ASSESSMENT OF INTEGRITY OF REASONING IN LARGE-SCALE DECISION SYSTEMS:

APPLICATION TO PUBLIC TRANSIT INVESTMENT PROJECT EVALUATION

by

Sharat C. Mangalpally

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DEDICATION

To my mother and father

Sujatha and Ravinder

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ABSTRACT

This thesis presents an approach to measure the integrity of reasoning process of large-scale public projects, such as civil infrastructure projects, and public transportation projects. Decision-making in public projects requires careful examination of the magnitude of impacts, cost responsibilities and benefits enjoyed by various stakeholders. The analysis of public projects is characterized by uncertainty associated with the large number of interactions among the system variables, subjective nature of the goals and objectives that are often interrelated, and the presence of many consequences and concerns of different population groups. The proposed method captures the uncertainty in the reasoning process during the project planning.

A four-step analysis is proposed to deal with uncertainty. First, the system's objectives are defined and the variables related to each objective are identified. Second, the system is decomposed into smaller subsystems based on each objective. These subsystems are developed such that the variables are all connected in a logical sequence of cause-effect relationships that originate from the initial conditions and lead to the objectives of the overall project. Third, the logical validity of the subsystems is examined by a group of experts from different backgrounds by providing the strength of agreement for each causal relationship expressed as the confidence measure. Finally the confidence measures of the subsystems are aggregated and the overall confidence in the performance of an alternative in achieving the objectives is obtained.

The study applies the proposed method to evaluate a monorail project in the northern New Castle County of Delaware. The variables involved in the monorail project

were identified and the causal network was constructed. Each causal relationship was evaluated using confidence measures obtained by interviewing a group of experts. The overall strength of reasoning for achieving an objective is calculated through aggregation of confidence measures. Considering the interdependency of the objectives, the confidence measure of achieving set of all the objectives by a given alternative is computed.

The potential benefit of the proposed method is in the process of evaluating the transit alternatives as prescribed by the FTA (Federal Transit Administration) for the New Starts Projects. The method does not point to a specific alternative as a solution, instead, it provides a set of numbers that reflect the strength of reasoning about the achievement of the desired outcome by each alternative. This will help the decision makers understand the opinions of different cross sections of the people and assess the need for additional studies and restructuring the reasoning network. The proposed method hence enforces more integrity and objective evaluation in the project funding decision.

Chapter 1

INTRODUCTION

Decision-making is an integral part of ones daily life. Starting from the time when we decide to get up in the morning to the snooping noise of the alarm to the time when we hit the bed in the night thinking about the next day's plans to be accomplished, our day is filled with decisions of different scales.

The process of decision-making gets initiated when the decision maker perceives the necessity to change the working path of a system. The importance of these decisions depends on the significance attached to the outcomes of these decisions. In today's world it has become essential to design effective decision-making techniques for obtaining the best possible solution for a given system with a minimum margin of error for the expected consequences of the selected plan of action.

Decision-making is required at various levels of organization like individual, group, society, nation, and even at the global level. Its complexity depends on the intricacy of the system's structure and the nature of the information available. Information has become a priced possession in today's world. The process of obtaining the information and the cost attached to it has made it impossible to get all the information needed for the analysis of a system. We should be able to understand, analyze and predict the working of the system and make wise decisions with the limited amount of information available.

In this thesis an analysis approach for the decision-making of large-scale public systems under uncertainty is presented. One of the traits of the public projects is that procuring information is a difficult and expensive affair. The proposed method takes into account the main sources of uncertainty involved in the study of public projects. The methodology is illustrated by applying it to evaluate an alternative of a large-scale transit investment project in the northern New Castle County of the State of Delaware. The end result of the analysis is the confidence level of achieving the objectives of the project for a given alternative by taking into consideration the perspectives of all the stakeholders involved.

Chapter 2 contains the problem statement of the thesis and discusses the motivation behind this study. It explains the three main sources of uncertainty associated with the analysis of large-scale public projects and identifies the characteristics of the analysis method to be adopted for dealing with these uncertainties.

Chapter 3 deals with the main features of the systems analysis and about the uncertainty involved in the analysis of the systems. It gives an overview of the general approach adopted in the analysis of large systems. It also delves on the nature of evidence and uncertainty, sources of uncertainty, and the different frameworks involved in dealing with this uncertainty. The chapter also explains about the confidence measure used in this study.

Chapter 4 presents the methodology of the proposed decision-making paradigm for the analysis of large-scale public systems under uncertainty. It gives an overview of decision-making paradigms under uncertainty and explains in detail about the four main steps involved in the approach. It also delves on the need for looking at such an approach.

Chapter 5 contains a discussion on the different levels of aggregation that form an important part of the whole analysis. The mathematical formulation for execution of each type of the aggregation is presented.

Chapter 6 contains discussion about the issues involved in the decision-making in transportation particularly in the analysis of transit investment projects. It also discusses about the approach followed by FTA in the decision-making of transit projects.

Chapter 7 presents the step-by-step explanation of the proposed method of analysis for the example application of the transit scenario in Delaware. The methodology for evaluating the monorail alternative to meet the transit objectives in the region is discussed. The interpretation of the findings from the analysis is also presented.

Chapter 8 discusses the advantages, and applications of the proposed method of analysis and some points to consider while implementing the method for evaluation of an alternative. It also consists of the interpretation of the values obtained from the proposed analysis.

Chapter 9 presents a summary of the complete study, and the conclusions.

Chapter 2

PROBLEM STATEMENT AND MOTIVATION

Large-scale systems are primarily characterized by a large number of components and the analysis of these systems involves study of the large number of interactions between these components. Large-scale public investment projects are a special category of systems, wherein the complexity in the analysis is more due to the diverse set of opinions about the functioning of the system as well as the structure of the system.

Investment decision of large-scale transportation projects has often met with some kind of discontent among the different sections of the stakeholders. It is difficult to reach a consensus with respect to the goals, and expected outcome of such projects. This can be attributed to the fact that government policies and decisions affect a wide spectrum of people with a diverse set of benefits and concerns, which are often conflicting.

The decision process in transit investment projects cannot be replaced by a purely technical evaluation scheme. The decision process is not straightforward, and it involves subjective and perceptive elements like values, goals, and satisfaction levels. Thus, these projects cannot be simulated by an objective evaluation procedure.

It is important to study the basic features common to the large-scale public investment projects in order to come up with an efficient decision making model. There are three basic features of such large-scale social systems.

The first feature is the intricate network of interactions among the large number of components in the system. These interactions are both direct and indirect in nature in terms of affecting the working of the system. Direct interactions are easy to comprehend and analyze but the indirect interactions are difficult to visualize. It can be tedious and complicated to estimate the relationship between different components and to assess the impacts of such interactions on the overall outcome of the system.

A second feature is the difficulty in defining the objectives of such public investment projects, as they might not be quantifiable. Also, there may not be a unique satisfactory level of achieving these objectives because of the varied interests of the people targeted by the public projects and thus, the desired outcome of these projects cannot be defined clearly.

A third feature of such projects is the difference in the perspectives of the analysts about the working and the desired outcome of the project. Since all the stakeholders involved in such projects can be counted as analysts, there is bound to be some kind of differences in understanding the system as well as the expectations from the system.

All these three features have an element of uncertainty involved in them. This uncertainty represents either lack of information or the lack of clarity of information about the issues related to each feature. The analysis of such large-scale systems is completely based on the information available and hence uncertainty forms a vital element in the decision-making process. Decision making of such projects should incorporate all the three sources of uncertainty mentioned above.

The need for such decision-making techniques for large-scale public investment projects is the main motivation for this thesis. In particular the aim of this thesis is to present the methodology for evaluating the alternatives of large-scale transit investment projects by incorporating the inherent nature of uncertainty involved in the analysis of such projects.

The problem to be discussed in the thesis comes under both multi criteria decision-making as well as decision making under uncertainty. The proposed decision making process should incorporate the following attributes:

- Decomposition of the system into subsystems such that it is easier to analyze the smaller subsystems under uncertainty instead of analyzing the entire system. These subsystems should be again combined in an appropriate manner to be consistent with the initial working nature of the large-scale system.
- The criteria used for judging the performance of the large-scale system must be considered in the analysis process in a qualitative manner, rather than a quantitative manner, which would reflect the significance of these criteria in choosing a given alternative in a much better way.
- The attitudes of the different analysts should be taken into consideration for presenting the best possible level of compromise among the conflicting opinions about the desired outcome of the large-scale system.

Chapter 3

ANALYSIS OF THE SYSTEMS UNDER UNCERTAINTY

Uncertainty is an important element to be considered in the analysis of large-scale systems. This chapter focuses on the aspect of uncertainty in the analysis process and has two main parts. The first part deals with the features of the systems analysis in general and the second part deals with the uncertainty involved in the analysis of the systems. The first part gives an overview of systems, and the characteristics of the large-scale systems. A general approach adopted in the analysis of such large systems is also discussed here.

The second part is divided into three sections. The first section delves on the nature of evidence and uncertainty, and discusses about the sources of uncertainty. The second section is about the different frameworks and measures involved in dealing with uncertainty. The third section explains the measure adopted in this study; namely the confidence measure and the formulation of attitude of the analyst using the confidence measure.

3.1 Systems Analysis

Systems and systems analysis are a ubiquitous terms in the field of science and technology. The analysis of systems is aimed at understanding the phenomenon and the process behind the working of any system such that the future course of action of the system is predicted. There are wide variety of systems and different procedures for analyzing these systems. The developments in simulating complex scenarios and strategies have reduced the margin of error in the prediction of systems' outcome and its performance.

3.1.1 Systems

The definition of system as provided by the Oxford Dictionary is the following: "A set or assemblage of things connected, associated, or interdependent, so as to form a complex unity; a whole composed of parts in orderly arrangement according to some scheme or plan; rarely applied to a simple or small assemblage of things". To give the gist of this definition, a system can be considered to be a systematic collection of a group of things, or activities that have a common goal or function to be accomplished. From the Latin and Greek, the term "system" is meant to combine, to set up, or to place together. Some of the well-known examples of the system are Solar System, Human System, Roman Numerals System, Intelligent Transportation System, Operation and Management System, etc.

3.1.2: Large Scale Systems

Perincherry (1994) states that the most important features of a large-scale system are:(1) a large number of components and interactions and (2) significant impacts of the indirect effects. The presence of large number of interactions and components and the multiple effects that they have on the system on the whole, lead to significant indirect effects. The indirect nature of these effects makes it difficult to study and analyze when compared to the direct effects.

To facilitate the analysis of such large-scale systems, two main attributes should be incorporated in the analysis methods. First the system should be divided into smaller subsystems, and these subsystems should be analyzed individually. This would ensure that the large number of interactions are studied and understood effectively. The second attribute of the analysis method is that the indirect effects should be modeled implicitly. This would ensure that the indirect effects are represented well in the whole analysis process.

In the present study more emphasis will be laid on the large-scale public investment projects as the large-scale systems. These projects are characterized by the presence of multiple objectives, which are mostly conflicting in nature, and a wide section of stakeholders to be satisfied with the outcome apart from the large number of interactions.

3.1.3 General Methodology of Systems Analysis

There are many different decision-making paradigms for large-scale systems analysis. Among these, multiobjective decision-making process is the most relevant procedure for the public projects. Multiobjective decision-making process has been extensively studied. The decision making process begins when the analyst perceives a need for change in the course of the system. The situation is then diagnosed and the overall needs of the system are determined to attain the satisfactory level from the existing situation. The nest steps are defining the problem statement, establishing the goals and objectives of the system to be attained, and specifying the elements of the system and its environment.

Once the system, the problem, and the goals of the system are determined the next step is to select an appropriate model for the analysis of the system. The model should facilitate effective, meaningful, and comprehensive analysis of the system to achieve the desired goals. A set of alternatives is then generated which are evaluated by obtaining the values of performance indicators or attributes for each objective. These attributes signify the value of attainment of a particular objective by the alternative.

Based on the values of the attributes, the alternatives are ranked using a predetermined decision rule. The alternative with the highest rank is then chosen for implementation. The whole process of decision-making has been well explained and depicted in the form of a flow chart by Chankong and Haimes (1983).

3.2 Uncertainty in Systems Analysis

Analysis of a system is done based on the information available to the analyst and information is always related to uncertainty. Thus, uncertainty is an integral part of any systems analysis. The degree of uncertainty can be reduced by obtaining more information but the process of gathering information may not always be affordable. Instead it is recommended to establish appropriate procedures that can account for uncertainty in the analysis process. In order to understand the analysis of systems under uncertainty we have to first study uncertainty. The following sections intend to shed some light on the well-discussed topic of uncertainty and in particular its presence in systems analysis.

3.2.1 Uncertainty and Available Evidence

Information can be treated as the entire body of evidence present in the system, and with information comes uncertainty. Uncertainty can be looked upon in terms of the evidence available. Based on the evidence available, uncertainty can be classified into three types. Perincherry (1994) presented the graphical interpretation of these three types of evidence. The three types of uncertainty with respect to evidence available are uncertainty due to:

a) Conflicting evidence
b) Overlapping evidence
c) Nested evidence

Conflicting evidence: In this category, each piece of evidence points to only one alternative. The different pieces of evidence are in conflict with each other in determining which one is correct.

Overlapping evidence: In this category, each piece of evidence supports more than one alternative as the evidence pieces overlap each other. It can be treated as a mixture of two extreme sets namely conflicting set and nested set of evidences, with conflicting evidence being the scenario with minimum level of overlapping.

Nested evidence: In this category, all the evidence point to nested subsets. It is a special case of overlapping evidence when the overlapping occurs only in nested sets.

3.2.2 Sources and Effects of Uncertainty

The main sources of uncertainty in the analysis of a system are:

1. The system interface with the external world
2. The subject system structure
3. The analysis criteria

These sources contribute to the uncertainty because of the three different kind of interactions that occur in a system. These are: 1) interaction within the subject system, 2) interaction between the system and the outside world, and 3) the interaction between analyst and the system. Figure 3.2 shows these three interactions involved the functioning of a system.

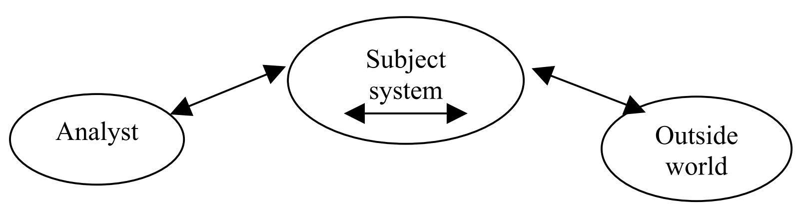


Figure 3.1 Sources of Uncertainty

Uncertainty due to system interface with the outside world: This uncertainty is mainly due to the inputs into the system from outside world and the outputs from the system into the outside world. To be more precise the uncertainty is caused due to the randomness or subjective nature of the input/output variables. For example if the variable follows a normal distribution or cannot be defined in crisp boundary sets, then input/output vector would carry some uncertainty associated with it.

Uncertainty due to the structure of the system: The perception of an analyst towards the cause-effect relationship existing among the system variables cause the uncertainty associated with the structure of the system. The relationship is expressed in terms of a function and a set of parameters related to the structure of the system. The parameters estimated may not be clearly known, and the type of observations used in the estimation affect the overall function. Both of them might add to the uncertainty.

Uncertainty in the Analysis criteria: The criterion for analysis usually reflects the objective of the working of the system, which may not be always perceived clearly. Take the example wherein according to the law of diminishing marginal utility, beyond a certain limit though profit would increase but the marginal increase in profit would decrease, hence the value for the increase in profit is lost. Hence maximizing the profit alone might not be the right objective. In addition to the vagueness in the objective, there also exists difference in the interpretation of the criteria caused due to the difference in the individual attitudes.

The effects of uncertainty in the analysis of the systems can be seen in two main areas:

1. Performance of the analyst and
2. Performance of the system

Both the effects lead to decrease in the level of performance. While the former is described as anxiety, the latter is described as risk. The effects of uncertainty on the analysis of the system are shown in Figure 3.2.

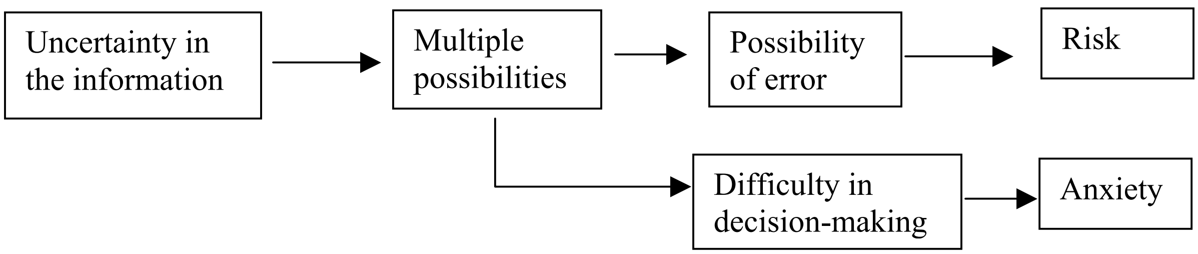


Figure 3.2 Effects of uncertainty on the analysis of systems. Perincherry (1994, pp 88)

Anxiety occurs when the analyst perceives more than one alternate decision and is not able to decide on any one particular one. It often prompts him/her to postpone the actions causing a decrease in the efficiency of the performance. Yager and Kikuchi (2004) have used an anxiety-based model for analyzing the decision-making in a traveler. Risk, on the other hand, describes the chance of failure in the system. It is the analyst's perception of risk that causes anxiety, rather than the actual risk.

3.2.3 Mathematical Frameworks to Represent Uncertainty

There are three main frameworks that are important: Probability theory, Possibility theory, and Evidence theory, which come under the broader classification of the framework of general theory of fuzzy measures. Apart from this, there are two other broad frameworks fuzzy set theory, and certainty theory. These two are different from the general theory of measures and do not satisfy many necessary axioms. Klir and Folger (1987) have presented a detailed study about these three measures and their functions.

Probability theory: The exact meaning or the implications of probability measure is strongly influenced by the viewpoint one takes between the two classes namely frequentist or subjectivist. While the former interprets the probability measure as the frequency of occurrence of an event, the latter interprets it as the degree of belief in the truth of proposition regarding an event. The field of Bayesian reasoning is a product of the school of thought based on the subjective interpretation of the probability measure.

