agreement or consensus. The Gradients of Agreement consist of a scale that ranges from 1 to 7, with each value having a different meaning in regards to how the individual feels about the proposed solution to the discussed problem.

The Gradients of Agreement scale was developed in 1987 by Sam Kaner, Duane Berger, and Community at Work, a consulting firm. Table 2-16 shows the Gradients of Agreement (Kaner et al. 2007). The different numbers in the gradient are used to express where each member of the group is at with respect to the proposed decision. There are also a number of recommended ways to poll the group to see where they are at, these are "show of hands," "pick one and say why," "simultaneous declaration," "secret ballot," and "two rounds of voting" (Kaner et al. 2007).

Table 2-16: Gradients of Agreement (Kaner et al. 2007)

Gradients of Agreement							
1	2	3	4	5	6	7	8
Whole-heart endorsement	Agreement with a minor point of contention	Support with reservations	Abstain	More discussion needed	Don't like but will support	Serious disagreement	Veto

2.4 Incentive/Disincentive Clauses in Construction Specifications

In the past UDOT has used incentive and disincentive clauses for construction projects and material specifications. One particular specification that has included incentive/disincentive causes is for Hot Mix Asphalt (HMA). The incentives/disincentives for HMA are based on gradation, asphalt binder content, and density. A minimum of four samples is required for the test to determine if incentives or disincentives are required. Table 2-17 shows the incentives/disincentives for gradation, asphalt binder content, and density used by UDOT (UDOT 2012b).

Table 2-17: Incentive/Disincentive for Gradation, Asphalt Binder Content, and Density (UDOT 2012)

Percent of Asphalt within Limits Based on Minimum Four Samples	Incentive/Disincentive (Dollars/Ton)
> 99	1.50
96-99	1.00
92-95	0.60
88-91	0.00
84-87	-0.26
80-83	-0.60
76-79	-0.93
72-75	-1.27
68-71	-1.60
64-67	-1.93
60-63	-2.27
<60	Reject

The incentives for HMA construction specifications are based on percent of asphalt binder content and density within limits. This is one example of how incentives/disincentives clauses have been used by UDOT (UDOT 2012b).

Schedule-based incentives and disincentives are also used in UDOT construction projects. Schedule-based incentives give the contractor pre-determined monetary incentives for finishing a project early. The earlier the project is finished, the larger the incentive. However, there is a maximum incentive that a contractor can receive from finishing the project early. Disincentives are also assessed based on if the actual completion date is after the projected completion date. To help with the schedule-based incentive and disincentives, an estimated contractor schedule are created. From this a minimum time and a maximum time is determined, along with the maximum incentive.

2.5 **Chapter Summary**

Decision-making methods were reviewed to help create guidelines for how mobility-based performance specifications should be written in the future. One of the first items reviewed were multi-criteria decision-making methods. The first of these methods is AHP. This method creates a decision hierarchy and uses a matrix to compare each of the objectives on the same level to help determine which alternative is preferable. In the matrix, values are given from a predetermined set of values from 1 to 7. These numbers correlate to how the alternatives relate to each other.

The next method reviewed is ELECTRE. This method uses an alternative/criteria matrix where numbers are assigned to represent the relationship between the alternative and each of the criteria. Weights are also determined by the decision maker. Using the matrix and the weights, two values are calculated, the concordance and discordance coalitions. The concordance coalition shows if one alternative outranks another, while the discordance coalition shows if an alternative is outranked by another. The preferred alternative will outrank the other alternatives while not being outranked in any one criterion too severely.

TOPSIS is another multi-criteria decision-making method that was reviewed for use in this project. TOPSIS requires the user to create a matrix that relates alternatives to criteria. These alternatives and criteria depend on the decision that needs to be made and what is most important to the decision makers. Using a predetermined set of numerical values, the matrix is created and values are used to show the relationship between the alternative and each of the criteria. Positive ideal and negative ideal solutions are then created. The preferred alternative is the alternative closest to the positive ideal and farthest from the negative ideal. This is determined by calculating the separation and closeness values.

Value Engineering was also reviewed. This process is prepared to help groups add value to a project. Value Engineering includes a series of meetings and discussions. Through the discussions the members of the decision-making group come to an agreement on what can be done to add value or improve projects or processes.

The Gradients of Agreement tool is a process by which the decision maker or the facilitator can determine if the group has come close to a consensus. This is done by each member giving a value that represents where they are at on a scale from whole-hearted endorsement to veto.

How UDOT used incentives/ disincentives clauses in HMA construction contracts was also reviewed. In particular, a specification that dealt with incentives/disincentives for gradation, asphalt binder content, and density was reviewed. Also discussed were schedule-based incentives and disincentives that have traditionally been used.

The literature reviewed in this section was used to help search for an appropriate decision-making method for this study. The selected method was then used to help a task force develop guidelines for mobility-based performance specifications.

3 TASK FORCE

To develop and discuss guidelines for the mobility-based performance specifications, a task force was formed. This task force participated in a series of meetings to discuss recommendations for the guidelines and also participated in further analysis and review of the guidelines. Included in the task force were representatives from UDOT, AGC of Utah, and JUB Engineers. Two staff members from JUB Engineers took part in the task force; they were invited because JUB Engineers was hired by UDOT to manage the testing of mobility-based performance specifications, which was performed on a project involving the reconstruction of four intersections on Bangerter Highway in Salt Lake City, Utah. Their involvement with this project provided them with unique insights into application of and concerns with mobility-based performance specifications. The contractor representatives for the task force were recruited from AGC. To recruit task force participants, the purpose of the study and need for task force members were presented at a meeting of the AGC Highway Committee and members were asked to participate in the task force. Four members volunteered to participate in the task force. Members of the UDOT's Technical Advisory Committee (TAC) members for this study were also invited to participate. Individuals from each of the UDOT regions were also asked to participate because they will play a key role in making this type of specification function properly. Those who would not be able to be present at the meeting were invited to participate through video conference.

Multiple meetings of the task force took place to discuss and set guidelines on how mobility-based performance specifications would be written for upcoming projects and what type of projects would be appropriate for application of mobility-based specifications. These meetings were organized by researchers from BYU, who acted as the intermediary between the contractor and the UDOT representatives. The purpose of these meetings was to have an open dialogue about concerns and questions pertaining to the mobility-based performance specifications. The meetings were also meant to help the task force come to an agreement on how the guidelines for how this type of specifications would be written in future projects. These guidelines are needed because these types of specifications would require both the contractor and UDOT to be willing to participate in the extra work that such specifications might require. The questions that needed to be answered for the specifications to function well, or the guidelines needed for implementing the specifications for each project, are listed below:

1. What projects will be subject to mobility-based performance specifications as compared to traditional schedule based incentive/disincentive specifications?
2. What are the equipment and mobility data requirements for mobility-based performance specifications?
    a. How are key movements determined?
    b. What are the sensor spacing requirements?
    c. What mobility data are used (e.g., travel time/speed/queue)?
3. What manpower will be needed?
    a. For monitoring traffic, analyzing data, and responding to alerts
    b. For recording the incidents in the work zone
    c. For determining what needs to be included in the record
    d. For determining queue dispersal period
    e. For determining how detoured traffic, from incidents or construction work nearby, affect traffic in the work zone
4. How will disincentives/incentives be determined?

a. How are penalty-tier thresholds determined (e.g. percentage or real value)?
b. How is preconstruction study on selected performance measures conducted (e.g., computer model or preconstruction study)?
c. How often are data analyzed?
d. Who does the analysis?
e. Who has ownership of the data?
f. What time period is used for analysis?
g. Should a correction time be given to the contractor before a penalty is assessed and if so, how long of a time?
h. What margins of error are acceptable in the data collection method?

These questions were used as a starting point for the task force meetings; topics not covered by these questions were also discussed and will be covered by the guidelines. It was expected that during the task force meeting new concerns would arise that would need to be added to the guidelines for mobility-based performance specifications. The remainder of this chapter presents summaries of the three task force meetings.

3.1 First Task Force Meeting

The first task force meeting was held on February 19, 2013. This was used to brainstorm ideas for the guidelines and to identify any additional concerns that were not considered. During the meeting, representatives from JUB Engineers summarized their experiences with the 7800 South and Bangerter Highway Project. This project was a test application of mobility-based performance specifications to work zone management. The project was carried out using standard specifications while the mobility-based specifications were being tested. From this project many lessons were learned that would be taken into account when writing recommended guidelines.

There seemed to be consensus among the participants in the first task force meeting that freeways or major arterials where access is limited are most likely to have success in applying mobility-based performance specifications. In the 7800 South project, 48 movements were tracked; the amount of data obtained from this high number of movements made it difficult to analyze and respond promptly and effectively. A recommendation was made to focus on a selected few movements, as limiting the number of movements would make the analysis easier and less time-consuming. By using this specification on a freeway or interstate, only one movement in each direction would need to be tracked for travel time calculation. This option would also remove the concern of having vehicles stop off the construction section. This can occur if there is a gas station or other land use types adjacent to the construction zone where some drivers may stop their vehicles for a prolonged time, thus increasing inaccuracies in travel time data.

There was also consensus in the first task force meeting that more testing of mobility-based performance specifications needs to be done. At the time when the first task force meeting was held, there was a project on I-80 that was scheduled to use a mobility-based performance specification; that pavement rehabilitation work was located on the I-80 freeway between 600 West and Saltair in Salt Lake City. This work zone used speed as the performance measurement parameter. From this project, more lessons were learned regarding the use of performance-based specifications. More tests of mobility-based performance specifications should be conducted on freeway projects to learn how mobility-based performance specifications can be incorporated into managing traffic in work zones and construction schedules.

Industry representatives shared concerns in the first task force meeting about implementing mobility-based performance specifications to projects with other construction projects underway along parallel roadways. Some of the major projects such as the I-15 reconstruction (I-15 CORE) have included work on adjacent roadways or routes. These projects on adjacent streets could affect the traffic pattern at the construction site under study.

In the first task force meeting, it was determined that the type of work being done also needs to be considered when applying mobility-based performance evaluations. Some work will require lane closures or full road closure at times. The type of work that needs to be completed must be analyzed to determine how mobility-based performance specifications should be written for the project and to determine if they are appropriate for a particular construction project.

Consensus in the first task force meeting seemed to be that travel time was the easiest and most appropriate mobility data to track. Since other mobility data such as delay and speed could be obtained from the travel time, task force members considered travel time as the most appropriate data for performance measurement and the most accurately collected among the typical performance measures considered. A number of technologies currently available for monitoring traffic are focused on finding travel time. Other measurements such as queue could also be used but are harder to define and measure in the field.

Industry representatives in the first task force meeting showed concern with how to determine financial risk for projects with mobility-based performance specifications. Without knowing how much disincentive to account for in the bidding process, it would be difficult to add potential disincentives into their cost analysis. One suggestion that was put forth to help with the contractor's bidding process was that UDOT would distribute any traffic-related information and traffic models available at the pre-bid meeting to allow the contractors time to determine how much risk they would have to assume and how much to put into their bid. It was also proposed that more time be given between the pre-bid meeting and the beginning of the bidding process for contractors to analyze the data. The extra manpower required by the contractor would also have to be taken into consideration during the bidding process. A key component of this type of specification arrangement would be that, if the contractor was required to hire a traffic engineer, such extra expense would eventually need to be included in the bids.

Another item that was discussed in the first task force meeting was how to deal with the mobility-based performance data collected from the project. One alternative was to have the majority of the analysis done by UDOT. Alerts for when the performance measurement reaches the tier levels set for disincentive will need to be sent both to the contractor and UDOT. In the mobility-based performance specifications, the UDOT resident engineer has the responsibility of making sure the analysis of the traffic data is completed. Another recommendation made in the first task force meeting was that an additional individual should be hired and be available on-call to deal with the alerts.

A proposal was made by an industry representative in the meeting that some of the night time hours should be made exempt from the specifications. The reasoning behind this exempt period was that some of the work done by the contractor would require lane closures that cannot be avoided. Traditionally, more lane closures have been allowed at night.

Safety was discussed in the first task force meeting and determined to always be a major concern in construction projects. There is always a need for traffic enforcement and the presence of the highway patrol to enforce the traffic laws. Industry representatives had concerns that trucks entering and exiting the work zone would slow traffic and that having the trucks enter and exit at higher speeds could cause safety issues. Also, there are concerns that mobility-based performance specifications would encourage faster speeds in work zones. Some types of construction require workers to be in close proximity to traffic, which can be a safety concern when vehicles travel at high speeds. This must be considered in preparation of the specifications. Physical barriers or other means might also be necessary to increase safety in such cases.

Industry representatives raised a concern in the meeting that the presence of construction would slow traffic. This must be taken into account when determining tier threshold values for disincentives. It was also brought up that the disincentive tiers would need to be considered on a case-by-case basis. A number of factors will need to go into determining the tier thresholds such as type of work to be done. Intersections need to be accounted for when determining travel time because there is a difference for vehicles that must stop at red lights. The number of detours should also be taken into account. One of the alternatives mentioned was to set a standard percentage of the travel time. It was determined, however, that this alternative would require more research and test projects.

The consensus from the first task force meeting seemed to be that an adequate problem correction period should be given to the contractor. This period should be given so that, if the contractor informs UDOT what the problem is and what they are doing to fix it, the correction period should be exempt from a penalty. One alternative discussed was that this exemption period should last for 30 minutes.

One major concern that was brought up by the industry representatives in the meeting was that these mobility-based performance specifications were just about giving disincentives and that there seemed to be no incentives for the contractor. UDOT expected that this specification would allow for more flexibility for the contractor in lane closures and when they could do their work with innovative procedures to contain delays within a tolerable range.

3.1.1 Summary of the First Task Force Meeting

In the first task force meeting a total of 12 topics were discussed. These topics included experiences by JUB Engineers with mobility-based performance specifications, key topics generated for discussion by BYU researchers, and concerns from the contractors or UDOT. The discussion items from the first task force meeting were the following:

- Experiences by the representative of JUB Engineers from testing mobility-based performance specifications for the 7800 South Project provided an informative introduction to the issues of mobility-based performance specifications for all task force members.
- Mobility-based performance specifications should be used on interstates or rural highways to limit the number of movements to be monitored.
- When mobility-based performance specifications are implemented, the guidelines for these specifications should be updated as additional concerns or issues arise.
- One concern that needs to be taken into account when using mobility-based performance specifications is the traffic that is detoured into the work zone from parallel roadways. Delay caused by detoured traffic should be exempt from penalty calculations.
- The type of work needs to be taken into account as some work requires more lane or road closures.
- Travel time should be used as a primary mobility-based performance measure because this is the easiest data to track and, at the same time, other data such as delay and speed can be obtained from travel time.
- The contractor representatives had a concern with how the financial risk would be distributed between the contractor and UDOT in projects that use mobility-based performance specifications. One way to help reduce this concern is to have a pre-bid meeting to discuss how much risk needs to be assumed by the contractors and how much extra manpower is required, if any, for the project.
- Employees from UDOT and the project contractor need to be assigned to receive and deal with alerts when the travel time reaches the penalty-tier level.

- The contractor representatives expressed a desire that periods that are exempt from penalties be given during night hours to reduce the risk assumed from mobility-based performance specifications.
- With projects using mobility-based performance specifications, as with all projects, safety should be of paramount importance.
- The contractor representatives also raised concern that the tier levels need to take into account the reduced speed limit in the work zone as the lower speed limits will increase the travel time.
- From past experiences with mobility-based performance specifications, it was also recommended that a correction period be given, where penalties will not be assessed if the contractor quickly fixes the issue causing the delay.
- The final concern discussed in the first task force meeting was that mobility-based performance specifications only add disincentives to construction projects.

3.2 Second Task Force Meeting

The second task force meeting took place on March 26, 2013, at the UDOT Complex. To begin the task force meeting, the key points from the first meeting were reviewed. One of the items of discussion from the first meeting was the type of projects that are appropriate for including mobility-based performance specifications. In this meeting, this topic was again briefly addressed to ensure that consensus was found and that more discussion on this topic was not needed. In the first meeting, the consensus was that mobility-based performance specifications should be used for freeway projects, at least during the first implementations of mobility-based performance specifications. Also, the type of work that needs to be done and the size of the project should be taken into consideration when determining if a mobility-based performance specification is appropriate.

A review of the first meeting discussion of the type of mobility data that will be used for the analysis in the specification was also needed to ensure that the consensus was reached and any more comments for concerns could be addressed. During the discussion it was brought up that queue length or travel time could be used in the specification; however, consensus seemed to remain that travel time should be the mobility performance measure to be used.

How to monitor for incidents and analyze the data received from the sensors was brainstormed in the first task force meeting. This item was also discussed in the second task force meeting. One suggestion was that video recording could be used to identify time periods where incidents occur. Records of incidents also need to be kept at the construction site. For analyzing the data, it was suggested that the UDOT resident engineer should take the lead on this option.

Based on the outcomes of the first meeting and the input from the representative of JUB Engineers, it was recommended in the first meeting that a 30-minute correction period be given to the contractor. This would allow the contractor time to correct any problems with the flow of traffic. When an alert is received, or when the travel time has become too long, the contractor is allowed a 30-minute period during which penalties will not be assessed. However, to qualify for this correction period, the contractor must be in contact with the UDOT resident engineer for the project and be actively working on correcting the problem with traffic flow. In the second task force meeting, this topic was again addressed. It was suggested that this is not necessarily something that should be written in the specification for every project but that could be determined by the resident engineer. Also, it was brought up that perhaps a trial period is needed so that the contractor has a chance to learn how lane closures and other work conditions affect traffic flow.

In the first meeting it was decided that there should not be a set formula or number used to calculate the increase in travel time that would trigger a penalty because this might not meet the needs of various projects. In the second task force meeting, this topic was briefly reviewed; however, a consensus was not reached, and it was determined that further discussion would be required.

In the second task force meeting, it was desired that some of the concerns that were brought up in the first task force meeting be addressed. In the first and second meeting, the following four concerns were brought up as items of discussion.

The first concern from the previous task force meeting was with the bidding process for projects with mobility-based performance specifications. One of the recommendations from the first meeting was to have a pre-bid meeting before the bidding process that would allow time for the contractor to assess the amount of risk they would be required to take on for the project. Also any impact analysis model or information available should be distributed by UDOT. When the second meeting was held, the project scheduled on I-80 in Utah, which was scheduled to use mobility-based performance specifications, was about to begin the bidding phase. Before the bidding process, an early pre-bid meeting was arranged for this project based on recommendations from the contractors. This gave the contractors more time to determine how to deal with the risk that mobility-based performance specifications introduce. The pre-bid meeting and communication throughout the bidding process are especially important for projects that use mobility-based performance specifications.

The second concern or item that the contractor brought up in the first task force meeting was the need for exempt periods during the project. These exempt periods are time periods where penalties cannot be assessed. Because some work will require lane closures that cannot be avoided, having an exempt period would allow the contractor to have less risk with the project. In the first and second meetings of the task force, it was determined that these periods should be given on a case-by-case basis based on the type of work done. This exemption needs to be determined according to discretion of the UDOT resident engineer in collaboration with the contractor. This would give the contractor a guaranteed time during which they would not be penalized.

The third concern that the contractors expressed in the second task force meeting was how safety would be affected by mobility-based performance specifications. The major concern was that this type of specification would incentivize the contractor to try and move traffic through the construction zone at higher speeds, which could decrease safety. However, by using an appropriate travel time level for assessing penalties, this concern would be minimized. The required travel time calculations would be based on the assumption that all the vehicles would follow the speed reduction in the construction zone, which means that the travel time thresholds for penalty-tiers would require speeds lower than the reduced speeds in the construction zone. Also, there was a concern with construction-related trucks that would be entering and exiting the construction zone. When the trucks enter and exit the traffic stream, vehicles behind the trucks would be required to slow down, which would increase the travel time of those vehicles. This might create an incentive for the contractor to have the trucks enter and exit at higher speeds, which could create unsafe traffic conditions. The concern with the trucks should be mitigated with using a 15-minute time interval. By averaging the travel time over a 15-minute period and over all the vehicles in that time period, the delay caused by the trucks entering and exiting should not cause a penalty. However, if there is a concern that trucks might be causing penalties, they should be recorded and discussed with the UDOT resident engineer.

The fourth and last concern from the first task force meeting discussed in the second task force meeting was how this type of specification would apply disincentives without giving any incentives. This topic was not completely discussed in the first task force meeting. In the second task force meeting, time ran out before this topic could be discussed in detail, so a third meeting became necessary. It was noted that these specifications would have some benefits, however, including more flexibility in lane closures and in the ability of contractors to determine when the work should be done.

During the first task force meeting, not all of the topics on the agenda were discussed. During the second task force meeting, the items missed in the first meeting were further discussed. The first one of these items was a discussion on who is in charge of recording incidents in the work zone and how the decision will be made for determining when the queue is dispersed. Workers in the construction zone must take note of any incidents that might affect traffic flow in the work zone under construction. Also, police records can help to extract information on crashes that take place in the work zone. When incidents, such as crashes, occur, the UDOT resident engineer for the project should be informed. The queue dispersal can be determined based on the records at the construction site and by analyzing the travel-time data.

Another item that was not discussed in the first task force meeting was the error margins that are acceptable in the data collection method. Some errors would exist with any data collection method. The representatives of JUB Engineers gave a brief description of statistical testing required to determine if collected data gave an accurate representation of travel-time distribution. Also mentioned was that a large number of vehicle samples were required for the sensors to get an accurate average travel time during a 15-minute period. Time periods without enough samples had to be eliminated from the delay calculations. Another item of discussion was the sensor and data collection requirements, such as unit spacing or number of units to be used. Most of these items should be given by the manufacturer of the data collection system;

however, some also depend on the type of work to be done and should be determined for each project. As to the locations of the sensors, they need to remain in the same locations during pre-construction studies and during all of the construction period.

At the end of the second task force meeting, a brief introduction to TOPSIS was made. Task force members were informed that more information would be sent to each member and they would be asked to participate in using TOPSIS to test for consensus, or to determine if the task force members were in agreement on certain issues that might otherwise require further discussion. TOPSIS was selected because of the ease of calculation and how it lends itself to groups such as the task force. It was decided that the third task force meeting would focus on the TOPSIS analysis.

3.2.1 Summary of the Second Task Force Meeting

During the second task force meeting, items that were not able to be discussed during the first task force meeting because of time constraints were addressed. Some items that had not been resolved in the first task force meeting, as well as new items brought up during the discussion, were addressed. These items included the following:

- During the first task force meeting, the task force members came to an agreement on a number of issues, including decisions that mobility-based performance specifications should be used for interstate and rural highway projects, travel time should be used for mobility measurement, and the type and size of projects need to be considered when penalty-tier levels are determined. These items were again brought up for discussion to determine if consensus was reached.
- In the first task force meeting, how to monitor for incidents in the work zone was discussed. In the second task force meeting, it was suggested that video recording could be used.

- In the first task force meeting, congestion correction periods were discussed. This discussion was continued in the second task force meeting, and the task force members came to the conclusion that this might be determined on a case-by-case basis and, instead of a pre-set correction period a trial period, be given at the beginning of the project where no penalties are assessed to determine the appropriate length of the correction period.
- In the second task force meeting, more discussion took place on the topic of pre-bid meetings. In the first task meeting, it was discussed that this should be held to give enough time for the contractor to determine the amount to risk they will have to assume. This was confirmed in the second meeting.
- One of the concerns brought up in the first task force meeting was the need for exempt periods. During the discussion in the second task force meeting, it was determined that the provision of exempt periods should be determined on a case-by-case basis.
- One of the concerns mentioned in the first task force meeting was how safety would be affected when mobility-based performance specifications are used. In the second meeting, it was determined that safety, although it always needs to be considered, is not the main objective of this specification and should be discussed in greater detail by the UDOT safety committee.
- In the second task force meeting, it was discussed how incidents should be recorded at the construction site. It was suggested that workers need to keep records and that police records could also be used.
- In the second task force meeting, it was discussed that tests need to be performed to ensure that penalties are correctly assessed. Statistical tests can help to determine if the penalties are due to chance or error, and to ensure that penalties are accurately assessed.

3.3 Third Task Force Meeting

The purpose of the third task force meeting, which took place on May 15, 2013, was to use the multi-criteria decision-making method TOPSIS to generate more discussion and insight into four different topics: a) incident recordings, b) night-time exceptions, c) penalty-tier calculations, and d) incentives. Four different inputs were needed from the task force members to complete the TOPSIS analysis. The first two inputs were the criteria and alternatives that should be considered. Each of the four different topics had a number of different alternatives. Because of time constraints in the task force meetings, a number of alternatives were initially recommended by BYU researchers in advance to solicit task force members' opinions during the third task force meeting. Some criteria were also recommended for each of the four topics. The other two inputs required were weights and preferences for the alternative-criteria matrix. The TOPSIS method requires weighted values to be used to measure the importance of each of the criteria. Then each member of the task force would supply a number from 1 to 7 to each alternative with respect to each criterion considered to show their preference.