Possibility theory: This concept originated from the concept of fuzzy sets proposed by Zadeh. It is today treated more as the extreme case of evidence theory, where in the elements are nested in nature. The two measures of this framework are possibility and necessity, which can be interpreted as the optimistic and pessimistic view of looking at the evidence available respectively.

Evidence theory: This concept is the fine thread that joins the above two theories because both these theories are in fact the extreme cases of evidence theory. The two measures of this theory are belief and plausibility. Belief is derived from the part of the body of evidence that supports the hypothesis in question whereas plausibility is the part that does not reject the hypothesis. In fact possibility and necessity can be assumed as the exact replicas of plausibility and belief with the only difference being that they refer to nested sets, which is not the case for the belief and plausibility measures.

Figure 3.3 summarizes the inclusion relationship between the three fuzzy measures. The two large classes shown in the figure are Belief and Plausibility measures. Together they form a theory that is usually referred to as the mathematical theory of evidence. When the focal elements are all singletons then the belief and plausibility are of the same value. This merging of belief and plausibility measures as shown in the figure produces the probability measures. Each probability measure can be uniquely represented by a function called as the probability distribution function defined on certain elements of the universal set. Possibility and Necessity measures are a special sub class obtained from the nested type focal elements. These measures can be uniquely characterized by a function defined on the universal set.

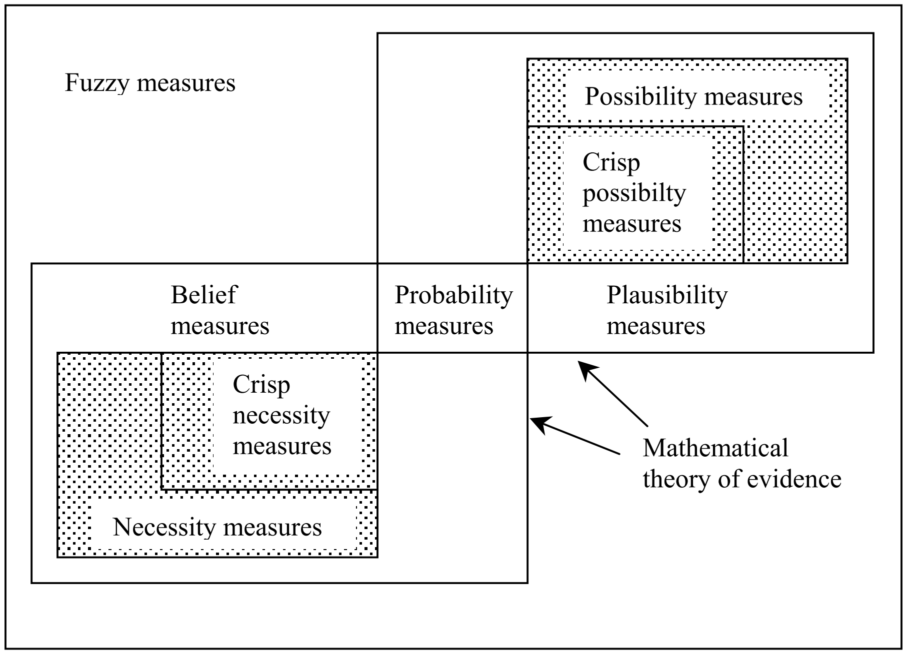


Figure 3.3 Fuzzy measures. (Reproduced from Klir and Folger (1987), pp 130)

When the possibility and necessity measures are of value 0 or 1, then they are called as crisp possibility and necessity measures. These measures reflect complete lack of information, total truth, or total falsity of the proposition, which have been explained briefly in section 3.2.4.1. The crisp possibility and necessity measures form a subset of the bigger set of possibility measure and necessity measures. The possibility, necessity, and probability overlap only along the border of these respective measures, which means that there is just one focal element and that too a singleton. This one element will have a value of 1 for all the three measures. This represents a perfect evidence scenario.

The measures probability, possibility, necessity, belief and plausibility are all the mathematical measures to represent uncertainty of a proposition. In addition to these, we will need measures for the analysis of systems under uncertainty. Perincherry (1994) has summarized the different measures that have been used for analysis of systems under uncertainty. Among these the prominent measures are Hartley measure, Shannon Entropy measure, U-Uncertainty measure and Dissonance and Confusion measures.

3.2.4 Confidence Measure.

The measure used in the analysis of this study is confidence measure. It was proposed by Perincherry (1994). The confidence measure is based on the possibility and necessity measures.

3.2.4.1 Formulation of the Measure:

If the truth of a proposition is mapped within the interval $\tau \rightarrow [0,1]$, the net truth of a proposition "*p*" can be defined as $\tau\ (p) = \tau\ (p) - \tau\ (\textit{not } p)$, which can be called as the level of confidence in the proposition.

Hence the level of confidence is mapped within the interval $C \rightarrow [-1,1]$. Now, under the possibility framework of looking at the uncertainty in a system the following three would hold:

Poss (p) = 1 and Nec (p) = 0, represents absolute lack of information

Poss (p) = 1 and Nec (p) = 1, represents complete truth of the proposition

$\Rightarrow$ Full confidence

Poss (p) = 0 and Nec (p) = 0, represents complete falsity of the information.

$\Rightarrow$ No confidence

Note: Lack of truth need not mean falsity; in fact it just points to lack of evidence pointing toward the truth. Hence lack of information is different from a proposition being false.

According to the above three observations, the confidence can defined as:

$$C(p) = Poss(p) - Poss(not\ p) = Poss(p) + Nec(p) - 1 \quad (3.1)$$

The positive values of c indicate the degree of confirmation of the proposition p by the evidence and the negative values indicate the degree of rejection of p by the evidence.

In the probability framework of analysis, the equation would be

$$C(p) = Prob(p) - Prob(not\ p) = 2 * Prob(p) - 1 \quad (3.2)$$

3.2.4.2 Confidence as a Measure of Uncertainty:

Since uncertainty and confidence have opposite trends, the relative elasticity of confidence with respect to uncertainty is negative.

$$(dC/C) / (dU/U) < 0 \quad (3.3)$$

The basic principle behind this equation is that the increase or decrease in confidence would result in change in the opposite direction in uncertainty. This relative elasticity is however is not constant over the range of information. The information received under ignorance or high uncertainty will significantly affect the confidence level whereas the information received when completely confident (less uncertainty) is likely to be redundant. Thus,

$$(dC/C) / (dU/U) = -f(U) \quad (3.4)$$

The above equation shows that at very less information (large uncertainty) even a small amount of information can increase the confidence level significantly, but when there is little uncertainty (already lot of information available), then the change in the confidence level would not be that high comparatively.

Assuming C=1, when U=0 (completely confident scenario), it can be shown that after integration the final equation for expressing the relationship between uncertainty and confidence is:

$$U = \log(1/C) \tag{3.5}$$

3.2.5 Attitude of the Analyst

Different analysts perceive a same given piece of evidence in different manner. Depending on a person's character the confidence for a proposition will be higher or lower than the confidence as provided by the evidence. The bias in the opinion is assumed to be an addition of a value to the fairly evaluated confidence level.

Perincherry (1994) has come up with an equation for representing the attitude of the analyst. For an analyst X who is optimistic in nature the confidence expressed by him will be given by

$$C^{(X)} = C + \Delta C^{(X)} \tag{3.6}$$

where $C^{(X)}$ is the confidence level expressed by the analyst, C is the level of confidence provided by the evidence, and $\Delta C^{(X)}$ is the effect of optimism on confidence. The value of the effect of optimism has been proved to be equal to $\alpha^{(X)}(1\text{-}C)$ where α is the constant of proportionality and is referred as the attitude factor. This value will be unique for each analyst. $\alpha^{(X)}$ represents the confidence experienced by the analyst when there is no evidence. This value gives the level of bias showed by the analyst. Thus the final expression for analyst X is given by,

$$C^{(X)} = C + \alpha^{(X)}(1-C) \tag{3.7}$$

In a similar fashion the level of confidence expressed by an analyst Y who is pessimistic in nature is given by

$$C^{(Y)} = C + \alpha^{(Y)}(1 + C) \tag{3.8}$$

Chapter 4

SYSTEMS ANALYSIS

This chapter presents the proposed methodology for the analysis of large-scale public systems under uncertainty. A brief overview of the two widely discussed decision making paradigms: decision making under uncertainty and multi criteria decision-making are presented at the beginning. Then the approach to be adopted in the proposed systems analysis is explained in four steps. The last section of the chapter delves on the need for looking at such an approach.

4.1 Multi-Criteria Decision Making under Uncertainty

Multiple criteria decision making (MCDM) was first introduced in the early 1970's. Since then there have been many variations on the theme of MCDM depending on the theoretical basis used for modeling. Some of the prominent theoretical approaches to have been originated from the MCDM paradigm are multiple attribute utility theory (MAUT) and multiple objective linear programming (MOLP). The basic idea behind all these paradigms is that the alternatives of the system have to be evaluated based on a given set of diverse conditions or requirements.

The terms MCDM and Multiobjective decision-making are often used interchangeably. Criteria refer to standards by which a given system can be judged and objective is the desired outcome of the system. In terms of formulation the former can be considered as constraints and the latter as goals. In the case of public systems these two terms are often defined interchangeably between different stakeholders. The goals of one group of people might act as the constraints of the other. For the study of this thesis considering any one of the two decision-making procedures is acceptable and hereafter the term MCDM will be used to refer to the decision-making paradigm relevant to this study.

Stewart (1992) has done a critical survey of the available MCDM methods and has outlined three main issues of focus for further research. These are: (1) the empherical validation of the approaches, (2) extension of the methods for group decision making with value-conflicts between the group members, and (3) the treatment of uncertainty. The last two issues clearly suggest that MCDM needs to take off in a new direction to meet the demands of decision-making.

Many decisions in our daily lives depend on meeting the constraints or goals by a certain perceived level and not the exact value. As a result more emphasis is being laid on the decision-making procedures that can deal with such ambiguity in defining the criteria in the analysis process. In the last few years there has been considerable amount of interest shown towards a new branch of decision-making paradigms that can deal with the uncertainty in defining the objectives, as well as other sources of uncertainty inherent in the decision process of large systems.

Bellman and Zadeh (1970) introduced the fuzzy sets, which resulted in the development of a new set of methods known as Fuzzy Multicriteria Decision Making (FMCDM) to deal with the problems that were unsolvable with the standard MCDM techniques. Carlsson and Fuller (1996) give a good summary of the different approaches in FMCDM paradigm that have come up over the last few decades. The main reason for this interest is the ability of fuzzy measures to represent the satisfaction of a performance in terms of a set rather than a single number. FMCDM defines the performance indicators of the alternatives as well as the weights of the criteria in the form of a fuzzy set, rather than a crisp number, which cannot be accomplished in the traditional approaches of performance evaluation.

The methodology proposed in this thesis aims at addressing the issue of decision-making in public systems under uncertainty by using the fuzzy measures and in particular the confidence measure. The basic premise of the analysis technique is that the proposed method is used to obtain the logical strength of accomplishing the desired function of the given system. This kind of analysis is different from the usual techniques by the fact that the result of the whole analysis process is the strength of achieving a certain outcome through the implementation of a given course of action or alternative as perceived by an analyst based on the information available. The quality of information and the nature of the analyst have a major level of influence on the final solution obtained in the analysis process. The following four sections outline the four steps involved in this analysis procedure.

4.2 Description of the System

As discussed in the previous chapter, the main feature of any large-scale system is the large number of components and the interactions between these components. In order to analyze such systems it is necessary to first understand the working of the system. System being a collection of many units that have a common function to be achieved, understanding a system’s working is to study the variables of the system and understand the function of these units working together.

Lewis Carroll (1936) in his famous book, Alice in Wonderland makes a very strong point about the importance of objectives. "One day Alice came to a fork in the road and saw a Cheshire cat in a tree. "Which road do I take?" she asked. "Where do you want to go?" was his response. "I don't know," Alice answered. "Then," said the cat, "it doesn't matter." The essence of this short piece of conversation is that if the objective behind a decision is not known then there is no point in making the decision. In the same vein, for studying the large-scale public investment projects as systems, the overall goals or objectives of the project have to be identified first.

A project is a temporary endeavor undertaken to create a unique product or service. A public project is especially aimed at serving a specific set of demands and needs of the public. The identification of objectives of a project is very crucial to the systems analysis. Most of these projects are initiated by the political bodies of the government who also determine the objectives of such project. An appropriate manner of deciding the objectives is by consulting different interest groups like users, community, and the operators in the case of transportation investment projects.

Once the objectives of the project have been identified the variables that represent each goal or objective have to be identified. A careful examination of the related literature and discussions with the decision makers and the stakeholders are other possible methods. In this manner, the function of the system as well as the components of the system is obtained. This would culminate the process of defining a large-scale public investment project as a system.

4.3 Decomposition of the System

In order to study a large system, it is necessary to divide it into smaller subsystems. Each subsystem would be much easier to manage and analyze when compared to the whole system in general. After studying the individual subsystems the results can be combined to obtain the overall result for the system. This concept of analyzing the system can be seen in the organizational structure of many systems. Some of the examples are: the government administrative structure, a typical company organizational system, the education system etc.

The process of dividing a large system into smaller subsystems is called decomposition. Decomposition must follow a basic principle which states that the subsystems generated by the process should be as much mutually exclusive as possible. This means that the relationship between any two subsystems must be minimal. This principle follows from the fact that if the subsystems have to analyzed independently then it is better to have independent subsystems.

Figure 4.1 shows the two types of interactions that exist in a system after decomposition. These are the inter subsystem interactions and the intra subsystem interactions.

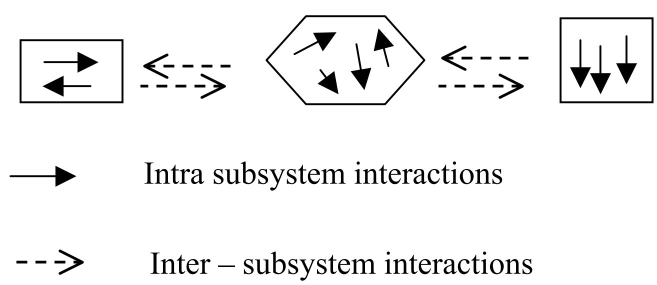


Figure 4.1 Two types of interactions in a system

Following the principle of decomposition, the number of inter subsystems should be as less as possible. One good way of achieving this is to separate the interactions between the variables related to each objective.

Thus, after obtaining the variables related to each objective of the system in the first step of system description, a hierarchical structure consisting of the interactions between the various variables is developed for each objective identified. The variables that influence each objective are listed in the form of a logical chain of reasoning. This is done by representing the interactions related to an objective in the form of a network of cause effect relationships. These causal relationships originate from a fundamental variable(s) and lead all the way to the system's objective. For public projects the fundamental variable can be the implementation of an alternative under a given set of initial conditions. It can be seen that any system will have certain cause-effect relationships that define the function of the system. Allen (2001) in his critically acclaimed book As a Man Thinketh had said that "…cause and effect are as absolute and undeviating in the hidden realm of thought as in the world of visible and material things".

4.4 Analyzing each small subsystem

In this step, the subsystems generated in the last step are analyzed independently for each objective. It should be noted that decomposition of the system based on the objectives is not the only way of determining the subsystems. However in this work, the objective based division is explained. As stated before the aim of this method of analysis is to obtain the logical strength that the given public project achieves the goals and objectives that have been stated in the initial step. The aim of the analysis of the subsystems should also be consistent with that of the system.

In order to obtain the strength of agreement or disagreement for a given cause effect relationship, the opinion of an analyst who is capable of using the available information to the best possible level is sought. The idea behind approaching an analyst for opinion is that the process of analyzing each interaction is done by the analyst rather than by a mathematical model. This kind of analysis has a special advantage in the case of large-scale public projects because the public opinion is being considered in the evaluation process and not just the initial stages of planning and development and hence it adds credibility to the decision-making process.

Many times it is seen that the public do not have any significant role to play in the evaluation of the alternatives, and their opinion is taken into account either in the beginning stages of the project or in the final stages of the project. Even when the public opinion is sought, the people who have a better knowledge about the whole system are neglected in the planning and development process. One main reason for this is because of the lack of suitable measures to gather, organize the information, and evaluate the responses of the interest groups.

In the proposed methodology, each analyst evaluating the cause-effect relationships of the system is asked to provide the strength of their agreement for each causal relation. This is done by rating the relation by giving a number that signifies the strength of agreement in the relation measured by the confidence value. The cause effect relations can be all in the affirmative sequence or open-ended sequences. The former scenario requires a rating for the positive side of the confidence alone and the latter scenario requires rating on both the sides of the confidence value. Depending on the method adopted for the scenario, the cause-effect relationship hierarchy has to be devised. A more detailed explanation for this is provided in Chapter 6.

The outcome of this step would be a series of numbers representing the confidence measure corresponding to each interaction within a given objective. The next step would be to combine these confidence measures by keeping in mind the nature of the analyst to obtain the logical strength of achieving each objective. This will lead to the confidence in the implementation of a given alternative for achieving the desired purpose of the system or project.

4.5 Aggregation

Aggregation is the process of combining the results from the independent study of the smaller subsystems to obtain a result about the overall system. The process should be done such that it is consistent with the original system. Consistency here refers to the preservation of uncertainty and information associated with the analysis of the subsystems. If there is any addition or reduction in the uncertainty during the process of aggregation then it implies that some amount of information had been lost or gained correspondingly. Thus by maintaining the total amount of uncertainty throughout the process, we can avoid misinterpretation of the results by accepting or missing unwanted information, which is the main idea behind the principle of aggregation.