Each of the TOPSIS worksheets for the four topics were reviewed in the third task force meeting to determine if they accurately represented the views of the task force members. First, the criteria and alternatives that would be used in the TOPSIS analysis were reviewed, and changes were suggested by the task force members present so that the criteria and alternatives would represent the views of the task force members.

TOPSIS was used to generate discussion on and gather the opinions of the task force members for how mobility-based performance specifications should be written. However, it was discussed in this meeting that perhaps there should not be a set way to record incidents in the work zone and there could be a number of accepted methods for the contractor to record incidents. Also, it was noted that employees of UDOT who are at the construction site can also record incidents and that it is not just the contractor who should record incidents. From this discussion, it was determined that a TOPSIS analysis would not be used on the first of the four topics selected for analysis, which was how records of incidents in the work zone should be kept. Instead, it was discussed that records need to be kept to remove time periods from the penalty analysis where not only traffic accidents or incidents but also severe weather or other unexpected events might have caused congestion. Furthermore, it was suggested that records should be kept of any events that cause traffic delay not associated with the contractor by any method that is deemed acceptable. These time periods should be removed from the analysis and penalties should not be assessed during these times.

The second topic used for the TOPSIS analysis was the night-time exemption period from the mobility-based performance specifications. The first item that was discussed for this topic was that these exceptions should not just be limited to night-time but should be extended to off-peak times. It was suggested that, at minimum, while the contractors and UDOT are gaining experience with mobility-based performance specifications, they need a hybrid specification where time periods outside of the penalty-exemption periods may not be subject to mobility-based performance specifications, until the contractors gain experience on how to maintain mobility in the construction zone..

With the help of TOPSIS, more detail was determined on how to determine when the penalty-exemption periods would take place and for how long they should be. The changes to the TOPSIS worksheet suggested in the third task force meeting were made before the TOPSIS worksheet was distributed to the members of the task force later on.

One item that was brought up during the discussion on the topic of night time exemption-periods was the desire of the contractor to use the mobility-based performance specification to change the speed limits in parts of the construction zone. The contractors felt that if they would be required to maintain the travel time they should be able to reduce the speed limit along portions of the construction zone where active work is occurring. This would improve safety in these zones and again give more freedom for scheduling to the contractor.

It was also mentioned in the third task force meeting that often the specification would require the contractor to maintain a number of lanes in each direction. When this is the case, the contractor will not be given defined times when work can be done or when lanes can be closed. During peak hours or time periods when mobility-based performance specifications are not being used, the specification could still be written in a way that requires a set number of lanes to be open for these periods. However, when mobility-based performance specifications are in use, the contractor should have the option to close lanes if they are able to maintain the travel time set through the construction zone.

The third topic of the task force meeting was the travel-time penalty-tier threshold value determination for the different levels of warning or penalties. The TOPSIS analysis of alternatives and criteria for the penalty-tier threshold calculations were only briefly discussed as time was running short in the third task force meeting. It was suggested that the percentage of the travel time appeared to be the most appropriate alternatives during the third meeting. The TOPSIS worksheet covered this topic to determine an alternative for computing the preferred penalty-tier threshold.

The fourth and final topic that a TOPSIS worksheet was created for was to solicit opinions on how incentives could be included in mobility-based performance specifications. This was an important topic that would need the TOPSIS method. All four of the incentive provision alternatives that were recommended by BYU researchers were brought up and discussed briefly for their use.

During the third task force meeting it was also brought up besides the four topics discussed above, that one-way flagging can sometimes be used to move traffic through the construction zone. This option needs to be considered when using mobility-based performance specifications.

With time limitations in the third task force meeting, entering criteria weights and alternative ratings needed for the TOPSIS analysis was not completed. Hence, it was determined that the input from the task force should be considered for modifying the TOPSIS worksheet and that the improved worksheet would be distributed to all members of the task force later. Responses to the TOPSIS worksheets would then be used in the TOPSIS analysis, and the results would be distributed to all the members for their input and review.

3.3.1 Summary of the Third Task Force Meeting

The third task force meeting was used to introduce the TOPSIS analysis. Four TOPSIS worksheets were presented that covered four different topics, each with their own criteria and alternatives. These worksheets were reviewed to ensure that the criteria and alternatives accurately represented the discussions that took place in the first and second task force meetings. The key points from the third task force meeting are the following:

- The first TOPSIS analysis topic was how to record incidents in the work zone. During the meeting it was decided that there should not be a set method but that any method that is agreed upon by the contractor and UDOT can be used. Because of this consensus, the TOPSIS analysis on this topic was not done.

- The second TOPSIS analysis topic was night-time exemption periods. Changes were made to the TOPSIS worksheet to more accurately represent the feelings of the task force members.
- The third TOPSIS analysis topic was how the travel-time tier levels would be calculated. Changes were made to the worksheet to reflect the opinions of the task force members.
- The fourth TOPSIS analysis topic was how incentives would be added to encourage the use of mobility-based performance specifications. Changes were made to the worksheet accordingly to reflect the opinions of the task force.
- During the third task force meeting, it was also brought up by the contractor representatives that they wish to use the scheduling flexibility provided by the mobility-based performance specifications to the contractors to lower speeds in the work zone section where work is currently being done. To maintain the travel time they would allow vehicles to travel faster in other sections of the work zone.
- The contractors also mentioned that often the traffic control specifications for a work zone would require that a predetermined number of lanes must be kept open at all times. One-way flagging might also be required for some projects. These items must also be taken into account when using mobility-based performance specifications.

3.4 **Chapter Summary**

This chapter reviewed the task force meetings that were conducted to develop guidelines for mobility-based performance specifications. Three task force meetings were conducted, with researchers from BYU conducting each meeting. Questions that needed to be answered through the task force discussions and the TOPSIS analysis were distributed to the task force members, and they were asked to add or change any of the questions. These questions included such topics as the amount of manpower needed, determination of travel time penalty-tier thresholds, sensor position requirements, and mobility data used in the specification. Through each of the three meetings, these topics were discussed. When a consensus seemed to be reached, the task force members were invited to give any final comments or objections. If there were no concerns or objections, then the discussion moved on to the next topic. During the meetings, the participants' discussions were recorded, with their permission, and meeting notes were prepared based on the recordings and distributed between meetings to inform the participants about the outcomes of their discussions.

4 TOPSIS ANALYSIS RESULTS

This section discusses the TOPSIS analysis that was conducted by the task force members. An example spreadsheet each of the task force member were asked to fill out is shown. Then, the criteria and alternatives for the risk management topic are discussed and the results of the analysis presented. The criteria, alternative and TOPSIS results for the second topic, penalty-tier calculations are then presented. The criteria, alternative and TOPSIS results third and final topic, incentive is then presented. Each of the three topics used a different set of criteria and alternatives for the TOPSIS analysis.

4.1 TOPSIS Spreadsheet Distributed to the Task Force Members

TOPSIS, a multi-criteria decision-making method, was used in this project to help solicit the opinions of the task force members. The original TOPSIS method and the absolute method, which removes any chance of rank reversal, were used in the analysis. However, the ranking order did not change when the absolute method was used in the analysis; hence the original TOPSIS method is presented in this report. The TOPSIS analysis required members of the task force to supply numerical values that represent their opinions about a selected number of alternatives under a set of criteria. To ensure that all members of the task force had an opportunity to participate in the TOPSIS analysis, a spreadsheet was created to help the task force members walk through the process. This spreadsheet was emailed to all members of the task force to solicit their input in the analysis (see Appendix B for this TOPSIS spreadsheet). Of the 22 task force members, 10 members responded with a completed spreadsheet; these responses can be found in Appendix C without revealing the names of the respondents. All members were, however, asked to review and comment on the results of the TOPSIS analysis regardless of whether they completed the TOPSIS spreadsheet or not. Some members indicated that the comparison of alternatives against criteria in the matrix format was difficult and time consuming, which was a likely cause for the relatively low survey return rate.

Three topics, risk management, penalty-tier calculations, and incentives, were required in the TOPSIS analysis as these were the topic areas where the task force members still needed to come to an agreement or they were selected because further discussion was desired for these topics. For each of these topics, a set of criteria and a set of alternatives were developed from the task force meeting discussions.

The first step to complete the TOPSIS spreadsheet that was distributed to all task force members was to give the criteria weights. This was done by assigning a percentage value for each of the criteria. The sum of the weights for the criteria should add up to 100 percent. Table 4-1 shows the weights provided by one of the task force members for the four criteria used for the risk management topic as an example. This example is taken from one of the completed TOPSIS worksheets that were filled out by the task force members.

Table 4-1: Example Weight Matrix

Weight Matrix			
Distribution of Risk	**Innovation**	**Amount of Delay**	**Exemption Need**
25%	25%	25%	25%

The next step in the TOPSIS analysis that each member of the task force was asked to perform was to fill in a matrix that relates each alternative to the criteria. The alternatives were listed in the vertical axis of the matrix, while the criteria were listed on the horizontal axis. A sample alternative-criteria matrix taken from one of the task force members can be seen in Table 4-2. A value from 1 to 7 was assigned to each cell of the matrix. The range of values 1 to 7 was selected to emulate the gradients of agreement, without the veto option. However, because they are to be used in the TOPSIS analysis, the meaning behind each of the values had to be adapted as the original purpose was a vote in a group setting. These values represent how the alternatives, which were developed from the task force meeting discussions, relate to each of the criteria. The legend for Table 4-2 shows the relative meaning of each of the values 1 to 7; this legend was also given in the TOPSIS spreadsheet distributed among the task force members to guide them through the rating process. The rating values in the legend were used for comparing each of the criteria for all the alternatives.

The values given by each member of the task force who completed the TOPSIS worksheet were used to calculate the preferred alternative. To perform the TOPSIS analysis, a new matrix was created using the average of the matrix values that were entered by each participating member of the task force on his or her worksheet. Then, through the TOPSIS analysis, a preferred alternative was selected for the topic. The weights given by the task force members were also averaged to determine the weights for the TOPSIS analysis. A review of the TOPSIS method is provided in Chapter 2.

Table 4-2: Alternative-Criteria Matrix

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	3	4	4	4
Mobility-based incentive	5	6	6	5
Provide other types of incentives	4	6	6	6
Make mobility-based specification optional	4	4	4	4

Legend

1 - This alternative is the worst possible for this criterion.
2 - The cost outweighs the benefits for this criterion.
3 - The cost slightly outweighs the benefits for this criterion.
4 - Evaluation is neutral or more discussion needed.
5 - The benefit only slightly outweighs the costs for this criterion.
6 - The benefit outweighs the costs for this criterion.
7 - This alternative is the best possible for this criterion.

4.2 **Risk Management**

This section presents the criteria and alternatives for the risk management topic used in the TOPSIS analysis and the results of the TOPSIS analysis.

4.2.1 Risk Management Criteria

For the risk management topic, four criteria were used in the TOPSIS analysis as a way to determine which of the alternatives was preferred by the task force. The four criteria used were 1) distribution of risk, 2) innovation, 3) amount of delay, and 4) exemption need. These criteria came from the task force meeting discussions on this topic and are unique to the TOPSIS analysis for this topic.

The first criterion was the distribution of risk. This criterion was used to allow the task force members to take into account how the risk would be distributed among the contractors and

UDOT for each alternative. For this criterion a higher number indicates that the risk is well distributed, while a low number represents that the risk is not well distributed to the contractor or to UDOT.

The second criterion was innovation. One of the goals of mobility-based performance specifications is to encourage innovation and new ways to help traffic flow smoothly through construction zones; the innovation criterion will help take this goal into account in the TOPSIS analysis. If the task force members feel that the alternative will encourage innovation, then a higher number should be given. If they feel that an alternative would not encourage innovation, then the task force member would give this criterion a lower value.

The third criterion was the relative amount of delay that would be caused by each alternative. The main purpose of mobility-based performance specifications is to reduce the amount of delay to the highway user caused by construction zones. If an alternative is expected to have a higher amount of delay, then the task force member should enter a lower value in the matrix. If they believe that this alternative would help to lower the amount of delay caused by construction, they should assign a higher value to the matrix cell that represents that alternative and the amount of delay criterion.

The fourth criterion was the need for exemption periods. The exemption periods, or periods when penalties will not be assessed, should be given when they are needed, or the use of mobility-based performance specifications should be made optional. If the task force members feel that the alternative they are ranking will give the contractor the right amount of time needed to complete their work without requiring the contractor to accept a penalty from the mobility-based performance specifications, the task force members assign a high value. If they feel that the need for exemption time is overestimated, a lower value is assigned.

4.2.2 Risk Management Alternatives

The first topic covered by the TOPSIS analysis is managing the distribution of risk in mobility-based performance specifications. This was one of the areas of major concern brought up during the task force meetings by the contractor representatives. Using mobility-based performance specifications requires the contractor to take more of the risk from the project than they have taken previously. This is because mobility-based specifications require the contractor to become accountable for the traffic flow through the work zone. This leads to concerns about the risk distribution, specifically that the contractor may be unsure about bidding on projects with such specifications because the traffic condition in work zones can be hard to predict. During the task force meetings, the members discussed a number of ways by which the risk in projects with mobility-based performance specifications could be managed. To get more insight into the opinion of the task force members about which alternative is preferable and to help them reach an agreement on this topic, a TOPSIS analysis was performed. The four alternatives included in the TOPSIS analysis for the distribution of risk were created based on the outcomes of the task force meetings and were reviewed in the third task force meeting. They are 1) penalty-exempt periods based on pre-construction analysis estimates, 2) penalty-exempt periods based on construction work, 3) mobility-based specifications optional during non-peak and 4) mobility-based specifications optional.

The first alternative gives the contractor penalty-exempt periods that have been identified in the pre-construction analysis or the study, conducted to calculate the travel-time thresholds.

Exempt periods, or periods where penalties would not be assessed, would be given to the contractor to perform their work with the time and duration of exempt periods provided by UDOT. This would mean that the outcomes of the pre-construction analysis would be used to determine if there are enough time periods with traffic volume low enough to perform the construction work while still maintaining the desired traffic flow through the work zone. If there is a concern that there is not enough time for the contractor to do their work without receiving penalties simply because of presence of a work zone or because the work that needs to be done requires lane closures, UDOT will give exemption periods to the contractor. During the time outside of these penalty exemption periods, the contractor would be required to use the mobility-based performance specifications.

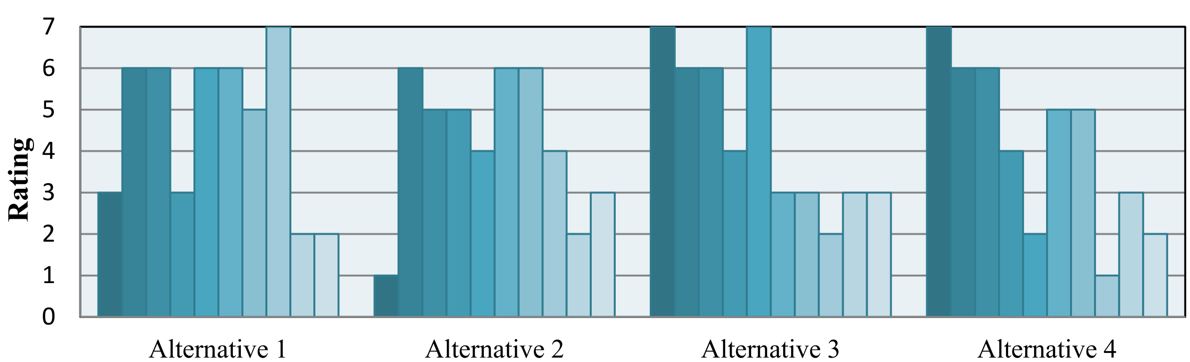
The second alternative gives the contractor penalty-exempt periods to perform their work. In this alternative, the exemption periods would be determined by a number of factors, including the type and amount of work to be completed. There is not a set way to determine the length of the penalty-exempt periods but they would be determined on a case-by-case basis; in particular, the amount of work that requires lane closures would need to be taken into account. A mobility-based performance specification would be used during all periods not covered by the penalty-exempt periods.

The third alternative gives the contractor the option to use mobility-based performance specifications during the non-peak periods. There would also be periods where this specification could not be used, but UDOT would specify the work that could be done during the given period or the number of lanes that must be open. These periods would mostly consist of the peak hours; however, if needed, other time periods could also be considered.

The fourth and final alternative makes the use of mobility-based performance specifications optional for the contractor. This alternative would mean that the contractor can choose to use mobility-based specifications. If they choose not to use mobility-based performance specifications, then they would use a more traditional traffic management specification in the work zone, where UDOT would set times when lanes can be closed or set a number of lanes that must remain open.

4.2.3 TOPSIS Analysis Results on Risk Management

Each member of the task force was asked to complete a matrix that showed the relationship between the alternative and the criteria. For this topic there are four criteria and four alternatives. The distribution of values for each alternative that was given by the participating task force members to the distribution of risk criteria is shown in Figure 4-1. Each bar represents a unique response by a task force member.



Legend

Alternative 1- Penalty exempt periods based on preconstruction analysis estimates
Alternative 2 - Penalty exempt periods
Alternative 3 - Mobility-based specifications optional during non-peak periods
Alternative 4 - Mobility-based specifications optional

Figure 4-1: Distribution of Risk Criterion Response Distribution

Figure 4-2 shows the distribution of responses for the innovation criterion. The distributions of responses for the amount of delay and the exemption-need criteria can be seen in Figure 4-3 and 4-4. These distributions of responses are taken from the 10 completed TOPSIS worksheets, and each bar represents a unique response.

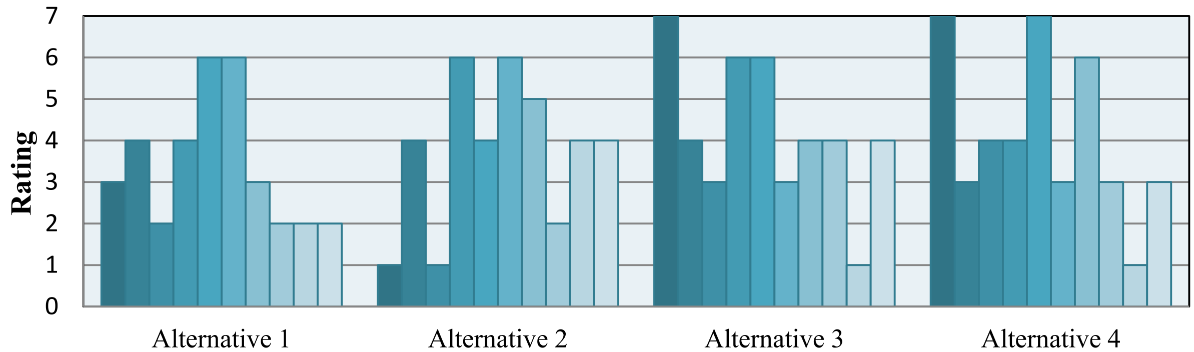


Figure 4-2: Innovation Criterion Response Distribution

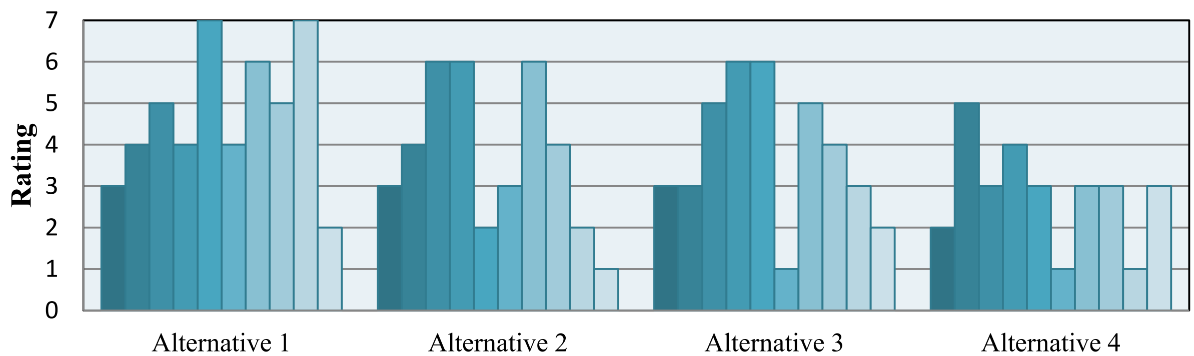


Figure 4-3: Amount of Delay Criterion Response Distribution

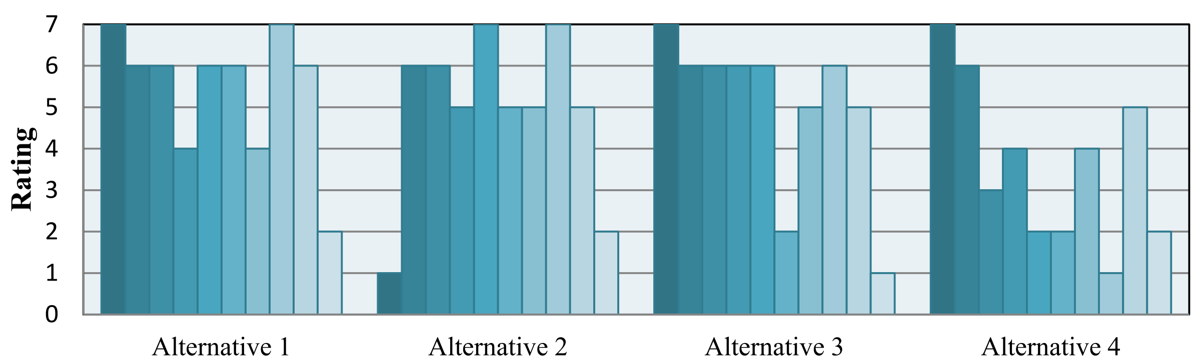


Figure 4-4: Exemption-need Criterion Distribution

The TOPSIS analysis requires subjective inputs which lead to variability in the task force members' responses. This can be seen, for instance, in Alternative 4 and the exemption need criterion, where the responses cover the range of each of the possible rating values. This variation shows that many of the task force members had differing options about how that alternative related to the criteria. For other criteria, there is more consistency in their responses, which shows more general agreement on the alternative.

The evaluation values in the TOPSIS matrices provided by each member of the task force who responded to the survey were averaged to determine the overall opinion of the task force for this topic. Table 4-3 shows the averaged criteria weights, and Table 4-4 shows the averaged response matrix values. Using this matrix, the TOPSIS analysis was performed, and the preferred alternative was selected. The first step of the TOPSIS analysis is to create a weighted normalized matrix based on the respondents' ratings. Equation 2-5 is used for computing the normalized matrix cell values, and Equation 2-6 is used to create the weighted normalized matrix as shown in Table 4-5. The next step is to determine the positive and negative ideal solutions; these can be seen in Table 4-6. Using the ideal solutions, the separation of each of the alternatives is calculated using Equations 2-7 and 2-8, and the relative closeness of each alternative is determined using Equation 2-9. The separation values, closeness values, and rankings are shown in Table 4-7. The closer the relative closeness value is to 1, the higher the priority of the ith alternative.

Table 4-3: Averaged Criteria Weights

Distribution of Risk	Innovation	Amount of Delay	Exemption Need
28.0%	23.5%	30.0%	18.5%

Table 4-4: Averaged Matrix Values

Alternatives	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
1	4.6	3.4	4.7	5.4
2	4.2	3.7	3.7	4.9
3	4.4	4.2	3.8	5.0
4	4.1	4.1	2.8	3.6

Table 4-5: Weighted Normalized Matrix Values

Alternatives	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
1	14.9	10.3	18.5	10.5
2	13.6	11.3	14.6	9.5
3	14.2	12.8	15.0	9.7
4	13.3	12.5	11.0	7.0

Table 4-6: Positive and Negative Ideal Solutions

	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Positive Ideal	14.9	12.8	18.5	10.5
Negative Ideal	13.3	10.3	11.0	7.0

Table 4-7: Alternative Closeness and Ranking

Alternatives	Separation from Positive Ideal	Separation from Negative Ideal	Closeness	Ranking
1	2.4	5.5	0.69	1
2	4.5	3.8	0.46	3
3	3.7	7.4	0.56	2
4	8.4	2.1	0.20	4

From the TOPSIS analysis, it was found that the first alternative was most preferred, that is, penalty-exempt periods based on pre-construction analysis. This alternative will give exempt periods to the contractors to complete their work when the pre-construction analysis shows that there is not enough time with low levels of traffic. During these periods, no penalties will be assessed.

4.3 **Penalty Tier Calculations**

This section covers the criteria and alternatives used in the TOPSIS analysis for the penalty-tier threshold calculations topic. Also included in this section are the results of the TOPSIS analysis.