The essence of aggregation is the combination of the confidence levels by keeping the level of uncertainty intact. There are two kinds of structures that are possible with respect to the chain of causal relationships: sequential and parallel. Perincherry (1994) derived the methodology for both these aggregations. The following equation shows the aggregation of uncertainty for sequential series of subsystems.

$$\begin{aligned} U(O|I) &= U(I) + U(O_1|I) + U(O_2|O_1) + \ldots + U(O|O_{n-1}) \\ &= U(I) + \sum_i^n U(O_i \mid O_{i-1}) \end{aligned} \tag{4.1}$$

where U (O|I) represents the uncertainty associated with the output O based on the knowledge imparted by input I, U (I) is the uncertainty with respect to the input I, and U (Oi) represents the uncertainty with respect to the output Oi from subsystem i. From section 3.2.4.2, uncertainty can be expressed in terms of confidence measure as U = log (1/C). Thus (**) can be rewritten as

$$C(O|I) = C(I) * \prod_i C(O_i \mid O_{i-1}) \tag{4.2}$$

The expression shows that the confidence level of an overall system constituting a sequential order of subsystems is less than the confidence level of the individual subsystems. A simple version of the expression for the confidence level of the system R obtained by combining the two subsystems P and Q in sequential order is:

$$C(R|P) = C(R|Q)\ C(Q|P) \quad (4.3)$$

Figure 4.2 illustrates a simple system consisting of two subsystems in sequential order.

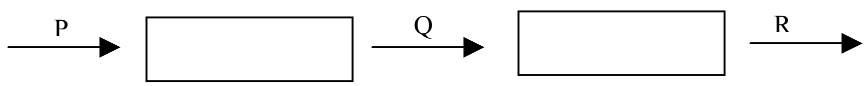


Figure 4.2 Subsystems in sequential order

In a similar fashion the equation for the aggregation of parallel subsystems is given by:

$$C(R|P, Q) = C(R|P) + C(R|Q) - C(R|P)\ C(R|Q) \quad (4.4)$$

where P and Q are two parallel inputs. The equation does not depend on any order of considering the subsystems for the aggregation. Figure 4.3 shows a simple system with two subsystems in parallel order.

Figure 4.3 Subsystems in parallel order

Once the casual relations in the hierarchical form under each objective are all combined, the overall confidence level for each objective is obtained. Thus we have a value that represents the logical strength of achieving a given objective by the implementation of an alternative as presented by the opinions of an analyst. The analysis process can stop after determining similar such values for a few more analysts. However, the varying attitude of the analysts and the respective importance given to their opinion can be incorporated in the analysis process through different methods of aggregation at various levels. These levels of aggregation can be combining the opinions across the different experts within a group, and then among the groups and finally even the objectives of the system. A more detailed explanation of these aggregations is provided in Chapter 5.

4.6 Need for such an approach

Decision-making is influenced by a crucial input called information. Acquiring information can be a very costly and daunting task and on top of it ensuring the wide reach of this information among all the key players in the decision-making is another massive effort to be accomplished. Under such circumstances, it becomes inevitable to deal with quality of information more than the quantity of information or in other words effectively manage the uncertainty involved in the decision making process for coming up with a solution with maximum backing from all the people concerned with the public projects.

Gardner (1996) studied the decision-making process of large-scale investment projects with a particular case of mass transit projects. The author believes that one of the main reasons for the differences between the funding agencies of the transport infrastructure and the beneficiaries might be because of the evaluation process. The author acknowledges that lack of information is detrimental to making good decisions and the quality of decision is based on the quality of information available.

The proposed method is based on the assumption that uncertainty is the demand for additional information and can be derived from the possibility and necessity values related to a given proposition. This kind of treatment of uncertainty is ideal for evaluation of alternatives of a large-scale investment projects as it captures the uncertainty involved in the analysis process very well and also it analyzes the values of confidence of small subsystems of the large-scale system and then aggregates these values to assess the overall strength of the argument, which makes it easier to apply.

This method has been applied for the problem of determining the capacity of a plant in terms of number of orders by Kikuchi and Perincherry (2004). In a more relevant application of the proposed paradigm of decision-making, Perincherry and Kikuchi (1997) devised a planning model for large-scale infrastructure systems for justifying the investment in Intelligent Transportation Systems (ITS) using this method. Perincherry(1994), who developed the confidence measure had implemented the concept to model a dynamic traffic control system, estimation of driver route choice, and to evaluate the feasibility of implementation of Intelligent Vehicle Highway Systems (IVHS).

The proposed approach helps to establish the research priorities in the decision-making activities based on the confidence levels of the interactions. The interactions with lesser confidence imply higher uncertainty and hence deserve more attention in terms of acquiring information. Another principal benefit of the approach is its ability to represent the information known to the analyst with complete integrity, which helps us to measure the value of information in an appropriate manner

Chapter 5

AGGREGATION AT DIFFERENT LEVELS IN THE ANALYSIS

Aggregation is the most crucial part of the analysis process in the proposed method for evaluating the implementation of the project. The main aim of aggregation is to quantify the total mandate for a given alternative from the opinions of all the experts involved, in a systematic manner.

This chapter deals with the different aggregations involved in the analysis process. The mathematical formulation for aggregation at each level and the importance of the aggregation are described. It should be noted that the sensitivity analysis in the proposed methodology can be obtained by changing certain values in the aggregation step of the analysis process as most of the remaining steps in the analysis follow a fixed pattern of formulation. The way in which different individuals are grouped and the importance given to the opinion of each group is decided by the analyst and is based on his or her discretion.

The procedure of aggregating the opinions of the experts to get the overall index of justification for a given alternative is divided into four main stages of aggregation. These are:

1. Aggregation of confidence values of the cause-effect relations based on the logical chain of reasoning.
2. Aggregation of the opinions of individual experts within a group based on their attitudes.

3. Aggregation of group opinions based on relative importance of the groups using weighted mean.
4. Aggregation of the overall satisfaction levels of objectives.

Figure 5.1 shows a schematic representation of these four aggregations. The small arrows from top to bottom show the flow of this hierarchy along with the constituents of each unit. The large arrows to the right of the figure show the movement of the aggregations in the systematic order of their occurrence in the analysis process. Starting from the first level of aggregation among the causal relationships at the bottom of the chart the aggregation moves upward all the way to the final level of aggregation among the satisfaction levels of the objectives. At each stage the units shown inside the closed figures are aggregated to get a single unit of the next higher stage. All the aggregations are unique in terms of the mathematical procedure used for the aggregation and the inputs and outputs involved in it.

Each of these is explained in detail in the following sections:

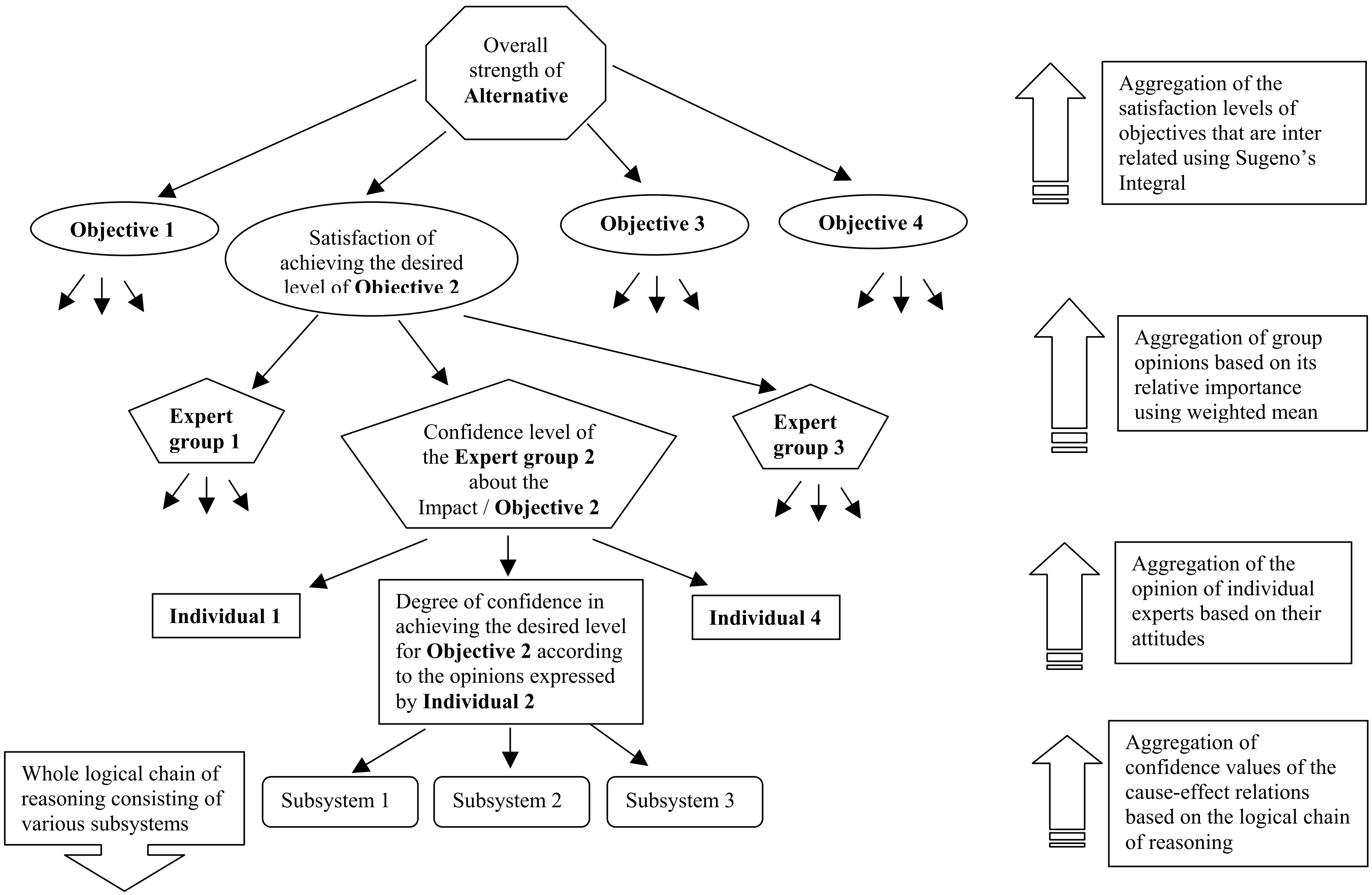


Figure 5.1 Schematic diagram of the four levels of aggregation

5.1 Level 1: Aggregation of Causal Relations

This aggregation is fundamental because the whole methodology of obtaining a measure for justification of a transit alternative is based on the cause-effect relationships between the variables and the objectives of the project.

Each relation has an input variable and an output variable and a decision-implementing element as an expert who provides the degree of confidence in the outcome of the interaction. These relations are linked to other relations either in series or parallel combination depending on the logical chain of reasoning connecting them. The variables are all aggregated according to the objective to which they belong to based on the principles of combining the confidence levels explained in section 4.5. Equation (4.3) and (4.4) are used to compute the confidence level of the systems from the confidence levels of the subsystems.

The expression for the sequential order of subsystems shows that, as the chain of the cause effect relationships propagates in a series form, the confidence level of the combined subsystems decreases. Thus, the level of detail adopted in expressing the underlying cause-effect relationship for a given objective must be consistent. In other words, the number of variables used under each objective of the system should be such that the ambiguity involved in the description of the overall phenomenon related to the accomplishment of an objective must be more or less the same with the other objectives as well. This will avoid unnecessary increase in the number of variables in the cause effect hierarchy and in turn reduce the uncertainty.

The expression for the combined confidence level of subsystems in parallel order shows an increase in the confidence measure of the output variable when compared to the confidence measure of the individual subsystems. It should be noted that though the confidence measure increases under a parallel order of the variables, it never exceeds the value of one. The maximum confidence measure of the output variable (a value of one) from the parallel combination occurs when each of the subsystems has a confidence measure of one.

Another interesting observation is that if either of the subsystems in the parallel combination has a confidence measure of value one, then the confidence measure of the resultant output is also one. This means that if someone is extremely confident about the influencing input variable causing the output variable, in a parallel combination of subsystems then it doesn’t matter what level of confidence is attached to the other contributing input variables. If one is completely confident about the occurrence of an effect from one cause, then the effect will be accomplished in any case irrespective of the strength of other causal variables.

The output of this basic level of aggregation is the consolidated confidence level of an individual about each of the given objectives.

5.2 Level 2: Aggregation of the Attitudes

The experts who are selected are from a wide range of fields and hence their opinions vary considerably, which results in an inevitable bias in the opinion of each individual. Considering the gamut of experts who are being approached for the analysis, it is advisable to group them into sets of people who have similar knowledge about the whole affair and who share a somewhat similar interest and benefit in the project as the stakeholders. This grouping will not however eliminate the biased opinion among the different experts in a given group. In order to accommodate the different views expressed into the final result it is necessary to aggregate all the different views.

In order to compute the confidence level of the group it is not necessary to know the attitude of each individual as proved by Perincherry (1994). It is sufficient to know the individual opinions. This kind of aggregation differs from the usual averaging method. The basic premise of the aggregation is that the difference in the opinions is due to the attitudes of the people and not due to the random error in expressing the opinion. The formula that is used for calculating the group opinion is given by:

$$\frac{\sum_{\alpha=1}^{t}(C_\alpha - C_0)}{\sum_{\alpha=t+1}^{N}(C_0 - C_\alpha)} = \frac{1-C_0}{1+C_0} \tag{5.1}$$

where, C_α is the confidence level for opinion of a optimistic person $\forall\ \alpha = 1\ldots.,t$

C_α is the confidence level for opinion of a pessimistic person $\forall\ \alpha = t+1,\ldots.,N$

C_0 is the confidence level for the opinion of the whole group

N is the total number of people in the group

t is number of optimistic people (confidence measure greater than C_0)

The value of C_0 can be obtained by trial and error. The value of C_0 for which, the left hand side matches with that on the right hand side is the correct C_0. The value C_0 lies between the maximum and the minimum values of C_α. A more detailed explanation is given in Section 7.3.1 under Level 2. The output of this aggregation is the confidence level of the whole group.

5.3 Level 3: Aggregation of Group Opinions

The groups of the experts determined in the second level of aggregation are distinct and unique in terms of their composition. Each group is a collection of people who differ from those in other groups in the amount and type of knowledge possessed about the large-scale public project. Unlike the last two levels of aggregation, the units to be combined in this stage namely the expert groups are fairly distinguishable. Capitalizing on this property, the confidence levels of each group obtained from the previous step are aggregated using the simple weighted mean of the units.

Detyniecki (2000) gives a very good overview of the different types of aggregation operators. The groups are formed such that they have a distinct feature attached to them. This can be done by grouping the experts based on the benefits provided by the public project, or based on the quality and quantity of the knowledge available with the experts about the project from the level of their association with a particular kind of projects. Thus, it is possible to group the experts into different sets with certain common attributes. The weight assigned to each of such groups is left to the discretion of the analyst. Care must be taken to ensure that the weights reflect the relative importance of the groups with respect to the theme of the grouping for the project under consideration

A simple weighted mean aggregation is adopted to combine the confidence levels of the groups. A general form of the aggregation is given below:

$$M(x_1, x_2, ..., x_n) = \sum_{i=1}^{n} \left(w_i \times x_i \right) \tag{5.2}$$

where w_i is the weight assigned to expert group "i" and x_i is the combined confidence level of group "i" obtained from aggregation at level 2.

The weights w_i s are non negative with $\sum_{i=1}^{n} w_i = 1$.

The output of this aggregation is the degree of satisfaction of achieving the desired level of impact or objective from the transit alternative.

5.4 Level 4: Aggregation of the Satisfaction Levels of Objectives

The criteria involved in the decision making process of a major transit investment process are not very precise and clear in definition. In addition there is an underlying uncertainty about the desired level of satisfaction of achieving the objective. As the objectives are all interrelated having individual weights that add up to one is not appropriate and hence the decision criteria should not be combined based on weighted mean kind of aggregation. The proposed method of analysis uses Sugeno's integral to integrate the different objectives.

The Sugeno's integral is essentially a weighted max min operator that is ideal for decision making of a system with conflicting and interrelated objectives. Sugeno's integral, also known as a fuzzy integral because of the use of fuzzy measure in the framework of analysis, has been mainly studied in a multi-criteria decision making framework. It has the ability to model the interaction between the criteria of a decision-making problem because the weight terms in the Sugeno's integral are ordinal values. The weight values for interrelated criteria should be able to add up to a value that is more than unity and at the same time reflect the degree of inter dependency of the elements which are combined using the weights. This can be done using Sugeno's integral. Marichal (2001) presents a method using discrete Sugeno's integral to combine different criteria and obtain single comprehensive criteria.

Dubois et al. (2001) highlights the advantages of using Sugeno's integral in decision-making that involves treatment of ordinal-scaled data, or subjective data. The authors discuss the use of Sugeno's integral as a global preference functional for ordinal values in the context of two decision frameworks: decision making under uncertainty and multi-criteria decision-making. In the proposed method of analysis, the uncertainty in decision-making has already been considered through the use of confidence measure. The

Sugeno's integral would be used for dealing with multi-criteria decision-making in the form of aggregation operator to convert into a single comprehensive criterion.

For a discrete set of elements X = {1,…,m}, which can be a set of criteria, attributes, or voters in a decision making problem, the general form of Sugeno's integral as an aggregation operator is described by Marichal (2000) in set notation as follows:

$$S_{\mu}^{(m)}(x_1,\ldots,x_m) = \bigcup_{T \subseteq X} [\mu_T \cap (\bigcap_{i \in T} x_i)] \tag{5.3}$$

where $(x_1, \ldots, x_m) \in [0,1]^m$, and μ is a fuzzy measure on X.

μ is a membership function of a fuzzy set whose constituents are different possible combinations of the criteria (elements) to be aggregated. If Sugeno's integral is looked as weighted max-min operator, μ acts as the weight in the whole formulation. As there are 2^n different possible subsets from the combinations of the elements, the formulation requires 2^n terms. To reduce this huge number, another expression for the discrete Sugeno's integral is:

$$S_{\mu}^{(m)}(x_1,\ldots,x_m) = \bigcup_{i=1}^{m} [x_{(i)} \cap \mu_{\{(i),\ldots,(m)\}}] \tag{5.4}$$

where, the vector $(x_1, x_2, \ldots, x_m)$ is arranged such that $x_1 \leq \ldots \leq x_m$.