4.3.1 Penalty Tier Calculations Criteria

Four criteria were used in the TOPSIS analysis for the penalty-tier threshold calculations topic to help determine which alternative is the preferred way of determining penalty-tier thresholds by the task force members. The four criteria used for this topic are 1) consistency, 2) ease of calculation, 3) room for calculation error, and 4) maintenance of traffic flow. These criteria were developed for this topic through the task force meetings and were discussed in the third task force meeting.

The first criterion, consistency, is important as the penalty-tier threshold calculations should be consistent from project to project or some projects might be unfairly penalized while others might be allowed to cause an excessive amount of delay. With this criterion, a higher value means that the task force member feels that this method of determining the tier threshold values is consistent, while a lower value means that the task force member feels that this method is not consistent.

The second criterion, ease of calculation, is the ease of penalty-tier threshold value calculation. Calculating the penalty-tier threshold values should not be overly difficult or burdensome for projects using mobility-based performance specifications. With this criterion, there would be no, or very little, debating on the threshold values as the computation process can be easily duplicated. When a lower value is entered in the TOPSIS matrix, it represents the opinion that the tier threshold calculation is too difficult. A higher value entered for this criterion for an alternative means that the tier threshold calculation in that alternative is not difficult, and a lower value means otherwise.

The third criterion is room for calculation error. The task force members were asked to consider the error that could be associated with a typical travel-time study. With the tier threshold value calculations, there needs to be room for this error, which can occur in any calculation of this sort, so that the contractors are not unfairly penalized when they did nothing to cause an increase in delay. If the task force members feel that an alternative is going to incorrectly cause penalties because of error in the calculations, the task force members should give the criterion a low value. If the task force members feel that this alternative does provide room for errors in the penalty-tier value calculations, a higher value should be assigned.

The fourth criterion for this topic, maintenance of traffic flow, is that the alternative selected should also have a travel-time tier threshold value that will not allow unnecessary amounts of delay throughout the work zone. The purpose of using mobility-based performance specifications is to reduce the delay experienced by the public traveling through work zones, and this needs to be taken into consideration. If task force members believe that the alternative will not give a low enough travel-time threshold to limit delay, a lower value is entered in the criterion cell that relates to the alternative, otherwise, a higher value is placed.

4.3.2 Penalty Tier Calculation Alternatives

One of the most important guidelines for mobility-based performance specifications pertains to the calculation of the penalty-tier level thresholds as these will be used to determine when the contractor will receive a warning or penalty. These penalty tier level thresholds need to be determined before the project begins. Three different alternatives were provided in the TOPSIS spreadsheet, which were used for selecting how these levels should be determined. They are 1) percent increase in travel time, 2) set travel time increase, and 3) lower of percent increase and set travel time increase. These alternatives were developed for the TOPSIS analysis on this topic from the discussions in the task force meetings, and were presented for member comments in the third task force meeting.

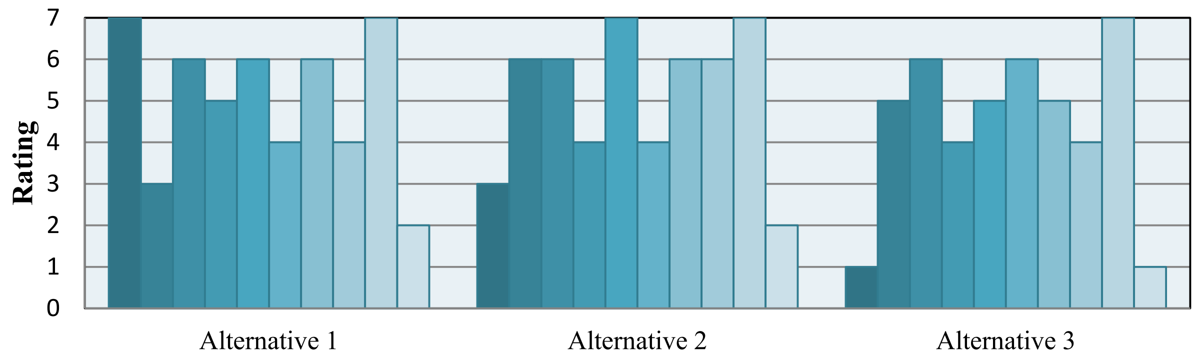
The first alternative uses a percent increase in the travel time that was obtained from the study conducted before the project began. An example of this would be to multiply the travel time obtained in the pre-construction analysis by 110 percent to obtain the first tier level.

The second alternative uses a predetermined travel time increase for each tier level. An example of this alternative is to add 5 minutes to the travel time obtained from the pre-construction analysis to obtain the travel time that would be the first tier level.

The third alternative uses a percent increase in the travel time, much like the first alternative. Unless the value calculated using this method is above a predetermined travel time increase limit, the lower calculated value is used. An example of this is using a 10 percent increase in travel time for the first tier level unless this increase is greater than a pre-determined increase of 5 minutes (i.e., if the percent increase becomes greater than 5 minutes, a 5 minute increase is used instead).

4.3.3 TOPSIS Analysis Results on Penalty Tier Calculations

Using the alternatives and criteria that were developed for this topic, a matrix was set up, and each participating task force member assigned values to each of the cells. Figure 4-5 shows the distribution of responses for the consistency criterion for each alternative. The distributions of responses for the other three criteria can be seen in Figures 4-6, 4-7, and 4-8, respectively.



Legend

Alternative 1 - Percent increase of travel time
Alternative 2 - Set travel time increase
Alternative 3 - Lower of percent increase and set travel time increase

Figure 4-5: Consistency Criterion Distribution

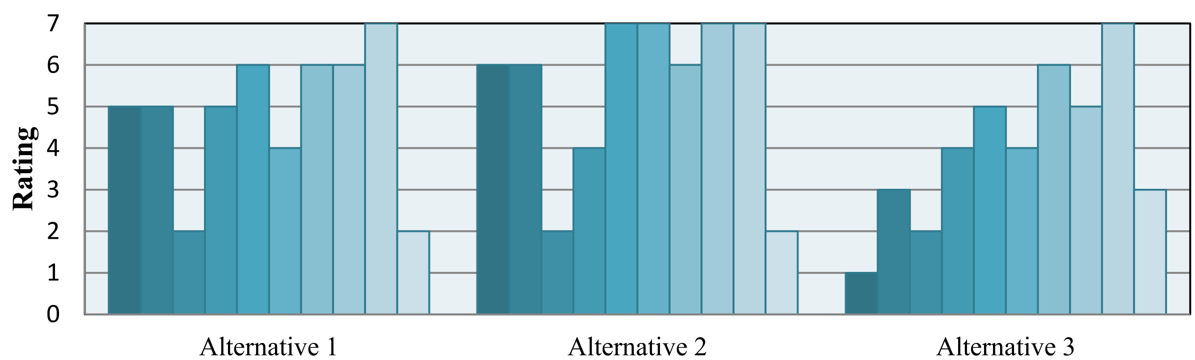


Figure 4-6: Ease of Calculation Criterion Distribution

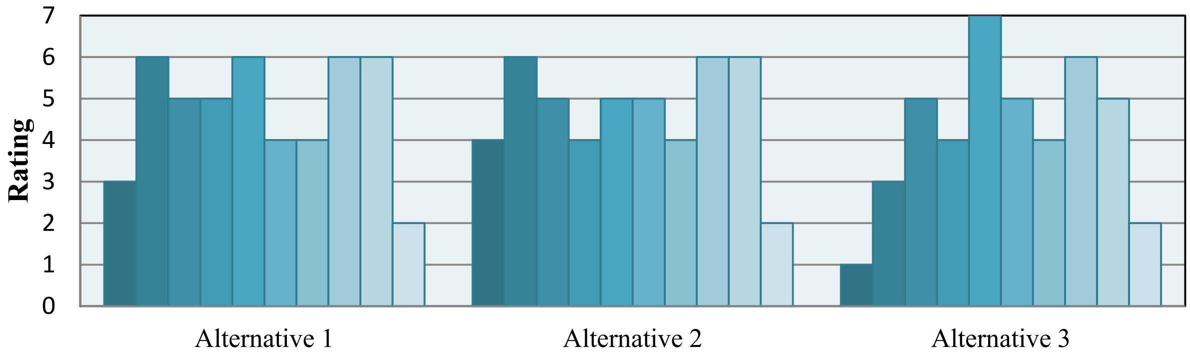


Figure 4-7: Room for Error Criterion Distribution

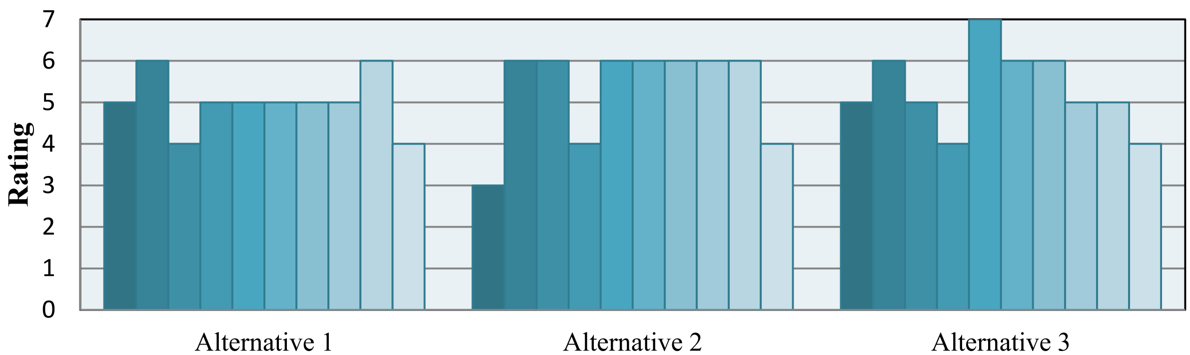


Figure 4-8: Maintain Flow Criterion Distribution

The task force members were asked to subjectively assign values to the criteria for each alternative based on their experience and the task force meeting discussions. Because each of the task force members viewed each of the alternatives and criteria differently, there is variation in the distribution of values. There is also consistency in some of the values the task force members assigned to the criteria, which shows agreement.

The averaged criteria weights are shown in Table 4-8. Using the distributions, an average value matrix was found to reflect the views of all of the task force members; this matrix is shown in Table 4-9. The matrix was then weighted and normalized, and the results can be seen in Table 4-10. Using this matrix, the TOPSIS analysis was performed, and the preferred alternative was selected. Table 4-11 shows the positive and negative ideal values for each criterion. The separation of each alternative from the ideal, the closeness to the ideal solutions, and the rankings are shown in Table 4-12.

Table 4-8: Averaged Criteria Weights

Consistency	Ease of Calculation	Room for Calculation Error	Maintenance of Traffic Flow
23.0%	22.0%	20.0%	35.0%

Table 4-9: Averaged Matrix Values

Alternatives	Consistency	Ease of Calculation	Room for Calculation Error	Maintenance of Traffic Flow
1	5.0	4.8	4.7	5.0
2	5.1	5.4	4.7	5.3
3	4.4	4.0	4.2	5.3

Table 4-10: Weighted Normalized Matrix Values

Alternatives	Consistency	Ease of Calculation	Room for Calculation Error	Maintenance of Traffic Flow
1	13.7	12.2	12.0	19.4
2	14.0	14.7	12.0	20.6
3	12.1	10.9	10.7	20.6

Table 4-11: Positive and Negative Ideal Solutions

	Consistency	Ease of Calculation	Room for Calculation Error	Maintenance of Traffic Flow
Positive Ideal	14.0	14.7	12.0	20.6
Negative Ideal	12.1	10.9	10.7	19.4

Table 4-12: Alternative Closeness and Ranking

Alternatives	Separation from Positive Ideal	Separation from Negative Ideal	Closeness	Ranking
1	2.7	2.5	0.48	2
2	0	4.6	1.00	1
3	4.5	1.2	0.21	3

From the TOPSIS analysis, it was found the second alternative was preferred. This alternative uses a set travel time increase, 5 minutes for example, to determine the travel time tier threshold for mobility-based performance specifications.

4.4 **Incentives**

This section describes the criteria and alternatives used in the TOPSIS analysis for determining incentives in mobility-based performance specifications, followed by the analysis results.