In this thesis, equation 5.4 will be used for the Sugeno's integral calculations. In this formulation for every element x_i, the analyst has to provide the corresponding membership function value of the fuzzy measure μ. Thus if there are 5 elements to be aggregated using Sugeno's integral the analyst is expected to provide 5 membership values among which, the value associated with the combination containing all the elements is known to be 1 always. Hence only 4 values have to be provided by the analyst. These values represent the importance of certain combinations of the objectives or criteria. The illustration of the working of Sugeno's integral is provided in chapter 7 wherein an application of the proposed method of analysis is presented.

The output of this aggregation is the final index of justification of a given alternative. This aggregation completes the process of evaluating a given project alternative in a systematic way without avoiding the inherent uncertainty involved in the analysis and decision making of such large-scale public projects.

Chapter 6

APPLYING PROPOSED METHOD TO DECISION MAKING IN TRANSIT INVESTMENT PROJECTS

6.1 Decision making in Transportation

Decision-making in transportation engineering and planning often deals with problems, which require subjective judgment. These may arise due to the difficulty in defining the problem statement, objectives or even the results of the projects. In addition to this, because projects are usually for the welfare of the public, the benefits and expectations of the individual stakeholders and the society on the whole cannot be estimated with certainty. Under these situations, the information available to the analysts during the decision-making has to be utilized effectively. The lack of proper methods to deal with information and uncertainty has been a major obstacle in the planning of transportation.

Uncertainty is an integral part of most of the transportation planning problems and the methods used for solving the problems must include the uncertainty in the analysis process in an honest manner. Kikuchi and Pursula (1998) studied the nature of uncertainty present in transport planning and the appropriate treatments for the situations like choice and decision process in travel, modeling driver behavior, classification of problems into categories, and large-scale system analysis. According to the authors, there are two types of uncertainty: fuzziness and ambiguity.

Consider the statement *" The environmental impact of the project is huge"*. The uncertainty in the proposition is due to the term "environmental impact" and the term “huge”. Fuzziness arises because of the inability to clearly define the state huge for determining the truth of the proposition. Fuzziness is more due to lack of distinct boundary in defining the transition between the states. The mathematical framework of fuzzy set theory is used to analyze the fuzziness. Kikuchi (2000) has demonstrated the use of fuzzy sets in solving the problem of inconsistency in the observed values in satisfying certain relationships by using a fuzzy linear programming method. Ambiguity, on the other hand, is caused by the incomplete information about “impact”. It is more because of lack of knowledge about certain elements in the decision-making. Ambiguity is analyzed using the evidence theory.

The emphasis in this thesis is to study the decision-making in large-scale public projects. The type of uncertainty involved in the analysis of these projects is ambiguity. This is because the objectives of the project like mobility improvement or socio-economic benefit are difficult to define and the analyst lacks sufficient knowledge about the satisfied level of achieving the objectives. Thus, the analysis technique to be used for dealing with the ambiguity in the investment projects should consider evidence theory in the mathematical formulation. The confidence measure discussed in section 3.2.4 is defined in terms of the possibility and necessity measures, which are fuzzy measures that come under evidence theory. The confidence measure takes into consideration the two different perspectives about the same given event or objective, which can model the ambiguity in the desired outcome more effectively. Hence, the proposed method based on the evidence theory is appropriate to deal with the ambiguity associated with the decision-making of the transit investment projects.

6.2 Analysis of Transit Investment Projects

The benefits of transit are numerous and especially in the fields of economical, social, and environmental impacts. Transit services provide transportation choices for the travelers apart from the widely used automobiles, which causes a more positive feeling towards traveling in general. It provides a relatively safe, comfortable and convenient mode of transport to the user in heavily congested downtown regions. In a broader angle, considering the impact on the community, transit reduces road congestion, and provides mobility for people with disabilities, and the senior citizens. In many communities, transit systems also serve schools and universities. Transit investment helps revitalize business districts and creates new activity centers, as most businesses would like to be easily accessible for their employees as well as their customers and clients.

Transportation professionals and academicians must take a stronger leading role in the planning of intermodal transportation systems for development of livable cities. Vuchic (2003), a staunch supporter of "transit" as the solution for the transportation problems has said that, " The livable city requires high-quality transit, reasonable accommodations for bicycles and cars, and good treatment of pedestrians." In order to implement the transit projects that meet the expectations of the users, community, and the operators, it is important to analyze the different alternative strategies that are available and choose the best among them. The magnitude of the costs involved in the implementation of the transit projects and the potential impact of the project on different groups of stakeholders makes the evaluation of large-scale transit investment alternatives a serious affair with significant consequences.

Wirasinghe (2003) describes the current transit planning in many agencies as at best an art and at worst as a collection of ad-hoc rules. According to him, the precise definition of the objectives to be satisfied in providing the transit service, let alone their attainment, is a difficult task and it is further complicated by the conflicting nature of the objectives. The decision-making of transit investment projects is actually a good example of applying the decision-making paradigm of MCDM under uncertainty. There are very few applications of MCDM under uncertainty in transportation on the whole. Li and Sinha (2004) have proposed a MCDM methodology for project selection in highway asset management system by analyzing the trade offs between the projects under the three scenarios of certainty, risk and uncertainty. However, MCDM with deterministic attributes and performance functions has been used in the decision making of transit systems.

Janarthanan and Scheider (1986) present the multicriteria evaluation of the alternative transit system designs by using weights to represent the relative importance of different criteria. The authors believe that there should be multiple weight sets that reflect the preference of different groups of stakeholders. However, the analysis did not consider environmental benefits and socio-economic impacts which are difficult to quantify and normalize. The transit alternatives in Vancouver (2004) were evaluated by analyzing the performance of each alternative for different accounts like transportation, urban development, environmental, social and ease of implementation and extendibility. The study had left the assignment of weights for the level of importance to each of these accounts to the discretion of stakeholders. The findings of the study were expected to assist the stakeholders to reach a decision regarding the preferred option.

The evaluation of the transit alternatives has been seen to be a mixture of analytical as well as theoretical methods in terms of the mathematical approaches for the analysis and the consultation of stakeholders for making the final selections. The Federal Transit Administration (FTA) controls the decisions about the funding of the transit projects. It is thus necessary for the evaluation procedure to comply with the guidelines set by the decision making body FTA. In the following section, the approach of the FTA towards the planning and development and the decision making of these projects is presented.

6.3 FTA: Approach towards Transit Investment Projects

Federal Transit Administration (FTA) is a body of the federal government for providing financial and regulatory assistance to develop new transit systems as well as to improve, maintain, and operate existing systems. FTA oversees grants to the various state and local transit providers. The New Starts program is the Federal government's primary financial resource for supporting, implementing and operating the local transit projects. The transit systems that come under its aegis include heavy and light rail, commuter rail, bus rapid transit system, automated guideway transit, people movers, and also exclusive facilities for buses and other high occupancy vehicles.

The official website of the FTA in Introduction to New Starts Program (2005) cites the definition of a New Starts Project as "Projects eligible for Section 5309 New Starts funding include any fixed guideway system which utilizes and occupies a separate right-of-way, or rail line, for the exclusive use of mass transportation and other high occupancy vehicles, or uses a fixed centenary system and a right of way usable by other forms of transportation."

The Transportation Equity Act for the 21st Century (TEA-21) allocates a large amount for New Starts funding program in every fiscal year. In the year 2003, the FTA through TEA-21 approved a total of \$ 8.2 billion for the New Starts Projects. TEA-21 authorizes a number of projects every year to compete for the Federal dollars assigned for transit systems. The projects have to go through a series of stages, during which they are termed to be in the “pipeline”, before getting the approval for funds from the New Starts program.

6.3.1 New Starts Projects: Planning and Development Process

TEA-21 directs the New Starts program to follow a comprehensive planning and project development process, which is intended to assist local agencies and decision-makers. The planning and development process for New Starts projects has three key phases: Alternative analysis, Preliminary Engineering, and Final Design. Each of these are explained in detail below.

Alternatives Analysis

Systems planning process precedes the alternative analysis and is considered the first step in planning and development of a project. It involves studying the regional travel patterns and identifying the segments that need improvement in the transportation. Alternatives analysis acts like a bridge between systems planning and the next major step, preliminary engineering. In alternative analysis phase, the alternative strategies are evaluated and the most appropriate among them is selected for advancing into the next stages of planning and development like preliminary engineering, design, and construction.

The alternatives analysis study is intended to provide the local citizens and officials, information about the benefits, costs, and impacts of alternative transportation investments. As part of this process, the potential local funding sources for implementing and operating the alternatives are identified and studied. All through this process the stakeholders, namely the users, the community, and the operators are involved by conducting workshops, discussions, surveys and public meetings.

Alternatives analysis is considered complete when a locally preferred alternative (LPA) is selected by local and regional decision-makers and adopted by the metropolitan planning organization (MPO) into the metropolitan transportation plan. A final report on the alternative analysis performed by the local planning agency is presented to the FTA for its approval as a New Starts project. The FTA under the guidance of the TEA-21 regulations scrutinizes the alternatives presented in the study according to a predetermined set of criteria to confidently give the go ahead signal to advance it into the next stages of the planning and development process.

Preliminary Engineering

In the preliminary engineering phase of project planning and development, the local planning agencies define the design of the project, taking into consideration all reasonable design alternatives. In this stage of the project development an estimate of the project costs, benefits, and the impacts are studied in a very detailed level and presented to the FTA. These studies are necessary to comply with the NEPA (National Environmental Policy Act) requirements. The NEPA requires the FTA to integrate the environmental considerations into any decision that they might take with respect to a project by considering the environmental impacts of the proposed actions.

Note that at this stage only the design alternatives are considered while, in the previous stage the project alternatives or rather the alternative strategies are considered. The proposed project’s New Starts criteria are thus accordingly refined in the preliminary engineering phase of development.

Final Design

The last phase of project planning and development is the Final Design phase, which includes right-of-way acquisition, utility relocation, the preparation of final construction plans, design specifications; construction cost estimates, and bid documents. The project's financial plan is finalized, and a plan for the collection and analysis of the data needed is undertaken. The completion of this phase signals the start of the implementation phase of the project and the construction of the project is initiated.

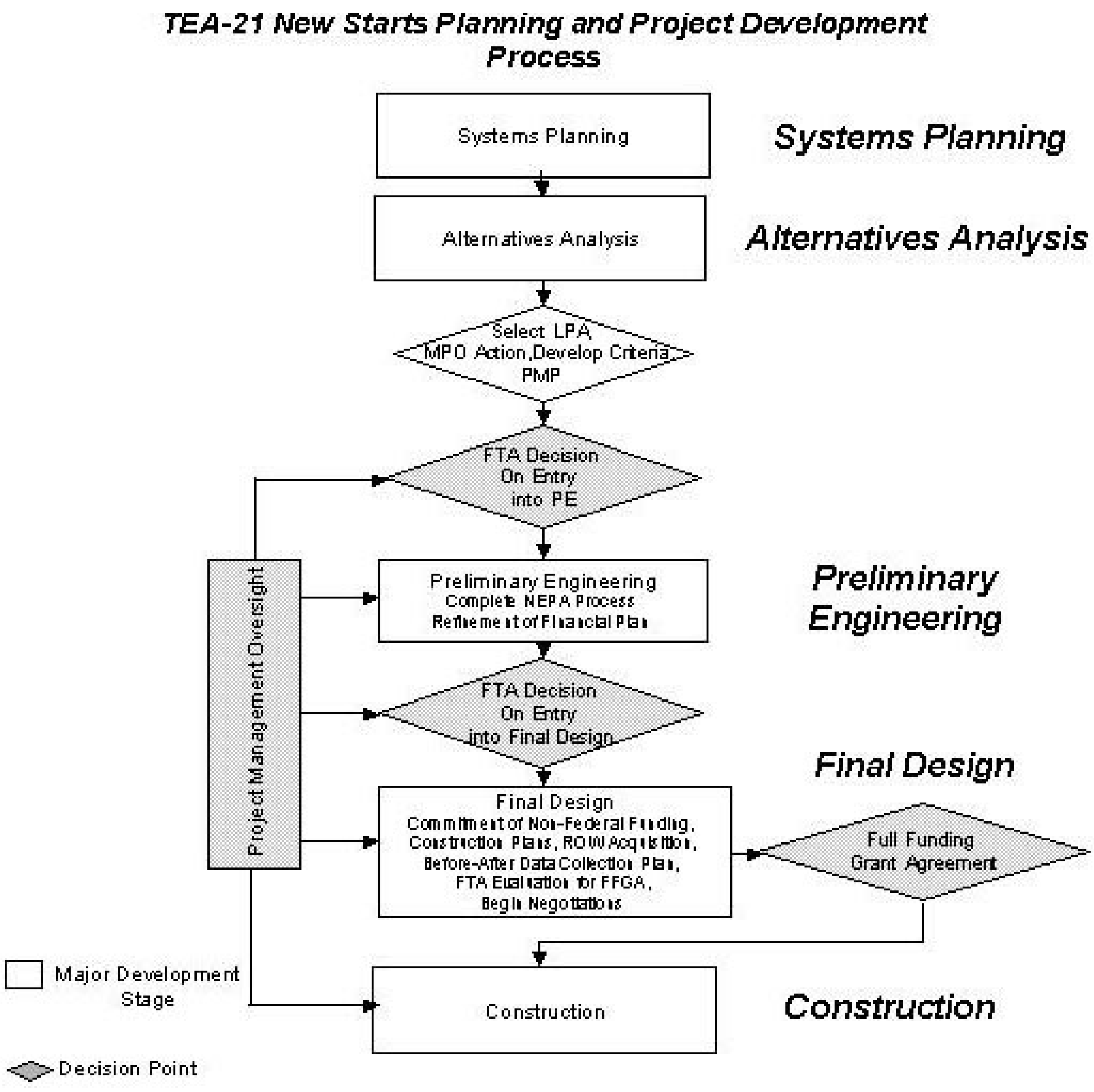


Figure 6.1 Phases in the Planning and Development of Projects. (Reproduced from Introduction to New Starts program, FTA. (2005))

An important feature to note in the planning and development process is that there exists a feedback loop in the form of project management oversight. The main function of this feed back loop is that after each stage the project has to be approved for entering into the next stage, failing which the project is sent back to the local planning authorities to rework and submit. In some cases the failure for approval might directly cause an end to the further study of the project.

6.3.2 Evaluation, Rating, and Recommendation of New Starts Projects

FTA in the Project Evaluation, Ratings, and Annual Reports provides the guidelines and requirements for the process of evaluation, rating and recommendation of the New Starts Program to Congress (2005). The procedures adopted by the FTA as outlined in that document are presented in this section by keeping in mind the scope of the study in this thesis.

Evaluation

FTA evaluates the proposed new start projects with respect to two main standards: Project justification and Local financial commitment, using a multiple measure method. For each of the five criteria: mobility improvement, environmental benefits, operating efficiencies, cost effectiveness, and land use, under project justification, the proposed New Starts project is evaluated against a "baseline alternative", which is the best that can be done to improve the transit service in the region without any new major capital investment. The project sponsors and FTA should agree upon the baseline alternative for the proposed New Starts project before going for the project evaluation and rating process.

For evaluating local financial commitment, the primary factors that are considered are the measures for the proposed local share of the capital costs and the strength of the capital and operating financing plans. That is the evaluations are based upon the status of the other non-New Starts projects being proposed in the region, and the financial capacity of the project sponsor to undertake the major capital investment and operate and maintain the planned transit system over a 20-year period.

Project Justification Evaluation

The context of study of the example using the proposed method is the project justification standard. TEA-21's project justification criteria are intended to reflect the range of benefits and impacts, which may be realized by the implementation of the proposed New Starts transit investment. Project justification criteria are initially developed as part of alternatives analysis and are refined throughout the preliminary engineering and final design phases of project development.

FTA assigns a summary project justification rating to each project based on consideration of the ratings applied to the following criteria: a) Mobility improvements b) Environmental benefits c) Operating efficiencies d) Cost-effectiveness e) Transit supportive land use and f) Other factors. The ratings are defined in detail in the next section.

Though all the five criteria are an integral part of the project justification evaluation process, the primary criteria that are given importance by the FTA are the measures for cost effectiveness, transit supportive land use, and mobility improvements. FTA attempts to reflect the unique characteristics and objectives of each New Starts project through the different criteria. Figure 6.1 shows the criteria chart depicting the different criteria involved in the project justification and local financial commitment evaluation of the New Starts Projects.

<u>Rating Scale</u>

The rating scale for a project assigned by FTA to each of the five criteria for project justification and the three criteria for local financial commitment are one among the following five descriptive ratings: high, medium-high, medium, low medium, and low. The individual criterion ratings are then combined into overall project justification ratings or local financial commitment ratings, which are again one among the five levels ranging from high to low. The project justification ratings are then combined with the financial commitment ratings to produce summary ratings of: highly recommended, recommended, or not recommended. The ratings are used for approving the project to enter into the next level of the project development. A proposed project must receive a rating of at least "Recommended" in order to be approved. It should be noted that the overall project ratings are intended only to reflect the merit of the project at any given point in time and a rating of "Recommended" need not necessarily translate into a funding recommendation.