4.4.1 Incentive Criteria

In the task force meetings, it was indicated that mobility-based performance specifications were meant only to add penalties to the project and that this might be hard for the contractor to accept. To help give the contractor a reason to accept the use of mobility-based performance specifications, the task force members discussed how incentives could be added to the specifications. Four criteria were developed to help determine how and when incentives should be given. These criteria are 1) cost, 2) manpower, 3) distribution of risk and 4) innovation.

The first criterion is the cost of the incentive. While the incentive should give the contractors motivation to use mobility-based performance specifications, it should not be too burdensome on UDOT. In other words, the incentives should not force UDOT to limit the size of the project because of the added cost. Alternatives with high costs are given low numbers, and alternatives with low costs are given high numbers.

The second criterion is that the selected alternative should not require an excessive amount of manpower, or require too many extra work hours from UDOT or the contractor. This mutual risk is taken into account because an increase in manpower can be burdensome to the contractor and to UDOT and it can increase the cost of using mobility-based performance specifications. Alternatives that require more manpower are given a lower number and ones that require less manpower are given a higher number.

The third criterion is the distribution of risk. While the main purpose of using mobility-based performance specifications is to decrease the amount of delay experienced by the highway user, this specification will also redistribute risk. If the task force member feels that the risk in an alternative is well distributed, then the cell that represents this criterion is given a high number; if it is not well distributed, then a low number is given.

The final criterion is innovation. During the task force meetings, it was explained that mobility-based performance specifications should also encourage innovations. If the task force members feel that the alternative encourages innovation, then the cell is given a higher value; if they feel the alternative will not encourage innovation, a lower value is given.

4.4.2 Incentive Alternatives

One major concern that was brought up by the contractor representatives during the task force meetings was that mobility-based performance specifications would only be used to add penalties to the contractor and would not give any incentives to use this specification. To help with this, a number of alternatives for adding incentives were discussed, and four alternatives were developed: 1) mobility-based incentive by percentage of time under the penalty-tier threshold, 2) mobility-based incentive by time under the expected travel time, 3) other types of incentives such as schedule-based, and 4) schedule-based incentives with the option to use mobility-based specifications.

The first alternative discussed and used in the TOPSIS analysis gives the contractor an incentive if they stay under the pre-determined travel-time tier thresholds for a set percentage of the analysis period. For example, if the contractor goes without a tier alert for 90 percent of the analysis period, they would receive an incentive based on that percentage. The percentage would have to be determined in a case-by-case basis, as each location is different and, in the busiest locations, a high percentage will be difficult to obtain.

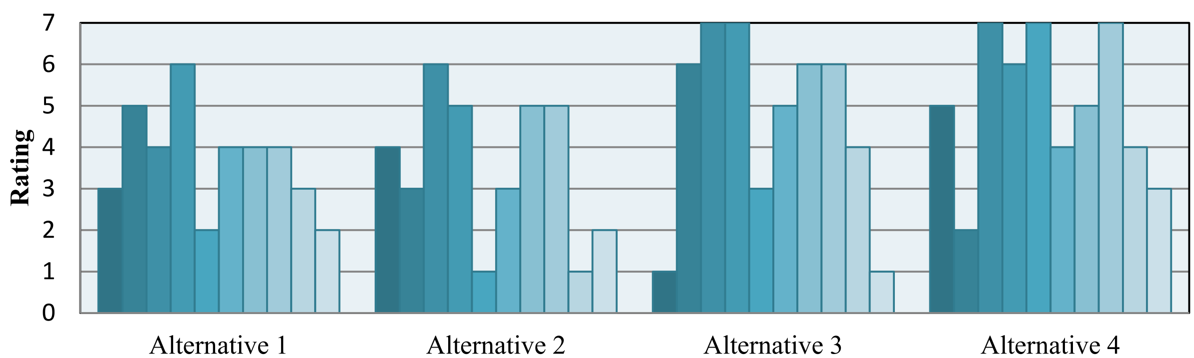
The second alternative uses the same system that is used to assess the penalties. For each 15-minute period, if the travel time increase through the work zone is lower than an expected level, an incentive would be given to the contractor. Some projects might require a limit to the amount of penalty and incentive that the contractor can receive.

The third alternative uses schedule-based incentives. For this alternative, no mobility data would be used in the incentive calculation. The incentives for the project would be based on price plus time, which is the current method for determining an incentive, where there are benefits for completing the project ahead of schedule.

The fourth and final alternative uses schedule-based incentives or price plus time, and makes the use of mobility-based performance specifications optional. This would mean that the contractor would be able to choose if they would be willing to use the mobility-based performance specifications provided by UDOT. With the mobility-based performance specifications, they would have more work hours during the day to complete the work and would be more likely to obtain the incentives.

4.4.3 TOPSIS Analysis Results on Incentives

The distribution of values given by the task force members in the alternative-criteria matrix for each of the criteria and the TOPSIS analysis results are presented in this section. Figure 4-9 shows the distribution of responses for the cost criterion. Figure 4-10 shows the distribution of responses for the manpower criterion, and Figures 4-11 and 4-12 show the distributions of responses for the distribution of risk and innovation criteria, respectively.



Legend

Alternative 1 - Mobility-based incentive by percentage of time under penalty tier threshold
Alternative 2 - Mobility-based incentive by time under expected travel time
Alternative 3 - Other types of incentives such as schedule-based
Alternative 4 – Make mobility-based specification optional

Figure 4-9: Cost Criterion Distribution

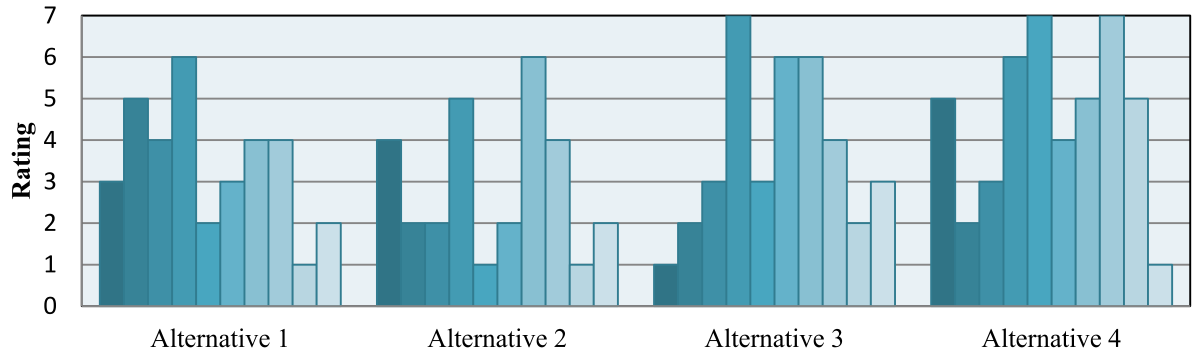


Figure 4-10: Manpower Criterion Distribution

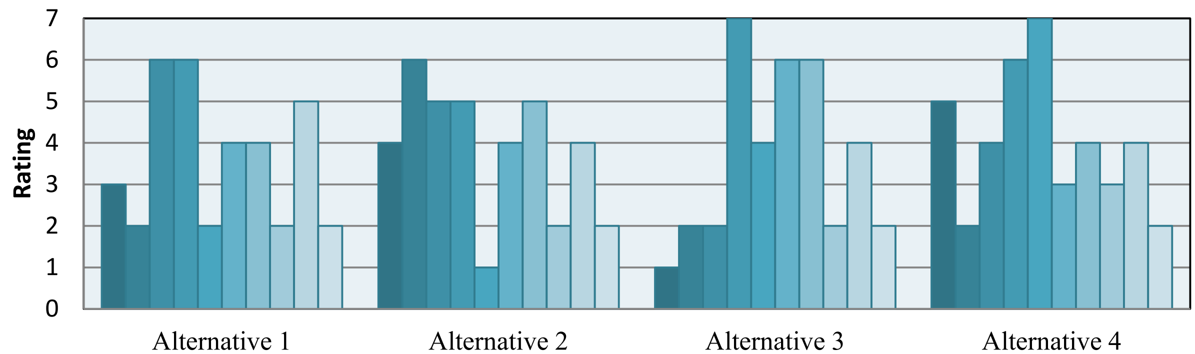


Figure 4-11: Distribution of Risk Criterion Distribution

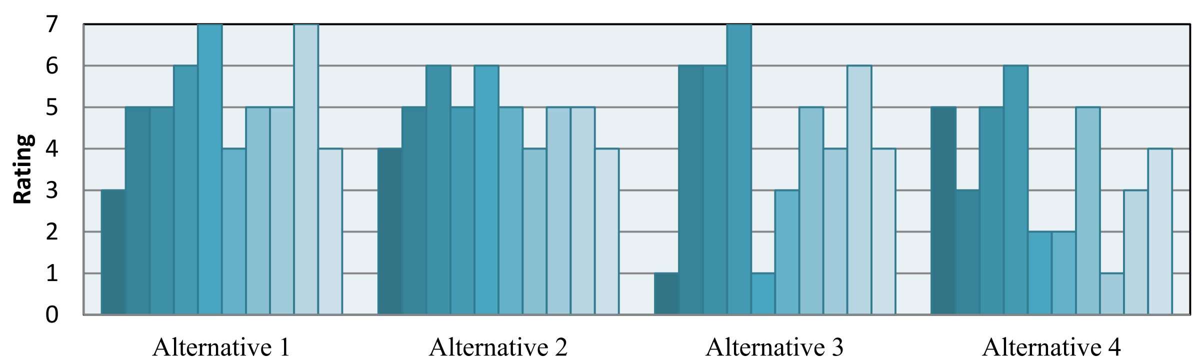


Figure 4-12: Innovation Criterion Distribution

The variation in the responses is an indication on how much the task force members were in agreement. Some variation is expected, as the backgrounds and experiences of the task force members differ and their view on mobility-based performance specifications also differ.

The average criteria weights are shown in Table 4-13. Using the distributions of responses given by the participating task force members, an average matrix was obtained. The average matrix reflects the views of all of the task force members who participated in the TOPSIS analysis, and this matrix is shown in Table 4-14. Using this matrix, the TOPSIS analysis was performed, and the preferred alternative was selected. The first step was to weight and normalize the matrix; the result of this step can be seen in Table 4-15. Next, the ideal solutions are created; these solutions can be seen in Table 4-16. Finally the separation was calculated. The separation to the ideal solution, closeness, and the ranking for the alternatives are shown in Table 4-17.

Table 4-13: Averaged Criteria Weight

Cost	Manpower	Distribution of Risk	Innovation
27.5%	22.5%	23.5%	26.5%

Table 4-14: Averaged Matrix Values

Alternatives	Cost	Manpower	Distribution of Risk	Innovation
1	3.7	3.4	3.6	5.1
2	3.5	2.9	3.8	4.9
3	4.6	3.7	3.6	4.3
4	5.0	4.5	4.0	3.6

Table 4-15: Weighted Normalized Matrix Values

Alternatives	Cost	Manpower	Distribution of Risk	Innovation
1	12.0	10.4	11.3	15.0
2	11.3	8.9	11.9	14.4
3	14.9	11.3	11.3	12.6
4	16.2	13.8	12.5	10.6

Table 4-16: Positive and Negative Ideal Solutions

	Cost	Manpower	Distribution of Risk	Innovation
Positive Ideal	16.2	13.8	12.5	15.0
Negative Ideal	11.3	8.9	11.3	10.6

Table 4-17: Alternative Closeness and Ranking

Alternatives	Separation from Positive Ideal	Separation from Negative Ideal	Closeness	Ranking
1	5.5	4.7	0.46	3
2	7.0	3.9	0.36	4
3	3.8	4.8	0.55	2
4	4.4	7.0	0.61	1

From the TOPSIS analysis, it was found that the fourth alternative was preferred most. This alternative uses schedule-based incentives to encourage the contractor to use mobility-based performance specifications while still giving the contractor the option to use mobility-based performance specifications or not.

4.5 **Chapter Summary**

TOPSIS, a multi-criteria decision-making method, was presented in this section along with the results of the TOPSIS analysis on three critical issues. The TOPSIS method requires criteria and alternatives in the selection of a preferred alternative. The criteria and alternatives used in the TOPSIS analysis were created from the discussions that took place in the task force meetings. They were used to create a TOPSIS spreadsheet that was distributed to all members of the task force. Each member of the task force was asked to fill out the spreadsheet; of the 22 members of the task force, 10 returned a completed spreadsheet. Some members indicated that the comparison of alternatives against criteria in the matrix format was difficult and time-consuming, which was a likely cause for the relatively low survey return rate (45 percent return rate). Regardless of participation in the TOPSIS analysis, task force members participated in the evaluation of the TOPSIS analysis results.