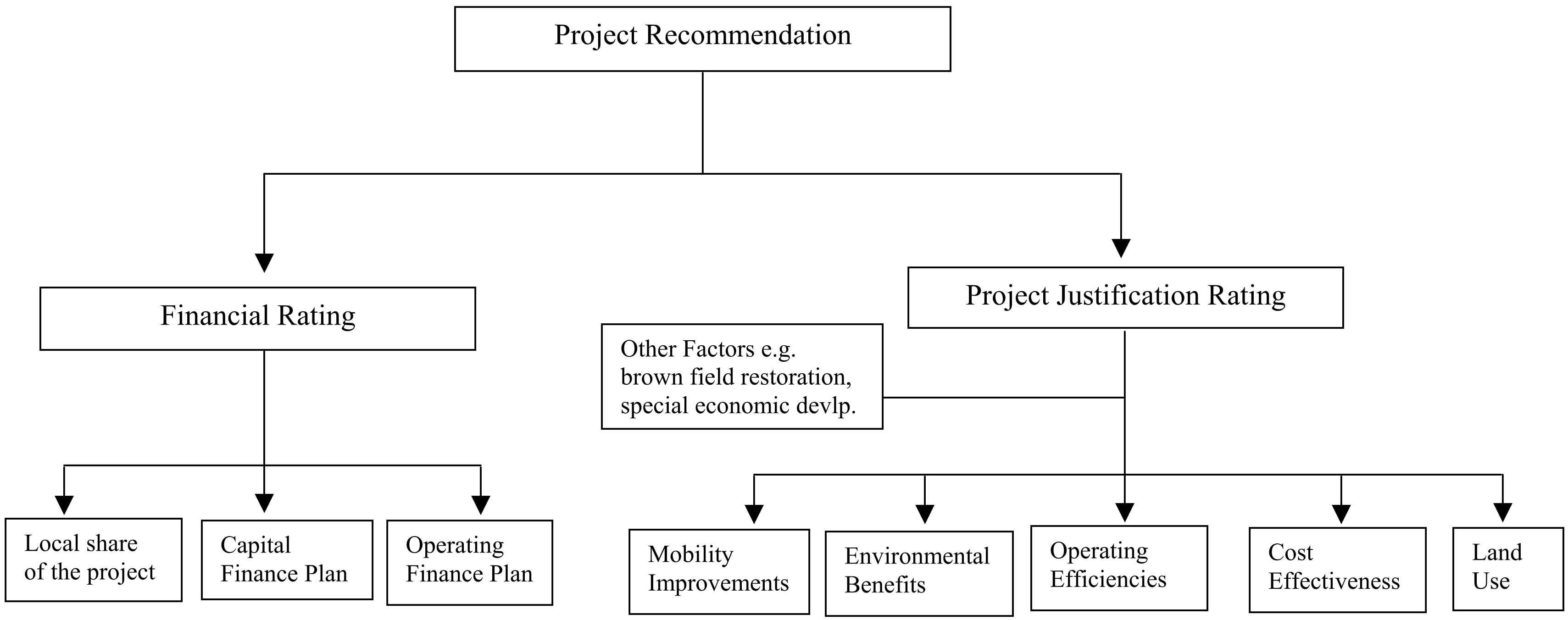


Figure 6.2 Criteria for evaluation of project justification and local financial commitment of the New Starts Projects

Recommendation

Based on the overall performance of the project measured by the ratings in various criteria for the project justification and local financial commitment, the proposed New Starts project is termed as "highly recommended", "recommended" or "not recommended" by the FTA. The ratings of the individual criteria are summarized to determine the overall project rating for the recommendation according to the following decision rules:

a) Highly Recommended: Projects must be rated at least "medium high" for both finance and project justification.

b) Recommended: Projects must be rated at least "medium" for both finance and project justification.

c) Not Recommended: Projects not rated at least "medium" in both finance and project justification will be rated as "not recommended".

It is important to emphasize that project evaluation is an on-going process and the FTA evaluation and rating occurs annually in support of project's request for FTA approval to enter into each of the project planning and development stages like preliminary engineering and final design and the ratings are updated regularly to reflect new information.

6.4 Defining Transit Investment Project as a System

The transit investment project can be considered as a system as it has the basic characteristics of a large system, which is the presence of a large number of variables and interactions having a common function. The variables involved are the different elements related to the social, economical, environmental, impact of the implementation of the transit alternative on the various stakeholders. The common function of the system is to provide a good transit service at a reasonable cost with minimal environmental impact.

According to the criteria for evaluating the New Starts Projects proposed by the FTA, any given transit investment project must achieve the five criteria: mobility improvement, socio-economic impact, cost effectiveness, operating efficiency, and environmental impact, to a certain desired level. The evaluation of the transit alternatives based on the proposed method of analysis should also incorporate these criteria. Hence the objectives of the system are considered along the lines of these five criteria and the whole analysis is based on the strength of agreement regarding the achievement of these objectives.

Thus, the variables involved in the system would be the causal relations pertaining to the achievement of each of these five objectives. The system definition accomplished by the identification of the objectives would complete the process of defining the variables and the interaction between them in a system. The analysis process in the decision making of large-scale transit investment projects following the initial step of system description has three broad steps. They are: 1) decomposition of the system into subsystems, 2) analyzing the subsystems, and 3) aggregating the subsystems and interpreting the results. These are elaborated in detail in the context of the application to evaluation of the transit alternatives for the transit scenario in the northern New Castle County in the State of Delaware in Chapter 7.

Chapter 7

EVALUATION OF A TRANSIT ALTERNATIVE

In this chapter the whole analysis process is presented in detail by taking an example application of evaluation of the implementation of monorail in the State of Delaware as a transit alternative along the Route 40 corridor in Northern New Castle County. The chapter is divided into four sections. The first three sections deal with the illustration of the application of the proposed method for the evaluation of a transit alternative and the last section discusses some general issues related to the decision-making paradigm presented in the thesis.

The first section explains the scenario under which the transit alternative is being evaluated. The process of developing the charts depicting the causal relationships involved in a transit investment project is also presented in this section. The second section presents the analysis of the subsystems obtained from decomposition of the system by considering the opinions of the experts. The third section provides the mathematical procedures involved in the aggregation of these subsystems and the interpretation of the results.

7.1 Step 1: Decomposition

The process of decomposing into subsystems is based on the description of the transit investment project as a large-scale system. As explained in section 6.4 the previous chapter, the variables involved in the system are defined with respect to the five objectives of the transit investment project. The exact variables under each objective would depend on the transit scenario for which the transit investment is being proposed. It is thus necessary to study the region of interest and the nature of the transportation related problems present in the region before we can decide on the variables for each objective.

7.1.1 Transit Scenario: A Study

The project studied in the thesis is an extension of a Monorail alignment along the Rt.40 corridor in the State of Delaware. Monorail was actively pursued in the State of Delaware in the year 2003, as a viable transit alternative to meet the future travel needs in the Northern New Castle County region. The Wilmington Area Planning Council (WILMAPCO) had undertaken the task of conducting a comprehensive study for the monorail project.

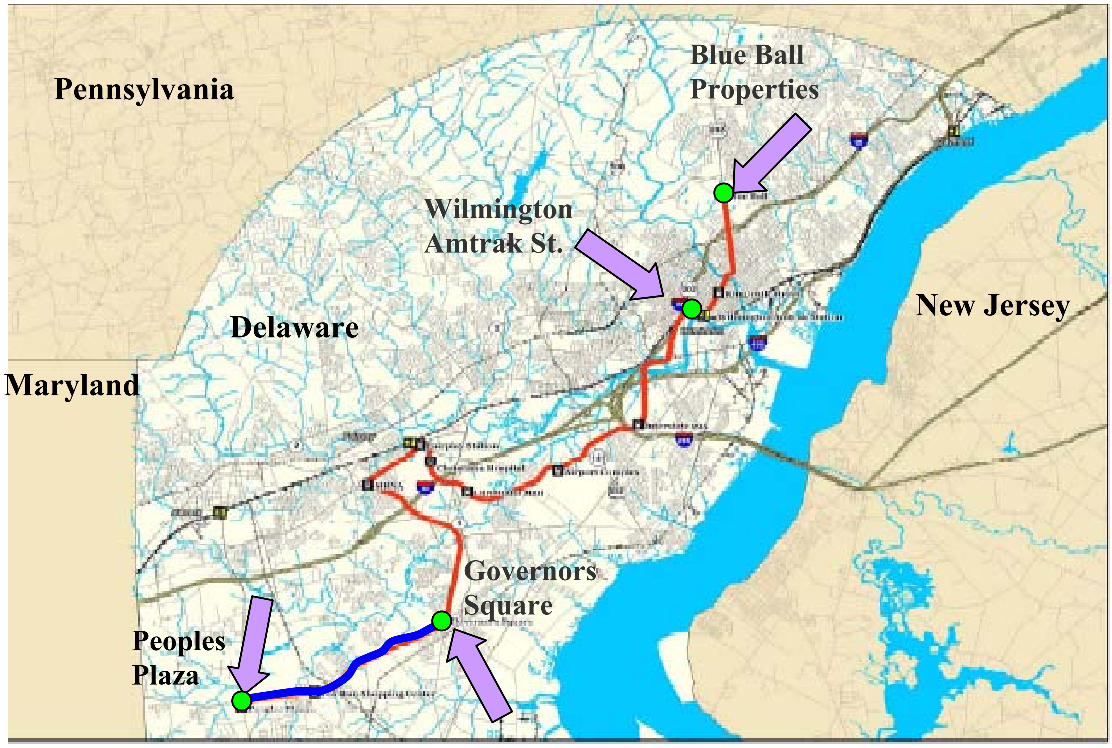
As part of this effort, a Regional Monorail Exploratory Study (2003) was conducted in partnership with DelDOT, Delaware Transit Corporation, City of Wilmington, New Castle County and the elected officials from the local administration and a report about the findings was prepared in September 2003. The main objective of this study was to investigate the feasibility of a monorail transit service in Northern New Castle County. The study involved only the systems planning phase among the phases outlined by the FTA as the standard procedure for any New Starts Project. The study was not pursued beyond this stage due to local administrative reasons and the project got shelved. Most importantly the alternative analysis was not initiated in the planning and development of the project.

The map in Figure 7.1 shows the alignment of the proposed monorail project. The alignment starts at the Blue Ball properties, which is home to the upcoming North American headquarters of the pharmaceutical giant Astra Zeneca. This entry of Astra Zeneca in Delaware was expected to increase the employment in the region significantly. The State of Delaware acquired the land area around the blue ball properties to address the environmental, recreational and transportation needs of the citizens in the region. The proposed alignment connects other high-density employment areas in the region like

MBNA, Christiana Mall, and the hub for economic activity in the region, the Wilmington City downtown that houses many residential units also. The alignment culminates at Peoples Plaza close to the Maryland Border along Route 40 Corridor.

For applying the proposed method to the evaluation of the monorail as a transit alternative, the region of interest was reduced to the Route 40 Corridor alone. The scope of the study is to analyze the transit scenario of implementing the monorail along the Route 40 corridor as an extension of the transit alignment to the already existing hypothetical monorail service from blue ball properties to Governors Square. The proposed extension of the alignment is a total length of 5.3 miles along Route 40 corridor between Governors Square and Peoples' Plaza. It should be noted that the area of interest for this study is the alignment along Route 40 corridor alone. This reduced alignment is taken, as just an example for applying the analysis presented in the thesis for evaluating the transit alternative. The proposed decision-making paradigm can be very well used for a whole section of a project being considered for implementation.

The Rt. 40 corridor has been under the limelight of development projects being considered in the region because of the drastic changes in the traffic and land use characteristics forecasted in the region. As part of the efforts being done for the corridor, a long-range 20 year Route 40 corridor improvement plan (2000) has been created and is already being implemented in stages. The vision of the project is to deal with the major issues along this corridor namely providing a safe, community friendly and less congested Route 40. Figure 7.1 shows the alignment of the monorail project and the extension along Route 40 corridor being studied in this thesis.



Extension of the Monorail alignment along Route 40 corridor.

Original Monorail alignment

Figure 7.1 Map showing the extension of the monorail alignment considered in this study.

7.1.2 Justification of the Project Selected for Application

The selection of this particular hypothetical project of monorail alignment extension along the Route 40 corridor as the example for applying the proposed method has been done, as it is felt ideal for testing the working of the decision-making paradigm. The proposed project involves a transit alternative that has been widely discussed and analyzed as a viable transit solution. Also the project deals with the transportation related problems of a region that has already been receiving significant attention from the planning authorities. Both the above points make it a relevant transit scenario for studying in the State of Delaware.

Monorail as a transit alternative has been debated often with respect to the costs attached to the overall performance and the benefits that are achievable from it. The Maglev monorail as a transit system has been studied with great interest in recent years especially in Europe. Maglev monorail follows the single guideway as conventional monorail does, but in this mode powerful magnets provide propulsion and lift, while the regular monorails run on rubber tires. The Transrapid in Germany is an example of a high-speed maglev monorail system. High-speed maglev systems have advantages despite higher initial investment cost because of the lower long run costs like operational and re investment costs compared to the traditional rail system. Monorails have lower energy consumption and causes lower CO2 emissions as well as lower noise emissions.

However there have been reports that indicate an opposition to their implementation too. Vuchic and Casello (2002) present a comparison of the high-speed rail systems (HSRS) and Maglev with respect to the technical operational and network aspects of the two modes and conclude from their study that there is no positive reason for building a maglev system. The report states that the travel time advantage of maglev over HSRS is very minor for transit routes of short inter station distances. In addition to that the high level of intermodal compatibility with other transportation modes and ease of integration with the built up areas combined with the relative low construction costs of HSRS make it a much better viable and efficient transit mode. Thus, the implementation of a monorail transit system deserves a careful consideration of the opinions of different sections of experts before a final decision is taken.

The proposed project in the study is justified with respect to the area of concern also. With 75% of the land being either already developed or earmarked for development, a 87 % increase in the employment in the region in the next 15 years and about 47% increase in population expected by year 2020, the Route 40 corridor features prominently in the list of transportation development plans to be identified and implemented in near future in the Northern New Castle County region. By 2020 70% of all the intersections on the corridor are expected to be working at a level of safety of F at peak hours and 82% of the traffic on the corridor is local traffic with the origin and destination within the corridor. Thus, a transit service is expected to solve the traffic and congestion on the Route 40 corridor. Figure 7.2 shows the Route 40 corridor. The Rt. 7 and Rt. 40 intersection at Governors Square is the most congested intersection among the total 19 intersections. The travel time for covering the whole stretch of the corridor, which is of a total length of just more than 15 miles, is expected to increase by 2-3 times.

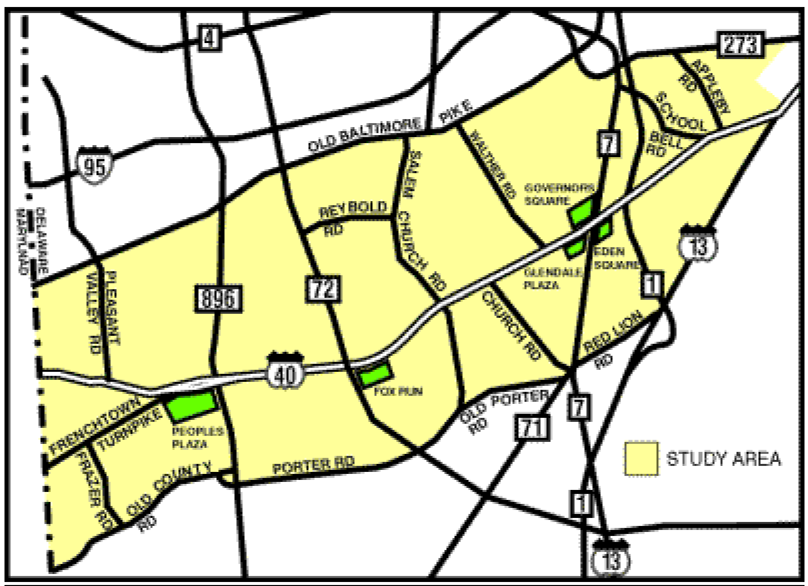


Figure 7.2 Route 40 Corridor (Courtesy Route 40 corridor improvement plan)

With respect to the implementation of monorail on the corridor, among the 7 segments that were evaluated in the initial process of corridor selection for the monorail alignment, in the Purpose and need statement of the monorail project, the Route 40 corridor segment obtained the maximum ratings in favor of the implementation of the monorail. The regional monorail exploratory study reported that the monorail service in Route 40 corridor would supersede the bus service enhancements contained in the 20-year plan. Thus, the proposed hypothetical project of extension of monorail alignment along the Route 40 corridor is very much justified for being considered for testing the decision-making paradigm for transit investment projects presented in the thesis.

7.1.3 Decomposition into Subsystems

Mobility Improvements

The FTA reviews two measures for evaluating the mobility improvements that would be realized by implementation of a proposed project: travel time savings and the number of low-income households served with a greater emphasis on travel time savings for assigning the mobility improvements rating. The FTA Reporting Instructions for the New Starts Criteria (2001) has added another measure to this list in the form of the level of employment near the stations and along the route.

The mobility and accessibility is directly related to the user benefits that the transit alternative can provide. User benefits are considered to be synonymous with the travel time savings as seen by the procedures adopted by the FTA to measure the improvements in accessibility. Friman and Garling (2001) have concluded in their study that there exists a direct relationship between the service performance of public transport (defined by travel time, wait time, frequency of service and number of transfers) and the overall user satisfaction. The study undertaken by Weyrich and Lind (2003) reports that the Silicon Valley commuters save over $2,500 annually by using trains for the daily 80-mile commute. Wilmapco (2005) has mentioned improvement of safety as an important factor in improving the mobility in the region.

Thus, it is seen that apart from obvious segment of travel time savings, the user benefits consists of other issues like user safety, convenience and travel cost savings that are usually neglected due to lack of proper methods for quantifying them. In the proposed method these issues can be easily incorporated. For the analysis of the transit scenario being considered in this study, mobility improvement is assumed to be directly affected by travel user benefits. The low-income household has not been considered in the analysis. However, by obtaining demographic information about the low-income group and their mode choice, the cause-effect relationship can be included in the hierarchy chart of mobility improvement.

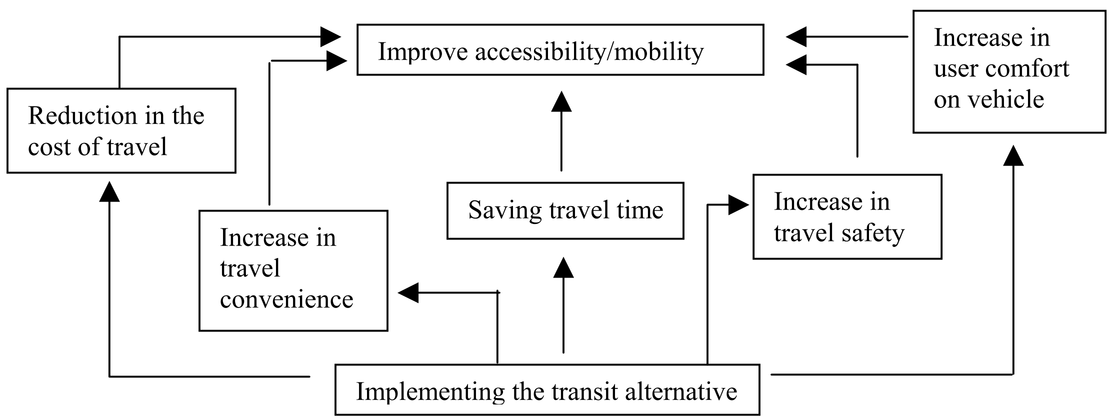


Figure 7.3 Cause effect relationship chart for mobility and accessibility improvements.

Figure 7.3 shows the cause effect relationship chart for the objective of mobility and accessibility improvement. As seen in the chart the implementation of the transit results in five different impacts namely reduction in cost of travel, increase in travel convenience, saving of travel time, increase in travel safety, and increase in user comfort on vehicle. Each of these five in turn cause a common effect mobility improvement.

Environmental Impacts

The FTA has listed the classifications of environmental impacts in Section 6 of Part II of guidelines for transit planning titled Estimation of Socio-economic and Environmental Impacts (1986) broadly as social environmental impacts, natural environmental impacts and historic and cultural impacts on environment. The social environmental impacts will be covered under the socio-economic impacts. Historic and cultural impacts on the environment need a detailed examination of the affected area and are difficult to study and analyze using a cause effect relationship based sequence of logical reasoning proposed in this study because these effect are region specific.

In the present study we would be analyzing just the impacts that can be measured in a fairly reasonable manner through a set of cause-effect relations and accordingly, environmental impacts hereafter would mean just the natural environment impacts. Figure 7.4 shows the cause effect relationship leading to the environmental impacts from the implementation of the transit alternative. There are two main contributions to the overall aggregated impacts on the natural environment, the first one is the effect on the air quality and the second one is the effect on noise pollution levels. The chart in Figure 7.4 depicts the events that lead to each of these effects.

Consider the causal relations tree below the air quality improvement. Starting from the bottom of this tree, the implementation of the transit alternative results in increase in traffic near the stations and decrease in the number of automobile trips on road. These two affect independently result in the reduction of the energy consumption in the region. Though these two effects are in opposite directions they affect the net energy consumption levels in the region, which has a direct bearing on the final air quality levels of the region. Shapiro et al (2002) observed that increased use of transit is the most effective strategy available for reducing energy consumption and improving the environment without imposing new taxes, government mandates, or regulations on the economy or consumers. The reduction in energy consumption affects the change in the air quality with respect to the air quality standards of NAAQS (National Ambient Air Quality Standards).

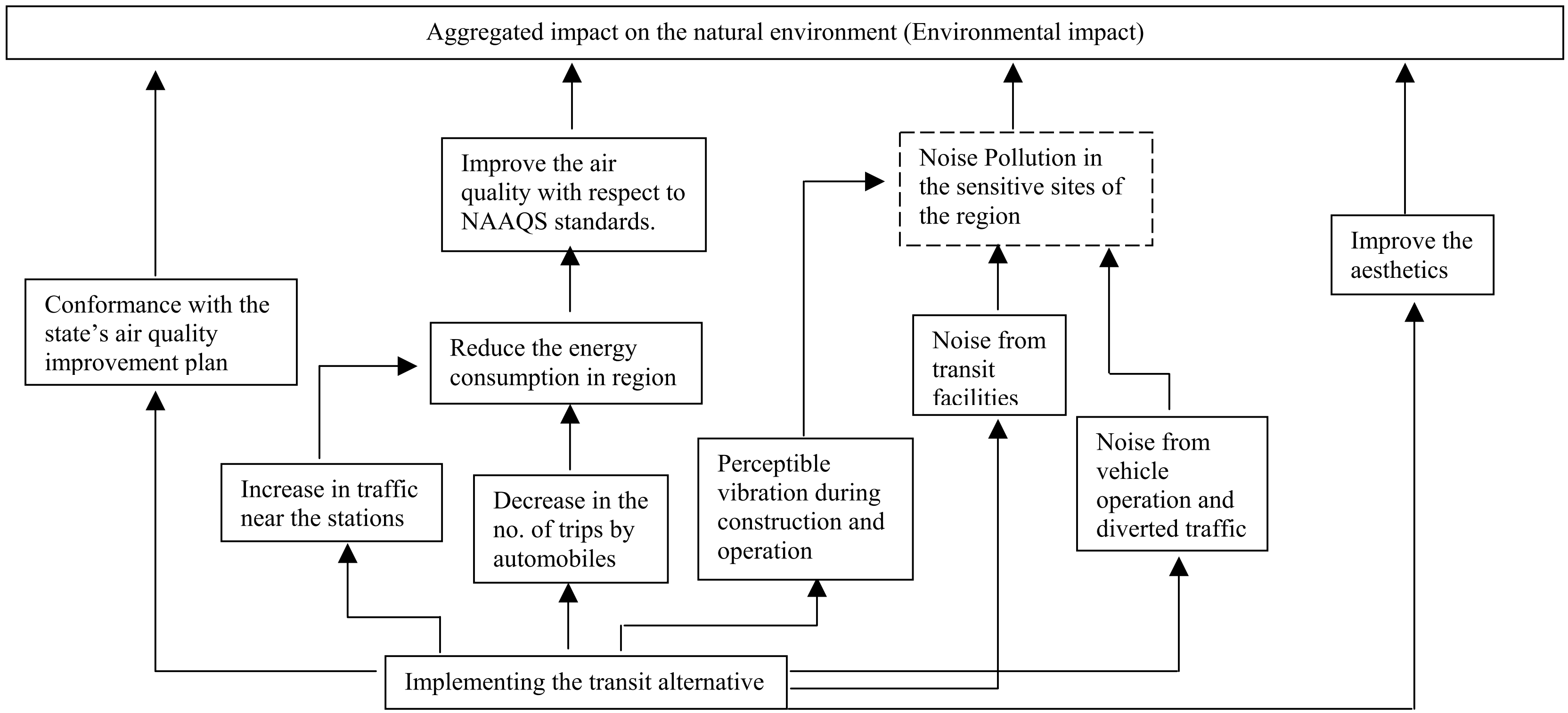


Figure 7.4 Cause effect relationship chart for environmental impact.

Consider the other major environmental impact noise pollution. The tree of causal relations under the noise pollution starts with the implementation of the transit alternative at the bottom, which causes three effects: 1) perceptible level of vibrations during construction and operation, 2) noise from transit facilities (stations, maintenance equipment and facility operations, etc.), and 3) noise from vehicle operation and diverted traffic. These three in turn cause the noise pollution in the region. The intensity of the noise pollution in the region is based on the presence of noise receptors in the region. Noise sensitive sites with low-density residential areas that give more importance to quite element in the neighborhood have a more severe effect on the noise levels than an industrial area or institutional area.

Apart from these two main influences there are two other major direct impacts of the transit alternative: effect on the aesthetics of the region and the conformity of the transit alternative with the state's air quality improvement plan. Both these influences have been listed in the FTA's Procedures and Technical Methods for Transit Project Planning (2005).

In all there are a total of four major impacts among which three are positive in nature: conformance with state plan, aesthetics, and air quality improvement and one negative in nature: noise pollution. The three positive impacts are aggregated using Sugeno's integral to get a single confidence level about the positive impact on the natural environment. The single negative impact would be combined with the negative impacts under other objectives of the project. This process is explained in detail later in the Section 7.3.

Operating Cost Efficiency

The FTA proposes the change in operating cost per passenger mile as the operating cost efficiency. Operating cost efficiency depends on two factors: operating costs and the transit ridership. The document Estimating the Impacts of Transportation Alternatives (1995) describes one way of expressing the constituents of operating and maintenance costs as 1) Costs measured per unit vehicle miles traveled, 2) Costs measured per unit vehicle hours traveled, and 3) Costs measured per unit number of vehicles.

The first cost element includes fuel costs and maintenance costs that depend on the amount of distance traveled by the vehicles. The second cost element includes driver wages and other costs for the employees. The third cost element includes costs incurred for cleaning and repairing of the vehicles and other amenities on the vehicle like power supply, which depend on the number of vehicles in service. Transit ridership determines the passenger-miles traveled through the transit service, which is an integral part of the operating cost efficiency. Transit ridership is the direct effect of the market competition between the transit service and automobiles and hence is shown as the immediate effect of the implementation of the transit service.

As seen in Figure 7.5 the operating cost efficiency is influenced by the increase in transit ridership and the operating and maintenance (O & M) costs. The O & M costs again are influenced by the three elements as discussed above. The O & M costs and the increase in transit ridership are both resulted from the implementation of the transit alternative. While the former is connected through the intermediate elements of the O & M costs, the later is directly affected by the implementation.

It should be noted that the effect of the constituent costs on the O & M costs are certain events and do not have any kind of uncertainty. In fact, these events are not cause effect relations in true sense and have been included in the chart just to emphasize the constituents of the major costs in the implementation of a transit service. Thus, the analysis of the causal relationships for the strength of agreement starts from the top of the three constituent elements of O & M costs. The arrows existing from the implementation to the three elements are shown in a different way to highlight this fact.

Cost Effectiveness

Cost effectiveness represents the total cost incurred for providing a unit amount of user benefits. Litman (2004) observes that the notion that rail transit is more costly than bus or even automobile transport as claimed by critics reflects a faulty analysis on their part. They usually consider just a small portion of total transit benefits and underestimate the actual costs of accommodating additional automobile travel under the same conditions like the costs of increasing road and parking capacity. van Ness

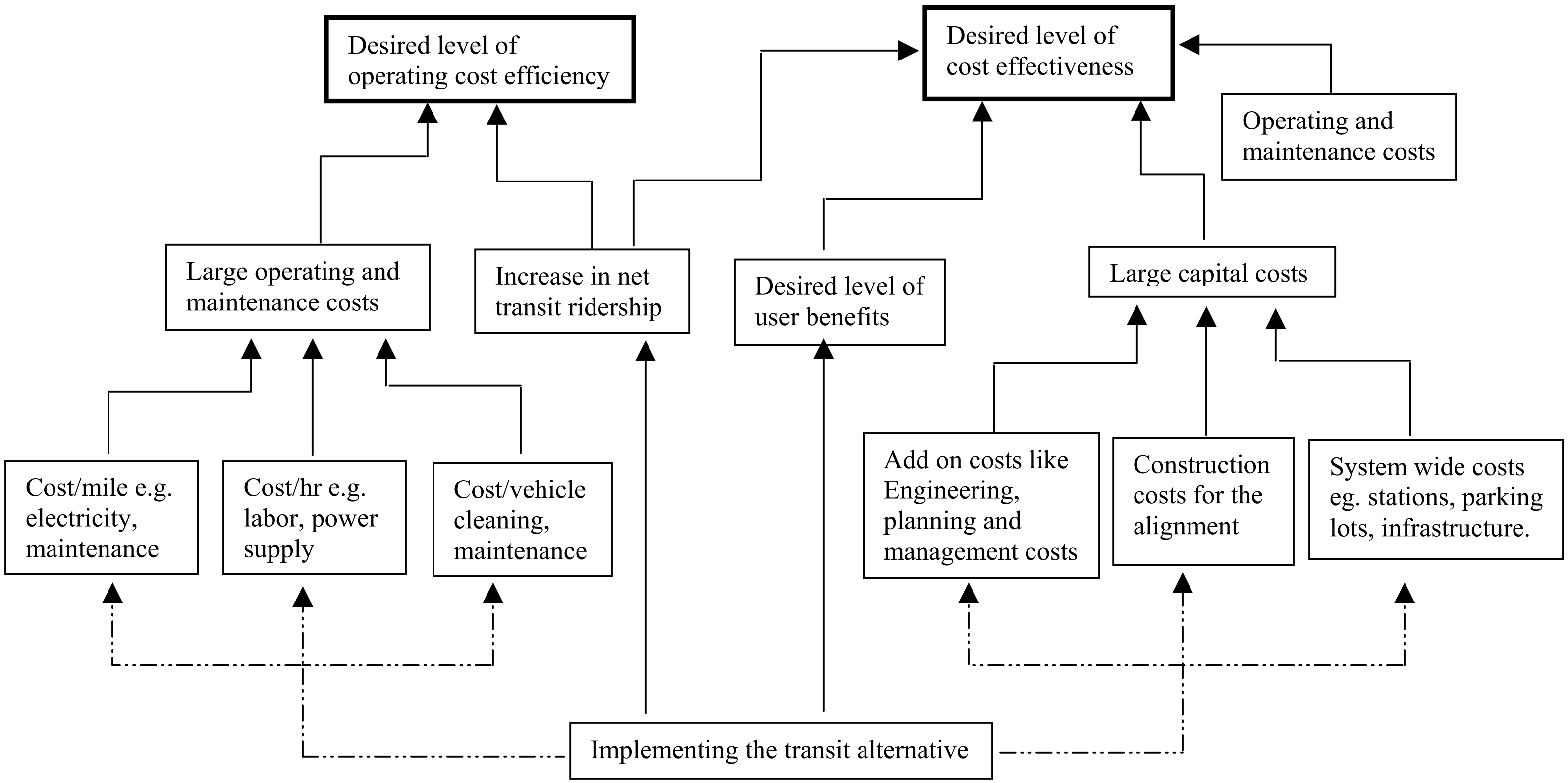


Figure 7.5 Cause effect relationship chart for operating cost efficiency and cost effectiveness.

(2002) proposed an analytical model for optimizing transit service networks wherein he defined the cost effectiveness as the ratio of total revenue and the operational costs.

User benefits can be transportation benefits like improvement in mobility and accessibility, which has been covered in the section of mobility and accessibility improvements. The total number of passengers riding the transit service is an indirect indication of endorsing the service and hence an indication of the magnitude of positive user benefits. Thus, the net transit ridership and the user benefits together represent the concerns of the user and define the cost effectiveness of the transit alternative, which can be considered as an indication of the effectiveness of the transit service in achieving the desired benefits.

Cost effectiveness reflects the benefits and interests of the users and the community while operating efficiency reflects the operators' benefits and interests. It should be noted that the objective is called cost effectiveness and not cost efficiency like in the previous objective. This is because the operators' benefit can be represented by number of passengers and passenger miles alone, whereas the benefit to the users and community depends on the perception of the user and can only be symbolically represented by parameters like hours of time savings or the number of passengers. Hence cost effectiveness would be more appropriate term for the user costs and operating cost efficiency is the suitable term for the operator costs.

The costs incurred for providing the above mentioned user benefits include capital costs and operating and maintenance costs. The elements of the operating costs are the same as mentioned in the previous section on operating cost efficiency. The document for estimating the impacts of transportation alternatives (1995) divides the capital costs into three main components: construction costs, system wide costs and add on costs. Construction costs depend on the alignment of the transit guideway or roadway as well as the mode of transit adopted for implementation. System wide costs consist of cost elements that are outside of the guideway and alignment costs. These include expenditures on vehicles, stations, power, signal systems, parking lots, lands etc. Add on costs consist of the planning and management costs and depend on the complexity of the project. Each of these three cost elements influence the capital costs resulting in large capital costs. Large is an adjective that has been added so that the relationship has a valid strength of agreement.

Now cost effectiveness depends on the operating costs also. The box on the extreme right of the chart in Figure 7.5 shows the effect of O &M costs on the cost-effectiveness. The box is assumed to have the three elements of O & M costs below it. The capital and the operating and maintenance costs are just two of the causes that affect the cost effectiveness. While these two for the part of the numerator of the cost effectiveness term the denominator is given by transportation benefits and the transit ridership. The transit ridership comes from the tree under operating efficiency, as it is common to both the objectives.

Socio-Economic Impact

The FTA has listed the different socio-economic impacts from the implementation of the transit alternative in Section 6 of Part II of the Procedures and Technical Methods for Transit Project Planning titled as Estimation of Socio-Economic and Environmental Impacts (1986). The transit service induces certain direct and indirect socio-economic impacts on the region and hence may be easy to identify but it is difficult to estimate the intensity of these impacts. The land use impacts of the transit project are mostly linked to the economic situation of the region. The FTA manual observes that the significance of the impacts is a matter of perception more than any kind of estimation.

Thus, the use of the proposed method will be effective as it can capture the perceptions of different analysts.

The chart in Figure 7.6 shows the hierarchical tree of the causal relations of socio-economic impacts. The chart clearly reveals two distinct sets of interactions leading to the ultimate aggregated socio-economic impact. All the direct cause effects relationships are listed on the right half of the chart and the indirectly affecting interaction are listed in the left part of the chart. There are a total three direct effects from the implementation of the transit alternative. These are 1) equity in providing opportunity, 2) disturbing the cohesion in the neighborhood, and 3) displacement and relocation. Of these, the first one is a positive impact and the last two are negative impacts on the socio-economic scenario in the region.

RTP 2025 (2005) mentions that transportation equity is referred to as environmental justice and should be part of every mission of federal agency according to the Title VI of the civil rights act of 1964 and a 1994 presidential executive order. Equity considerations for the region according to the RTP 2025 are to ensure that the negative impacts of the transportation system, such as displacement, pollution, or destruction of existing environment and the benefits of transportation, mobility, and accessibility are fairly shared between all segments of the population.

The two negative impacts are the other two direct impacts of the implementation. Development of a new urban transportation system usually needs some kind of displacement and relocation of families, businesses or public facilities. The severity of these displacements depends on the present conditions and the standard of living of the affected parties. Thus, this issue needs to be analyzed by incorporating the perception of the affected people, which can be done in the proposed analysis. The disturbance of cohesion in the neighborhood is another direct effect, which has a lot of prominence from the perspective of the community. Manville and Shoup (2004) have studied the reason for the lack of urbanity or cohesion in the CBD of the city of Los Angeles. The authors believe that the zoning requirement related to providing parking for the new jobs created in the city is the main culprit in having a very dense downtown as well as suburban area around LA.

The indirect cause-effect relations are all in the left half of the chart shown in Figure 7.6. The left most among the four in this category is the effect of redistribution of regional urban development on the socio-economic scenario. Urban sprawl is a major impact on the socio-economic condition. This effect is cause by the implementation of transit alternative through the improvement of mobility. The mobility improvement drives the creation of jobs in the region too. Employment opportunities from creation of jobs can be caused from the increase in the local economic activity also. Thus, there are two chains that lead to creation of jobs (apart from directly getting influenced from the transit implementation), which in turn affects the socio-economic scenario.