The TOPSIS spreadsheet contained three topics. These topics were selected because the TOPSIS analysis was needed to be able to reach consensus among the task force members for determining guidelines on these topics. The three topics evaluated by TOPSIS were risk management, penalty-tier threshold calculations, and incentives. For the first topic, risk management, four criteria and four alternatives were developed. Using the TOPSIS analysis, it was determined that the preferred alternative was to give exempt periods to the contractor to complete their work when the pre-construction analysis shows that there is not enough time with low levels of traffic. For the second topic, penalty-tier threshold calculations, four criteria along with three alternatives were developed. It was determined that the preferred alternative was to determine the travel-time tier thresholds by using a set time increase. The final topic, incentives, used four criteria, and four alternatives and it was determined that the preferred alternative was to use schedule-based incentives while at the same time making the mobility-based performance specifications optional to the contractor.

5 RECOMMENDED GUIDELINES

From the task force meetings and the TOPSIS analysis, the following 12 guidelines for implementing mobility-based performance specifications were developed. These guidelines should be taken into account when preparing mobility-based performance specifications for work-zone traffic management. Guidelines 1 to 9 were determined based on the discussion in the task force meetings. Guidelines 10, 11, and 12 resulted from the TOPSIS analysis.

1. Until enough experience is obtained using mobility-based performance specifications, their applications should be limited to projects where the main movements are free flow, such as freeways or rural highways. This will reduce the amount of movements to be tracked, as well as reduce the variation in travel time due to signals or other traffic control devices. Freeways will also remove many of the concerns that come from driveways in the construction zone.
2. In cases where there are numerous movements, only key movements should be monitored. These movements should be determined on a case-by-case basis before the bidding process, and all sensor spacing or location requirements provided by the sensor manufacturer should be followed. The locations of the sensors should remain intact throughout the duration of the project.
3. Travel time should be used as the mobility-based performance measure and should be collected for each 15-minute period throughout the duration of work.
4. UDOT will take the lead role in the analysis of the travel-time data, and weekly or biweekly meetings should be held between the contractor and the UDOT resident engineer on the project.

5. Incidents or other events, including traffic crashes, severe weather, and traffic detoured into the work zone from other work zones nearby, or events that affect the travel time in the construction zone that are outside the contractors' control and for which they should not be held responsible, should be recorded in a method acceptable to UDOT and the contractor. Some acceptable methods include video recording, consulting police records and phone calls to the resident engineer about the event. However, the method used should be determined on a case-by-case basis and agreed upon by UDOT and the contractor. The records should include, at minimum, the date of the event, the location, the beginning time, the duration of the event, the ending time, and the type of event.
6. A pre-bid meeting needs to be held before the bidding process begins. This meeting should be held early enough to give the contractor sufficient time to identify the amount of risk that they have to assume. The contractor would also need time to calculate additional costs added by mobility-based performance specifications. Any traffic analysis or pre-construction study information available should be distributed to the contractors.
7. A congestion correction period should be given to the contractor. The purpose of this correction period is to give the contractor adequate time to either set up or remove traffic control measures, as well as to fix a problem that is increasing the travel time. Thirty minutes is the recommended remediation period length, but this can be determined on a case-by-case basis. During this remediation period, penalties will not be assessed if the contractor contacts the UDOT resident engineer and is actively working to solve the problem. This remediation period might no longer be necessary after the contractor and UDOT gain more experience with the use of mobility-based performance specifications.
8. Before the construction work begins or right after the work zone has been set up, a travel-time study needs to be conducted to establish a baseline for the travel time in the work-zone. This penalty-tier threshold should take into account the effects of the reduced work zone speed limit that will be used during construction. From this study the threshold values of the penalty-tier levels will be calculated.

9. To ensure that the data obtained from sensors are accurate, a statistical test is required. For this test, the travel-time data from each 15-minute interval needs to be compared to the distribution of all the intervals to determine if the data point is within a 95 percent confidence interval. Outliers from the 95 percent confidence interval should be discarded to avoid the influence of extreme values in threshold value calculations.
10. To manage the risk between the contractor and UDOT, it is recommended that the contractor be given penalty-exempt periods. The time and duration of penalty-exempt periods should be determined using the results of the pre-construction analysis. If there is not enough time with low levels of traffic during which the construction work can take place, the contractor should be given enough penalty-exempt periods to ensure that the work can be completed.
11. To calculate the travel-time penalty-tier thresholds, a predetermined increased amount such as 5 minutes, should be added to the travel time that is determined in the traffic study conducted before the bidding process begins. This increase needs to be determined through experience with mobility-based performance specifications. Different types of construction work might require different predetermined increases.
12. An incentive is needed to help encourage the use of mobility-based performance specifications as they are often used or considered for use in determining penalties. These incentives should be schedule-based (i.e., if the project is finished early, then incentives should be given). The mobility-based performance specifications should also be available as an option for the project.

6 CONCLUSION AND RECOMMENDATIONS

Implementing mobility-based performance specifications to maintain traffic flow in work zones for highway construction has been shown to be feasible (Chau 2012). There is technology available to continuously monitor traffic conditions throughout a work zone. However, this is a new concept for managing traffic flow in work zones to minimize delays to the highway users as they drive through the work zones, and there are no clear guideline existing for developing and implementing such specifications. Therefore, this study was conducted to discuss issues of implementing such specifications between UDOT and contractors.

To meet the objective of the study, a literature review was first conducted on group decision-making methods and tools. These methods and tools were studied to help the task force members as they develop guidelines for implementing mobility-based performance specifications in highway construction contracts. Among the decision-making methods and tools evaluated, several methods and tools were identified and studied in depth to determine which could be used by the task force members. The multi-criteria decision-making methods evaluated included AHP, ELECTRE, and TOPSIS, as well as Value Engineering, which has been extensively used by many organizations. The two tools reviewed were Functional Performance Specifications and Gradients of Agreement. Out of the decision-making methods and tools reviewed, TOPSIS was considered most appropriate to help the task force members come to a group decision when the task force members' opinions were wide apart and seemed difficult to reconcile with typical meeting-style discussions.

After the literature review was completed, a task force was created to discuss issues with implementation of mobility-based performance specifications. Members of the task force were invited from both UDOT and the contractors. Members from UDOT included one individual from each of the regions and others from the TAC members for this study. To represent the contractors, members of the AGC were asked to participate. Four individuals from the AGC volunteered to join the task force. In addition to the members of the AGC, two engineers of JUB Engineers were also invited to participate in the task force. JUB Engineers was asked to participate because its engineers were involved in a project where mobility-based performance specifications were tested in the field and their experience was invaluable for the study.

Through a series of task force meetings and using the TOPSIS multi-criteria decision-making method, a set of 12 guidelines were developed. These guidelines are meant to be used to help write mobility-based performance specifications for future highway construction projects to manage traffic through work zones. During the course of the task force meeting, the members of the task force were asked to review the guidelines. The majority of the task force members accepted these guidelines, with only minor changes, which include guidelines 10, 11, and 12 where the TOPSIS analysis was used. With these guidelines developed, the purpose of the study was achieved.

Using the guidelines created through this project, mobility-based performance specifications should be tested on real-world projects. After testing mobility-based performance specifications, it is recommended that these guidelines be reviewed and updated. UDOT and the contractors should be consulted on any updates. The guidelines should also be reviewed as technology improves or other issues such as safety concerns arise.

REFERENCES

Behzadian, M., Otaghsara, S. K., Yazdani, M. and Ignatius, J. (2012). "A State-of the-Art Survey of TOPSIS Applications." Expert Systems with Applications, http://dx.doi.org/10.1016/j.eswa.2012.05.056 (August 2012).

Brans, J.P., and Vincke, P. (1985). "A Preference Ranking Organization Method: (The PROMETHEE Method for Multiple Criteria Decision-Making)." *Management Science*, 31, 647-656.

California Department of Transportation. (Caltrans). Division of Design Office of Special Projects. (2011). "Value Analysis Program Annual Report." V4, 1-12.

Figueira, J., Mousseau, V., and Roy, B. (2004). "ELECTRE Methods." *Multiple Criteria Decision Analysis*, 1, 1-35.

Garcia-Cascales, M. S., and Lamata, M. T. (2012). "On Rank Reversal and TOPSIS Method." *Mathematical and Computer Modelling*, 56, 123-132.

Hokkanen, J. and Salminen, P. (1997). "ELECTRE III and IV Decision Aids in an Environmental Problem." *Journal of Multi-Criteria Decision Analysis*, 6, 215-226.

Hwang, C. and Yoon, K. (1981). *Multiple Attribute Decision-making Methods and Applications A State-of-the-Art Survey*. Berlin: Springer-Verlag.

Kaner, S., Lind, L., Toldi, C., Fisk, S., and Berger, D. (2007). "Facilitator's Guide to Participatory Decision-making." John Wiley & Sons, Inc.

Lootsma, F. A., and Schuijt, H. (1997). "The Multiplicative AHP, SMART and ELECTRE in a Common Context." *Journal of Multi-Criteria Decision Analysis*, 6, 185-196.

Lotfi, F.H., Fallahnjad, R., and Navidi, N. (2011). "Ranking Efficient Units in DEA by Using TOPSIS Method." *Applied Mathematical Sciences*, Vol. 5, No. 17, 805-815.

Millet, I., and Saaty T. L. (2000). "On the Relativity of Relative Measures - Accommodating both Rank Preservation and Rank Reversals in the AHP." *European Journal of Operational Research*, 121, 205-212.

National Cooperative Highway Research Program. (NCHRP). (2005). "NCHRP SYNTHESIS 352 Value Engineering Applications in Transportation A Synthesis of Highway Practice." Washington, D. C.

Olson, D. L. (2004). "Comparison of Weights in TOPSIS Models." *Mathematical and Computer Modelling*, 40, 721-727.

Ontario Ministry of Transportation. (2006). "Functional Performance Specification." <http://www.mto.gov.on.ca/english/transtek/roadtalk/rt12-1/rt12-1.pdf> (August 28, 2012).

Opricovic, S., and Tzeng, G. (2004). "Compromise Solution by MCDM Methods: A Comparative Analysis of VIKOR and TOPSIS." *European Journal of Operational Research*, 156, 445-455.

Raj, P. A., and Kumar, D. N. (2013). "Ranking of River Basin Alternatives Using ELECTRE." *Hydrological Sciences Journal*, 41, 697-713.

Saaty, T. L. (1994). "How to Make a Decision: The Analytic Hierarchy Process." Institute for Operations Research and the Management Sciences, 24, 19-43.

Saaty, T. L. (2003). "Decision-making with the AHP: Why is the Principal Eigenvector Necessary." *European Journal of Operational Research*, 145, 85-91.

Saito, M., Schultz, G. G., and Chau, E. J. (2012). "Evaluating the Feasibility of Incorporating Mobility-Based Work Zone Traffic Control Performance Measures in Highway Construction Project Specifications." Utah Department of Transportation, Report No. UT-13.13a.

SAVE International. (2007). "Value Methodology Standard and Body of Knowledge." 2007 edition.

Triantaphyllou, E., and Mann, S. H. (1995). "Using the Analytic Hierarchy Process for Decision-making in Engineering Applications: Some Challenges." *International Journal of Industrial Engineering: Applications and Practice*, 2, 35-44.

Utah Department of Transportation (UDOT). (2012a). "Hot Mix Asphalt (HMA)." Section 02741, 1-17. http://www.udot.utah.gov/main/uconowner.gf?n=94557621849667574. (June 2013).

Utah Department of Transportation (UDOT). (2012b). "Manual of Instruction Value Engineering."

Vaidya, O. S., and Kumar, S. (2006). "Analytic Hierarchy Process: An Overview of Applications." *European Journal of Operational Research*, 169, 1-29.

Virginia Department of Transportation. (2012). "Value Engineering." <http://www.virginiadot.org/projects/VE-studies.asp/> (June 12, 2012).

Wang, S. (2006). "Comments on Operational Competitiveness Rating Analysis (ORCA)." *European Journal of Operational Research*, 169, 329-331.

Wang, X., and Triantaphyllou, E. (2008). "Ranking irregularities when evaluating alternatives by using some ELECTRE methods." *Omega*, 36, 45-63.

Zanakis, S. H., Solomon, A., Wishart, N., and Dublish, S. (1998). "Multi-attribute Decision-making: A Simulation Comparison of Select Methods." *European Journal of Operational Research*, 107, 507-529.