The increase in local economic activity is influenced directly from the transit implementation as well as from the creation of jobs in the region. The arrows between the creation of jobs and the economic activity are in both directions, which is actually true. Either of these two drives the other. Politicians like to say that jobs lead to economic development, which is true, but sometimes, economic development leads to more jobs coming in because companies like being located in a safe place with good accessibility and plenty of social and recreation options.

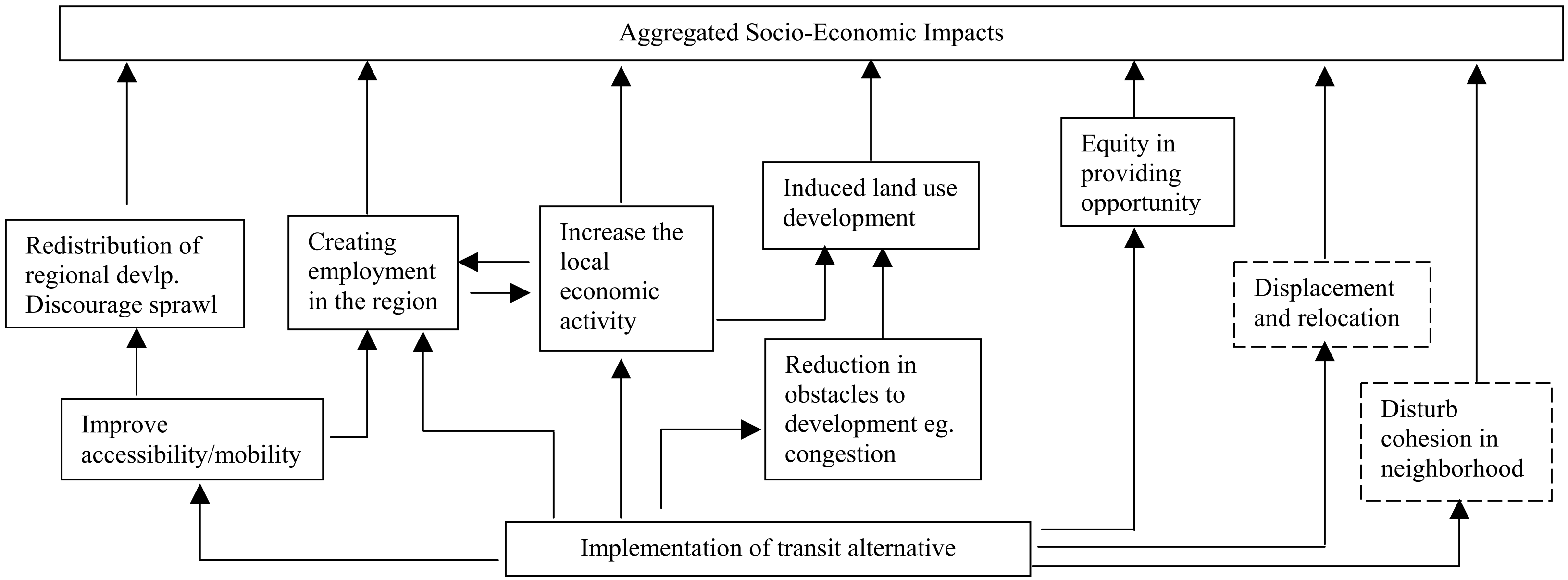


Figure 7.6 Cause effect relationship chart for socio-economic impact

The induced land use development is also influenced by the reduction in obstacles to urban development (e.g. congestion) from the transit implementation and also the increase in local economic activity. These two parallel causes effect the land use development, which in turn has effects the socio-economic scenario. Many of these interrelated cause effect relations are egg and the chicken kind of problems. Cervero (2003) has done extensive research in the aspects of studying such a cause-effect chains between the supply and demand under the title of induced demand phenomenon. In these circumstances the chronological sequence of the events cannot be determined clearly. The proposed method however provides the facility to consider both the possible cause effect relationships that can occur.

The confidence levels of all the impacts (five positive and two negative) caused by the events that come under the objective of socio-economic impact on the region are aggregated using Sugeno's integral to obtain the overall confidence in the achievement of the positive of negative influence on the socioeconomic scenario of the region caused by the implementation of the transit alternative.

7.2 Analyzing the Subsystems

The last section delved about the decomposition of the large-scale system into smaller subsystems. The charts discussed in the last section present the cause effect relationships under each objective of the transit investment project. The next step in the proposed method is to analyze the subsystems. The interactions between the subsystems are the cause effect relationship between each pair of subsystems. These relationships occur in a systematic order starting from the basic event of implementation of the transit alternative. From this event the interactions between the subsystems go all the way to the achievement of the five objectives.

Downs (2004) in his paper on congestion has suggested that it is better to learn to live with congestion, as it is almost certain to get worse at any cost in near future. He believes that congestion is a mark of prosperity and encourages people to learn to make congestion a part of their daily life. He identifies four possible ways to reduce traffic congestion: charge peak hour toll, expand road capacity, expand public transit and living with congestion. He discards the first three as either politically or financially infeasible in U.S. But there are strong supporters of transit as the ideal solution for congestion like Vuchic (2003) who points out that reports such as these that are noncritical, narcissist and void of innovative solutions is a serious issue in today's transportation scenario and it reflects the prevailing influence of persons defending the status quo.

In order to come up with a good solution for public projects that satisfies in a best possible manner, the concerns and the interests of a majority of the stakeholders it is necessary to incorporate the voice of a diverse set of people with varying beliefs and values. The proposed method aims at achieving this by considering the public opinion in this step of analyzing the subsystems.

Approaching a set of experts has been adopted time and again especially in the decision making of the systems that involve public interest. This kind of analysis by the experts helps in getting a valid credible opinion about the performance of the subsystems or the system on the whole.

Sharifi et al. (2004) apply an MCDM method for the evaluation of an integrated plan for public transport system wherein a hierarchy of the various elements involved in the decision-making called as the criteria tree, is developed with the ultimate goal of the project at the top and the objectives, criteria and performance indicators coming at the lower levels. The relative importance of the various indicators, criteria and objectives is obtained by interviewing people in two groups of stakeholders, one being political, and the other being technical in composition.

Horowitz and Thompson (1995) established the important objectives and goals involved in the design of intermodal transfer facility from a list of 70 generic objectives by interviewing a panel of experts and asking them to rate each objective. The panel members were selected carefully and were divided into three groups. The rating scale used in the survey was from 0 to 10 and it was observed that most of the members rated the objectives fairly high.

7.2.1 Expert groups

The subsystems in the proposed method are analyzed by taking the expert opinion about the each causal relationship into account. The selection of the experts is not done in ad hoc basis but is done systematically by keeping in mind the proficiency of each expert in terms of the knowledge about the project under consideration and exposure to similar public investment systems. It should be noted that in this process of analysis the analyzing model is the expert himself and the input information and the output of result takes place with respect to the expert as explained in the section 4.4.

In all a total of 10 experts were considered for the analysis process. These experts have been grouped into three broad groups: 1) Experts from local planning agencies, 2) Non-local experts, and 3) Local experts. The identity of each of these three groups is discussed below:

Group1: Experts from local planning agencies

The experts in this group have been chosen from three different planning agencies namely Wilmington Area Planning Council (Wilmapco), Transportation

Management Association (TMA) and Delaware Transit Corporation (DTC). Out of these one official from Wilmapco and the official from TMA were present in the Monorail management committee. The monorail management committee consisted of 9 representatives from the major local transportation planning agencies as well as regional government decision-makers. This expert group consisted of another official from Wilmapco who was in the Management committee of the Route 40 corridor 20-year improvement plan. Thus, this expert group has a good level of representation of the two main projects that are related with the study in the thesis: monorail project and route 40 corridor project. The fourth member in the group is from Delaware Transit Corporation, which is the transit sub division of DelDOT.

Group2: Non local experts

The experts in this group are people who are from outside the State of Delaware. These experts give their opinion from the perspective of an outsider to the project. The people in the group are adept in understanding the transportation related problems in general and have been involved with the planning and development of transit services. One of the group members in this group is from FTA, whose opinion will represent the viewpoint of the FTA, which makes the ultimate decisions in such transit projects. The second member is an official from Virginia Department of Transportation. The third member is from the academic community who has been actively involved with transit systems and has evaluated the benefits of monorail compared with other modes of transit. This group is a good collection of people who though are not familiar with the microscopic features of the project being considered but have a very good know-how about the impacts of the project at the macroscopic level.

Group3: Local experts

The members of this group are the people who are very well aware with the local transit scenario and also very qualified in terms of experience in studying the transportation projects. This group consists of a professor from the department of Transportation Engineering, an associate professor from the department of Marine Studies, and a senior citizen who was the chairman of the transit committee for the City of Newark. These people are local residents of the region and represent the perspective of the users and the community. Compared to the experts in the second group, this group has a better idea about the transportation problems in the region of interest. This group also provides more unbiased opinion compared to the experts in the first group, as they are not affiliated to any transit planning agency.

7.2.2 Obtaining the Expert Opinion

The experts were asked to take part in the survey as part of the proposed method. They were approached either in person or through phone conversation. The discussion with the experts about the project details and about the survey was done though phone conversation for the non-local experts alone. The local experts and the experts from local planning agencies were all approached in person. The procedure of interviewing all the experts was common. They were given a short description of the project and given details related to each objective of the project based on the information from the Monorail Exploratory Study (2003) and Route 40 corridor improvements plan (2000).

The experts were asked to assign a number between 1 and 10 that relates to the strength of their agreement for each cause effect relationship expressed in the charts shown in Figures (7.3, 7.4, 7.5, and 7.6). Each arrow that represents a cause effect relationship was rated based on each individual's knowledge about the whole project. The rating of 1 indicates very little agreement about the causal effect and the rating of 10 indicates total agreement of the relationship. The respondent is encouraged to freely express his opinion based on his knowledge and exposure to similar projects and the survey is aimed purely to capture the unique perspective of an expert. No negative values are used for confidence measures in the survey.

Though the ratings are from 1 to 10, these numbers are converted into confidence measures by multiplying them with 0.1. The whole intention behind using numbers from 1 to 10 instead is that it is easier for people to rate any given statement on a scale from 1 to 10 instead of a scale from 0.1 to 1. The rating on a scale of 10 is commonly used for measurement in the daily life like one's strength during job interviews, grade points for courses, fitness levels in exercises etc.

Figure 7.7 shows a sample rating of the causal relationships for the chart of mobility and accessibility improvement.

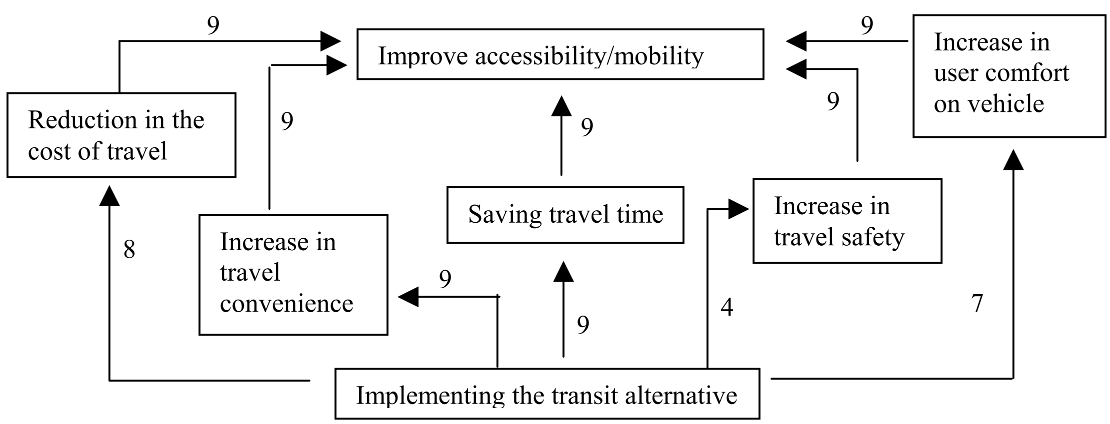


Figure 7.7 Sample ratings for the evaluation of achieving improvement in accessibility and mobility

It should be noted that the opinions from the experts have been considered for the affirmative cause-effects alone. In other words the expert has not been given the choice of rating the cause-effect in terms of disagreement about the relationship. This could be done by allowing the experts to rate on the negative scale for any disagreement. The negative value of the confidence measure indicates the strength in the negation of the causal relation. However, most of the causal relationships in the charts provided to the experts are affirmative in nature and very rarely are considered the other way around.

7.3 Step 3: Aggregation and Interpretation of Results

This section explains about the aggregation of the opinions obtained from different experts and the interpretation of the results from each level of aggregation. The exact procedures for the aggregation have been explained in Chapter 5. This section deals with the fourth step of the analysis process as described in section 4.5 of Chapter 4. The process of aggregation is essentially the evaluation of the responses. The responses of each cause-effect relationship do not reveal anything about the overall system without aggregation. It is only when the responses are looked at after combining them in a systematic manner that the responses produce the evaluation of the project. After the responses are evaluated the interpretation of the results is a matter concerning with the decision maker and analyst as well as the experts. The four steps involved in the proposed analysis culminate with the evaluation of the responses, but the decision-making based on the analysis process is considered finished only with the appropriate interpretation of the results obtained from the evaluation of responses.

7.3.1 Evaluations of the Responses

As mentioned above, the evaluation of responses in nothing but aggregation of the responses in the four levels discussed in Chapter 5. In this section the aggregation done at each level for the expert opinions in the form of a number on a scale from 1 to 10 is presented.

Level 1

The responses of each expert for each of the four charts are first aggregated based on the order in which the causal relationships occur in the chart. The relations in sequential and parallel order are aggregated according to the equations 4.3, and 4.4. In the next few pages, the calculations for obtaining the combined opinion of a given experts on each objective is show. Consider the response of an expert to the mobility and accessibility improvements. The chart and the ratings for the causal relations are shown in Figure 7.8.

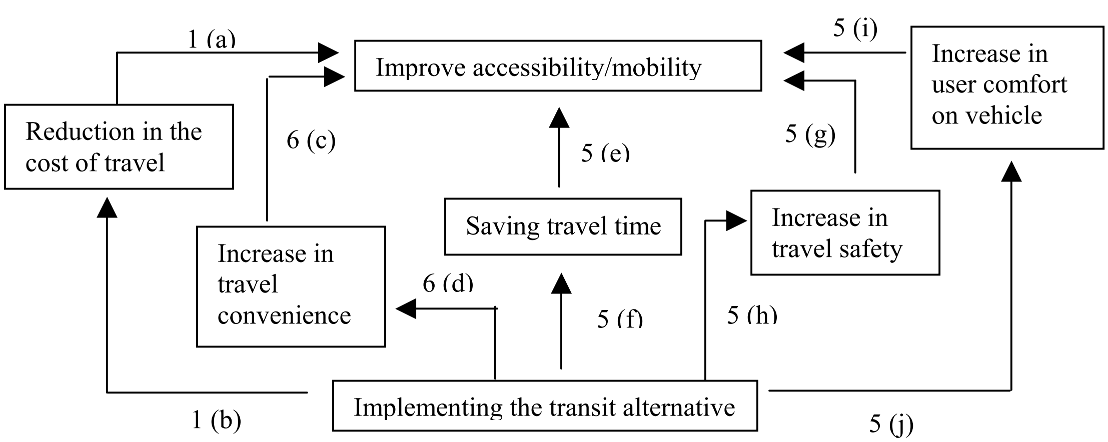


Figure 7.8 Calculation of overall confidence measure for achieving improvement in accessibility and mobility

Figure 7.8 shows the confidence value on a scale of 1 to 10 followed by a variable in parenthesis that is assigned to each causal relationship. The confidence values are first scaled down within a range of 0 to 1 by dividing each number with 10. The formula for obtaining the overall confidence based on confidence values obtained from Figure 7.8 can be expressed as:

$$C = P\left\{S(a,b), S(c,d), S(e,f), S(g,h), S(i,j)\right\} \tag{7.1}$$

where,

P (X_1, X_2, …, X_n) indicates that the n causal relations are combined in parallel order using the Equation 4.4 and

S (X_1, X_2, …, X_n) indicates that the n causal relations are combined in sequential order using the Equation 4.3

Thus, Equation 7.1 is an expression for combining five parallel causal relations each of which again is obtained from the sequential combining of two causal relations. The five parallel relations give a value of 0.01 (0.1 X 0.1), 0.36 (0.6 X 0.6), 0.25 (0.5 X 0.5), 0.25 (0.5 X 0.5), 0.25 (0.5 X 0.5) for the relations involving the pair a and d, pair c and d, pair e and f, pair g and h, and pair i and j, respectively. The parallel combination of these five confidence measures would result in a value of 0.73. This is based on the following calculations.

P (0.01,0.36, 0.25, 0.25, 0.25) = P [P (0.01,0.36), P {P (0.25,0.25), 0.25}]

= P [0.366, P{0.437,0.25}]

= P [0.366, 0.578] = 0.732

Thus, the total strength of agreement for the mobility improvements as expressed by the given expert is 0.73, which is seen in the mobility accessibility improvement column and Group 1 row in the matrix shown in Figure 7.1.

Table 7.1 shows the evaluated results of all the ten expert's responses for the five different objectives. The negative and positive impacts on socio-economic and environmental impact are aggregated separately as they are different in terms of the ideology of evaluation.

Table 7.1: Confidence value for the opinion of each expert about the achievement of the objectives.

	Objective No.	1	2	3	4	5	6	7
S.No	Expert Group	Mobility/ Accessibility	Socio-economic Impact		Cost Effectiveness	Operating Efficiency	Environmental Impact	
			Positive	Negative			Positive	Negative
1	Group 1	0.73	0.9	0.15	0.58	0.56	0.28	0.62
2	Group 1	0.95	0.9	0.3	0.94	0.9	0.99	0.06
3	Group 1	0.86	0.98	0.13	0.89	0.7	0.8	0.45
4	Group 1	0.98	0.99	0.87	0.95	0.91	0.94	0.95
1	Group 2	1	1	0.25	1	0.96	0.96	0.25
2	Group 2	0.98	1	0.51	0.98	0.82	0.95	0.31
3	Group 2	1	0.95	0.03	0.96	0.72	0.77	0
1	Group 3	0.96	0.73	0.07	0.9	0.66	0.82	0.02
2	Group 3	0.68	0.6	0.01	0.47	0.1	0.3	0
3	Group 3	0.97	0.99	0.4	0.97	0.9	0.96	0.91

As seen in the table the experts are grouped in the three groups. The next step would be aggregating the opinions of the experts within a group.