APPENDIX A. LIST OF ACRONYMS

AHP	Analytical Hierarchy Process
AGC	Association of General Contractors
BYU	Brigham Young University
Caltrans	California Department of Transportation
CI	Consistency Index
CR	Consistency Ratio
ELECTRE	Elimination and Choice Expressing Reality
FHWA	Federal Highway Administration
FPS	Function Performance Specification
HMA	Hot Mix Asphalt
MEW	Multiplicative Exponential Weighting
NCHRP	National Cooperative Highway Research Program
OCRA	Operational Competitiveness Rating Analysis
PROMETHEE	Preference Ranking Organization Method for Enrichment and Evaluation
SAW	Simple Additive Weighting
SMART	Simple Multi-Attribute Rating Technique
SUV	Sports Utility Vehicle
TAC	Technical Advisory Committee

TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UDOT	Utah Department of Transportation
VDOT	Virginia Department of Transportation
VIKORS	Multicriteria Optimization and Compromise Solution

APPENDIX B. TOPSIS SPREADSHEET

TOPSIS Worksheet

The TOPSIS method requires two different inputs from the user, criteria weights and alternative-criteria matrix values

The first input is the criteria weights, the values in the weight matrix can range from 0 to 1.00 and the total across the row should add up to 1.00
under each of the criteria place the value that you feel represents the importance of each criteria
For example if all four of the criteria under the Incentives topic are given a .25 weight then all the criteria would be considered equal

In the outlined cell for the Alternatives and Critiera tables below place a number from 1 to 7
Place that value that you feel accurately represents how each alternative relates to the criteria,
a brief description of each of the values 1 to 7 can be seen below:

1 - this alternative is the worst possible for this criteria
2 - the costs outweight the benefits for this criteria
3 - the costs slightly outweight the benefits for this criteria
4 - neutral or more discussion needed
5 - the benefits only slightly outweight the costs for this criteria
6 - the benefits outweight the costs for this criteria
7 - this alternative is the best possible for this criteria

The same rating can be given to more than one alternatives for each criteria

Three different topics and sets of criteria are listed below as well as some questions to consider while you give values to the criteria
Using the values obtained from each of the task force members the TOPSIS method will be used to analyze the alternatives

Example

Weight Matrix		
Criteria 1	Criteria 2	Criteria 3
0.35	0.15	0.5

Alternatives	Criteria		
	Criteria 1	Criteria 2	Criteria 3
Alternative 1	5	4	6
Alternative 2	2	6	3
Alternative 3	7	2	4

Risk Management

Alternatives

This topic will be used to help determine the guidelines for how specification should be written, the assumption is that time will be given for the contractor to do their work, such as a penalty exemption period, during which the mobility-based specification will not be used

Penalty exemption periods based on before study estimates - Exemption periods based on before study analysis, mobility-based specification will be used during all other periods
Penalty exemption periods - Exemption periods negotiated between contractor and UDOT, mobility-based specification will be used during all other periods
Mobility-based specification optional during off-peak - Give the contractor the option to use or not to use mobility-based performance specification during non-peak hours
Mobility-based specification optional - Give the contractor the option to use or not to use mobility-based performance specification for all hours

Criteria

Distribution of risk - Will both side of the project share in the risk and reward? (1 Not evenly distributed, 7 evenly distributed)
Innovation - Will this create an incentive for innovation in the project? (1 less innovation, 7 more innovation)
Amount of delay - Will this alternative help reduce delay for the public? (1 no reduction in delay, 7 large reduction)
Penalty exemption needs - Is the need for penalty exempt periods accurately determined by this alternative?
(1 need for exemption determined at random, 7 exemption will only be given when needed)

Weight Matrix				
Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
				(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates				
Penalty exemption periods				
Mobility-based specification optional during off-peak				
Mobility-based specification optional				

Tier Calculations

Alterntatives — Assumption is that different types of work will have different tier level calculations, and before study is completed

Percent increase of travel time -	Percent increase in travel time, using the speed limit reduction for the construction zone
Set travel time increase -	Travel time increase set for the different tier levels
Lower of percent increase and set travel time increase -	Percent increase of travel time unless it is greater than a set travel time increase

Criteria

Consistency -	Which alternative will give consistent results for all projects? (1 tier calcuations are random, 7 tier calcuations dependable)
Ease of calcuation -	Which alternative will be the easiest to calcuate? (1 Calculations diffcult/burdensome, 7 Calcuations as simple as possible)
Room for error -	Will it be high enough to have some room for errors and peak hour travel times?
	(1 before study errors cause penalties, 7 tier levels reach only when appropriate)
Maintain flow -	Will it be a low enough tier level to require the contractor to maintain a good traffic flow?
	(1 penalties never reached even during severe congestion, 7 tier levels reach only when appropriate)

Weight Matrix				
Consistency	Ease of Calculation	Room for Error	Maintain Flow	
				(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time				
Set travel time increase				
Lower of percent increase and set travel time increase				

Incentives

Alternatives — Assumption is that mobility-base specification is in the contract

Mobility-based incentive using percentage-	Use a percentage of time without a tier violation to give incentive
Mobility-based incentive -	Use the amount of time under an expected level of delay
Provide other types of incentives -	Use schedule-based incentives to give an incentive, perhaps increased schedule-based incentives
Make mobility-based specification optional -	Give the contractor option to use or not to use mobility-based performance specification given schedule-based incentives
No incentive alternative -	Use the mobility-based specification, no incentives added

Criteria

Cost -	How much will this alternative cost? (1 highest cost, 7 lowest cost)
Manpower -	How much time will be required for this alternative? (1 most manpower required, 7 least manpower required)
Distribution of Risk -	Will both side of the project share in the risk and reward? (1 risk poorly distributed, 7 risk well distributed)
Innovation -	Will this create an incentive for innovation in the project? (1 less innovation, 7 more innovation)

Weight Matrix				
Cost	Manpower	Distribution of Risk	Innovation	
				(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage				
Mobility-based incentive				
Rely on other types of incentives				
Make mobility-based specification optional				
Do nothing alternative				

APPENDIX C. TASK FORCE MEMBERS RESPONSES

C.1 Risk Management

Weight Matrix				
Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
0.3	0.3	0.2	0.2	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	2	2	2	2
Penalty exemption periods	3	4	1	2
Mobility-based specification optional during non-peak	3	4	2	1
Mobility-based specification optional	2	3	3	2

Weight Matrix				
Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
30	20	20	30	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	3	3	3	7
Penalty exemption periods	1	1	3	1
Mobility-based specification optional during non-peak	7	7	3	7
Mobility-based specification optional	7	7	2	7

Weight Matrix				
Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
0.1	0.6	0.2	0.1	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	6	4	4	6
Penalty exemption periods	6	4	4	6
Mobility-based specification optional during non-peak	6	4	3	6
Mobility-based specification optional	6	3	5	6

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	0.35	0.1	0.35	0.2	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	6	2	5	6
Penalty exemption periods	5	1	6	6
Mobility-based specification optional during non-peak	6	3	5	6
Mobility-based specification optional	6	4	3	3

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	25	25	25	25	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	3	4	4	4
Penalty exemption periods	5	6	6	5
Mobility-based specification optional during non-peak	4	6	6	6
Mobility-based specification optional	4	4	4	4

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	0.1	0.2	0.6	0.1	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	2	2	5	7
Penalty exemption periods	2	2	4	7
Mobility-based specification optional during non-peak	3	4	4	6
Mobility-based specification optional	3	3	3	1

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	0.4	0.1	0.4	0.1	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	6	6	7	6
Penalty exemption periods	4	4	2	7
Mobility-based specification optional during non-peak	7	6	6	6
Mobility-based specification optional	2	7	3	2

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	0.25	0.1	0.4	0.25	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	6	6	4	6
Penalty exemption periods	6	6	3	5
Mobility-based specification optional during non-peak	3	3	1	2
Mobility-based specification optional	5	3	1	2

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	0.25	0.2	0.3	0.25	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	5	3	6	4
Penalty exemption periods	6	5	6	5
Mobility-based specification optional during non-peak	3	4	5	5
Mobility-based specification optional	5	6	3	4

	Weight Matrix				
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need	
	0.5	0.3	0.1	0.1	(= 1.00)

Alternatives	Criteria			
	Distribution of Risk	Innovation	Amount of Delay	Exemption Need
Penalty exemption periods based on before study estimates	7	2	7	6
Penalty exemption periods	4	4	2	5
Mobility-based specification optional during non-peak	2	1	3	5
Mobility-based specification optional	1	1	1	5

C.2 Penalty Tier Calculations

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.2	0.2	0.2	0.4	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	2	2	2	4
Set travel time increase	2	2	2	4
Lower of percent increase and set travel time increase	1	3	2	4

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	25	25	25	25	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	7	5	3	5
Set travel time increase	3	6	4	3
Lower of percent increase and set travel time increase	1	1	1	5

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.3	0.2	0.2	0.3	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	3	5	6	6
Set travel time increase	6	6	6	6
Lower of percent increase and set travel time increase	5	3	3	6

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.4	0.1	0.1	0.4	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	6	2	5	4
Set travel time increase	6	2	5	6
Lower of percent increase and set travel time increase	6	2	5	5

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	25	20	25	30	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	5	5	5	5
Set travel time increase	4	4	4	4
Lower of percent increase and set travel time increase	4	4	4	4

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.25	0.1	0.15	0.5	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	4	6	6	5
Set travel time increase	6	7	6	6
Lower of percent increase and set travel time increase	4	5	6	5

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.1	0.2	0.2	0.5	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	6	6	6	5
Set travel time increase	7	7	5	6
Lower of percent increase and set travel time increase	5	5	7	7

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.1	0.2	0.3	0.4	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	4	4	4	5
Set travel time increase	4	7	5	6
Lower of percent increase and set travel time increase	6	4	5	6

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.25	0.25	0.25	0.25	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	6	6	4	5
Set travel time increase	6	6	4	6
Lower of percent increase and set travel time increase	5	6	4	6

	Weight Matrix				
	Consistency	Ease of Calculation	Room for Error	Maintain Flow	
	0.2	0.5	0.1	0.2	(= 1.00)

Alternatives	Criteria			
	Consistency	Ease of Calculation	Room for Error	Maintain Flow
Percent increase of travel time	7	7	6	6
Set travel time increase	7	7	6	6
Lower of percent increase and set travel time increase	7	7	5	5

C.3 Incentives

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.2	0.1	0.3	0.4	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	2	2	2	4
Mobility-based incentive	2	2	2	4
Provide other types of incentives	1	3	2	4
Make mobility-based specification optional	3	1	2	4

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	25	25	25	25	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	3	3	3	3
Mobility-based incentive	4	4	4	4
Provide other types of incentives	1	1	1	1
Make mobility-based specification optional	5	5	5	5

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.4	0.2	0.2	0.2	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	5	5	2	5
Mobility-based incentive	3	2	6	5
Provide other types of incentives	6	2	2	6
Make mobility-based specification optional	2	2	2	3

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.2	0.1	0.3	0.4	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	4	4	6	5
Mobility-based incentive	6	2	5	6
Provide other types of incentives	7	3	2	6
Make mobility-based specification optional	7	3	4	5

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	25	25	25	25	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	6	6	6	6
Mobility-based incentive	5	5	5	5
Provide other types of incentives	7	7	7	7
Make mobility-based specification optional	6	6	6	6

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.2	0.2	0.1	0.5	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	4	4	2	5
Mobility-based incentive	5	4	2	5
Provide other types of incentives	6	4	2	4
Make mobility-based specification optional	7	7	3	1

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.4	0.1	0.4	0.1	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	2	2	2	7
Mobility-based incentive	1	1	1	6
Provide other types of incentives	3	3	4	1
Make mobility-based specification optional	7	7	7	2

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.3	0.3	0.2	0.2	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	4	3	4	4
Mobility-based incentive	3	2	4	5
Provide other types of incentives	5	6	6	3
Make mobility-based specification optional	4	4	3	2

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.25	0.35	0.25	0.15	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	4	4	4	5
Mobility-based incentive	5	6	5	4
Provide other types of incentives	6	6	6	5
Make mobility-based specification optional	5	5	4	5

	Weight Matrix				
	Cost	Manpower	Distribution of Risk	Innovation	
	0.3	0.4	0.1	0.2	(= 1.00)

Alternatives	Criteria			
	Cost	Manpower	Distribution of Risk	Innovation
Mobility-based incentive using percentage	3	1	5	7
Mobility-based incentive	1	1	4	5
Provide other types of incentives	4	2	4	6
Make mobility-based specification optional	4	5	4	3