Level 2

The opinions of the experts are combined within a group for each objective. The outcome of this aggregation gives the opinion of each of the three groups about the achievement of each of the five objectives. The aggregation is done based on the equation

(5.1). Table 7.2 shows the confidence levels of each group for the five positive impacts and two negative impacts.

Consider the negative socio-economic impact of Group 1. The responses expressed by the four experts in Group 1 are 0.15, 0.3, 0.13, and 0.87. These values are confidence levels of each of the expert obtained by aggregating the confidence values of the parallel and sequential cause-effect relationships in Level 1.

Assume a group confidence level of 0.6, then the value of $C_0 = 0.6$ should satisfy equation 5.1, where $C_\alpha > C_0$ for $\alpha \leq t$ and $C_\alpha < C_0$ for $\alpha \geq t$.

$$\frac{\sum_{\alpha=1}^{t}(C_\alpha - C_0)}{\sum_{\alpha=t+1}^{N}(C_0 - C_\alpha)} = \frac{1-C_0}{1+C_0}$$

which, is given by the following expression

$$\frac{(0.85-0.6)}{(0.6-0.15)+(0.6-0.3)+(0.6-0.13)} = \frac{1-0.6}{1+0.6} \tag{7.2}$$

It can be seen that the value on the right hand side of equation 7.2 is 0.25 and the value on the left hand side is 0.20. Thus the assumed value of 0.6 is not correct. Hence, a next value with an increment of 0.001 to the initially assumed value of 0.6 is tested for equation 7.2. The trial and error testing is continued for all the values between the minimum (0.15) and the maximum (0.87) confidence values of the four experts. The minimum being 0.15 the values with an increment of 0.001 starting from 0.15 are all tested using equation 5.1. The value for which, the difference between the left hand side and the right side of the equation 5.1 is within a tolerance limit of 0.005 is selected as the group confidence level. The value of C_0 for Group 1 and negative socio-economic impact is calculated to be 0.552. Substituting this in equation 5.1, it can be seen that

$$\text{R.H.S} = \frac{(0.85-0.552)}{(0.552-0.15)+(0.552-0.3)+(0.552-0.13)} = \frac{0.298}{1.053} = 0.283$$

$$\text{L.H.S.} = \frac{1-0.552}{1+0.552} = \frac{0.448}{1.552} = 0.288$$

The confidence level C_0 is obtained through trail and error by testing different possible values between the minimum and the maximum confidence levels of the group. In order to compute the value of the confidence level of the group opinion, a code has been written in Matlab. The programme is provided in Appendix B. The confidence value obtained from the code for Group 1 corresponding to the negative socio-economic impact is 0.552. See Table 7.2.

Table 7.2: Confidence value for the opinion of each group for the five positive impacts and two negative impacts

Objective No.	1	2	3	4	5	6	7
Expert Group	Mobility/ Accessibility	Socio-economic Impact		Cost Effectiveness	Operating Efficiency	Environmental Impact	
		Positive	Negative			Positive	Negative
Group 1	0.973	0.988	0.552	0.938	0.889	0.974	0.806
Group 2	1.000	1.000	0.322	1.000	0.949	0.954	0.211
Group 3	0.964	0.981	0.193	0.955	0.804	0.930	0.616

The confidence level of the opinion of an optimistic person will be greater than the overall confidence level of the group opinion, and the confidence level of the opinion of a pessimistic person will be less than the confidence level of the group opinion. The group confidence value is the unbiased response obtained based on the pessimistic and optimistic responses of the experts. In other words, if the confidence levels of the experts are very different from each other then, the group opinion from the aggregation gives an indication of the measure of bias expressed by each expert.

Level 3

The aggregation at this level combines the confidence levels for all group opinions into one single confidence level. The group opinions are combined for each objective, which in the present case would result in one value each for the five positive impacts and one negative impact. The aggregation used is the simple weighted mean aggregation. Equation (5.2) is used for the computations. The weights assigned for the three groups depend on the nature of the groups and signify the value given to the opinion of each group. The weight set adopted reflects the perception of the decision-maker in terms of the importance or credibility that the decision-maker assigns to each group of experts in the whole process of project planning and development.

A total of five different weight sets are adopted in the analysis to reflect five different viewpoints and values of the stakeholders. Each of these weight sets is given below:

Weight Set 1: Group1 (0.5), Group 2 (0.2), Group 3 (0.3)

Weight Set 2: Group1 (0.6), Group 2 (0.2), Group 3 (0.2)

Weight Set 3: Group1 (0.2), Group 2 (0.2), Group 3 (0.6)

Weight Set 4: Group1 (0.2), Group 2 (0.6), Group 3 (0.2)

Weight Set 5: Group1 (0.33), Group 2 (0.33), Group 3 (0.33)

It can be seen that the first weight set reflects a reasonable degree of importance assigned to the three groups. Group 1 consists of the people who have the best knowledge about the project being studied due to their involvement with the transit planning agencies. Hence it has got the maximum weight among the three groups. Group 3 with local experts is more aware with the transit scenario and the transportation problems of the region compared to the non-local experts of Group 2, which is reflected in the corresponding weights of 0.3 and 0.2, respectively.

Weight set 1 assigns a reasonable set of values as the weights for the three groups, with more importance given to Group 1 consisting of local planning agencies, and higher importance to the local experts of Group 3 compared to the non-local experts of Group 2. Weight set 5 gives equal importance to all the three group of experts, while, with Weight sets 2, 3, and 4 give more prominence to group 1, 3, and 2, respectively. These weight sets are aimed at presenting the scenarios where any single group of stakeholders holds more dominance over others in the decision making process. The combined group opinion values for the five different sets are shown in Table 7.3.

The calculations for combining the three group opinions are explained as follows. Consider weight set 2, and the objective cost-effectiveness. The values representing the confidence levels of Group1, Group 2, and Group 3 in achievement of cost-effectiveness are 0.938, 1, and 0.955, respectively. See Table 7.2.

Table 7.3: Final confidence levels of achieving the objectives for different weight sets

Objective No.	1	2	3	4	5	6	7
Weight Set No.	Mobility/ Accessibility	Socio-economic Impact		Cost Effectiveness	Operating Efficiency	Environmental Impact	
		Positive	Negative			Positive	Negative
1	0.976	0.788	0.398	0.956	0.876	0.957	0.630
2	0.977	0.789	0.434	0.954	0.884	0.961	0.649
3	0.973	0.786	0.291	0.961	0.850	0.944	0.573
4	0.987	0.394	0.342	0.979	0.908	0.953	0.411
5	0.969	0.650	0.352	0.955	0.872	0.943	0.539

Using the equation 5.2, for the weight set 2, the expression for the combined confidence level is given by

$$G = (0.938 \text{ X } w_1) + (1 \text{ X } w_2) + (0.855 \text{ X } w_3)$$

$$G = (0.938 \text{ X } 0.6) + (1 \text{ X } 0.2) + (0.855 \text{ X } 0.2) \quad (7.3)$$

Where, G is the confidence level aggregated from the three groups. The value of G obtained from equation 7.3 is 0.954, which can be seen in the entry for weight set 2 under cost-effectiveness in Table 7.3.

Level 4

The final stage of aggregation aims at combining the group opinions for all the objectives. It should be noted that the group opinion for the positive and negative impacts must be joined separately as there is a fundamental difference between the two types of impacts. Accordingly, the five positive impacts are joined using Sugeno's integral and the two negative impacts are joined using their mean value. The reason for using mean for the negative impacts is that there are only two values for the negative impacts and Sugeno's integral will either result in minimum or maximum of the two values. Instead a mean value would be more appropriate. Sugeno's integral is used for the aggregation for the positive impacts, as the objectives are interrelated and hence difficult to be assigned weights that add up to unity. A more detailed explanation has been given in section 5.4.

An example calculation of the aggregation for the weight set 1using Sugeno's integral is discussed below. From the first row of Table 7.3, the group opinions about the five positive impacts that have to be combined are obtained. Table 7.4 (b) shows the five values with the confidence values corresponding to the five positive impacts. Table 7.4 (a) shows the same five values in an ascending order of the confidence values corresponding to the positive impacts. The numbers for the positive impacts are assigned in Table 7.1. It can be seen that the socio-economic impact has the lowest confidence level and the mobility and accessibility improvement has the highest confidence level.

Table 7.4: Confidence level of achievement of each objective (a) ascending order (b) normal order

Confidence level of objective	Objective no.
0.7883	2
0.8755	5
0.9555	4
0.9568	6
0.9758	1

(a)

Confidence level of objective	Objective no.
0.9758	1
0.7883	2
0.9555	4
0.8755	5
0.9568	6

(b)

As explained in section 5.4 the analyst is required to provide the values of the membership function in the calculations of Sugeno's integral. The membership function values represent the importance of a set of elements that are combined using the Sugeno's integral. Table 7.5 shows the membership values of the subsets.

Table 7.5: Membership values for the different subsets obtained for weight set 1, and 2.

Elements in the sub set	Membership value
2,5,4,6, and 1	1
5,4,6, and 1	0.8
4,6, and 1	0.7
6 and 1	0.4
1	0.25

Based on the membership values given in Table 7.5 and using the expression for the Sugeno's integral presented in Equation 5.4, the value of final aggregated value for the confidence about the satisfaction of achieving the positive impacts is obtained. This value is found to be 0.8. The confidence levels of the two negative impacts in socio-economic and environmental impacts, for weight set 1 are 0.398, and 0.630, respectively.

The average of these two values is taken as the final confidence level, which is given by the value 0.51.

The ascending order of the confidence values of the objectives for weight set 2 is same as that of weight set 1 as shown in Table 7.4 (a). Hence, the order of the subsets for weight set 1 shown in Table 7.5 is same for weight set 2. The order of subsets for weight sets 3, 4, and 5 are same. The corresponding membership values for the weight sets 3, 4, and 5 are shown in Table 7.6.

Table 7.6: Membership values for the different subsets obtained for weight set 3, 4, and 5.

Elements in the sub set	Membership value
2,5,6,4,and 1	1
5,6,4,and 1	0.8
6,4, and 1	0.7
4 and 1	0.5
1	0.25

The working of the Sugeno's Integral is depicted in Figure 7.9. The calculation involved in equation 5.4 is shown graphically in Figure 7.9.

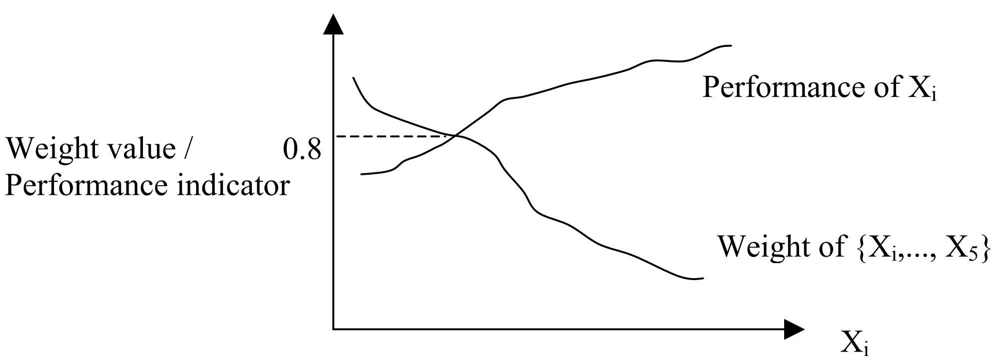


Figure 7.9 Sugeno's Integral: Weight function and performance function

The values of the performance function for each element X_i, in ascending order are plotted. The corresponding values of the weight function, which is the membership function of the set consisting of all the elements with a performance value greater than or equal to that of the given element, are also plotted. The Sugeno's integral considers the maximum value of the minimum of these two plots as the final solution.

7.3.2 Findings and Summary of Results

Consistency:

In the analysis, the response of the experts is tested for consistency. Consistency, in this context refers to showing a constant level of bias for the cause-effect relationships that are similar. Consistency gives an indication that the perspective of an expert remains same through out the analysis process. Comparing the confidence measure for the same causal relation expressed in two different ways in the hierarchical charts during the analysis checks consistency. The cause-effect relationship for improvement in accessibility and mobility appears in two different instances in the logical chain of reasoning. In the socio-economic chart (refer Figure 7.6), it appears as a direct effect from the implementation of the project, in the mobility improvement chart (refer Figure 7.3) it is represented as the objective obtained as an outcome of many indirect relationships. Table 7.7 shows the opinion about this cause-effect relationship in the two charts from different experts. The values under the column "Mobility accessibility chart" are obtained from aggregation of the confidence values of the causal relationships for each expert. These values are same as the values in the first column of Table 7.1. The values under the column " Socio-economic chart" are obtained from the responses given by each expert in the form of the confidence value for the causal relationship between the implementation of transit alternative and accessibility improvement. (Refer Figure 7.6)

Table 7.7 Consistency in the response of the experts by comparing the confidence measures

Expert number	Group number	Mobility accessibility chart	Socio-economic chart
1	Group 1	0.7312	0.5
2	Group 1	0.95	0.6
3	Group 1	0.86	0.6
4	Group 1	0.98	0.8
1	Group 2	1	0.8
2	Group 2	0.98	0.8
3	Group 2	1	0.8
1	Group 3	0.96	0.85
2	Group 3	0.68	0.4
3	Group 3	0.97	0.5

The values in the Table 7.7 refer to the consistency of each expert in evaluating the same causal relationship in two different contexts. The causal relationship being tested for consistency is mobility and accessibility improvement, and the contexts are based on the two objectives mobility improvement, and socio-economic impact. Assuming a tolerance of 0.2 as the allowable variation between the two responses, it can be seen that expert 3, and expert 4 in Group 1, all the experts in Group 2, and expert 1 in Group 3 have been consistent in their responses. Among the ten experts, expert 3 of Group 3 has been the least consistent. Among the three groups, the experts in Group 2 have been better, with respect to consistency in their evaluation, when compared to the other two groups.

Alternative Evaluation:

Consider the two final values obtained from the analysis. The values have been calculated in the section Level 4. The values are given by:

Positive Impacts: 0.8 and

Negative impacts: 0.51.

These two values are presented to the decision-makers for helping them in understanding the overall confidence level of all the experts. Similar such values for other alternatives can be computed based on the opinion of the experts. Based on these aggregated confidence values obtained for all the alternatives, a decision regarding the recommendation of the alternative can be made.

Weight Set Consideration:

The computations presented for weight set 1 were performed for all the remaining 4 weight sets also. These results are shown in Table 7.8.

Weight Set 1: Group1 (0.5), Group 2 (0.2), Group 3 (0.3)

Weight Set 2: Group1 (0.6), Group 2 (0.2), Group 3 (0.2)

Weight Set 3: Group1 (0.2), Group 2 (0.2), Group 3 (0.6)

Weight Set 4: Group1 (0.2), Group 2 (0.6), Group 3 (0.2)

Weight Set 5: Group1 (0.33), Group 2 (0.33), Group 3 (0.33)

Table 7.8: Overall confidence levels for positive impacts and negative for the different weight sets

Weight Set	Negative Impacts	Positive Impacts
1	0.515	0.8
2	0.542	0.8
3	0.432	0.8
4	0.377	0.8
5	0.4455	0.8

It can be seen that the overall confidence level about the positive impacts remains same but the overall confidence level about the negative impacts changes with the dominating group among the three expert groups in the decision-making. Each type of weight set adopted for the analysis will result in a unique value indicating the strength of confidence about the negative impact that the Monorail project extension can result in the region of Route 40 corridor.

To summarize the results from the proposed method, the decision makers can be now given numbers that represent the opinion of all the stakeholders involved with the project in a best possible manner.

Chapter 8

DISCUSSION

This chapter discusses the advantages, applications, and some points to consider during the formulation with respect to the proposed method.

8.1 Advantages

The advantages of the proposed method are the following:

- A very useful feature of this process is that we can identify the weak spots in the causal relationships in terms of high uncertainty and assess the issues to be studied for further research in the planning of large investment projects.
- The proposed method performs the decision-making by incorporating all the three main sources of uncertainty (from the large number of interactions in the system, the subjective nature of the objectives, and the diverse set of benefits and concerns of the stakeholders) involved in the analysis of large-scale public projects. The method provides a solution by considering the lack of information in the analysis process in a reasonable and logical manner.
- The interests and concerns of the various stakeholders involved in the decision-making of large public projects are represented in the proposed method. The decision-making paradigm can consider the dominance in the perspectives of certain groups of stakeholders over others.
- The decision makers are presented a set of values, which reflect the collective opinion of a group of people about their strength of confidence in achieving a

given objective from the implementation of the large-scale public investment project. These numbers will make it easier for the decision making body to understand the public opinion and facilitates a sound judgment on the part of those involved in final decision making process.

8.2 Applications

The basic framework of the systems that can be analyzed using the proposed method of decision-making is that of a large-scale public investment project which is characterized by multiple and often conflicting objectives and involves large number of variables and interactions, and requires understanding and incorporating the values and interests of a wide spectrum of stakeholders.

Based on the characteristics of the large-scale projects described above, the proposed method can be applied to many large-scale investment projects. The proposed method can be applied at any stage in the planning and development of transportation projects.

Though the project that has been discussed as an example for application involves mostly qualitative information about the variables involved in the interaction, but the method can be applied for projects, which have more quantitative information about the interactions. The experts can be provided numbers about the exact performance of different attributes and asked about the confidence in the cause-effect relationship. This makes the method open for application in the systems where in the variables are deterministic at many levels like for example the election of a candidate based on his performance on the implementation of various government schemes and the overall growth factors in the region. Also the proposed method can be applied in other fields like decision-making about public policies, financial planning and future investments in a state or county, reaching a consensus in a committee.

8.3 Points to Consider

- The proposed method relies heavily on the opinions of the experts who are consulted for the analysis of the system. It is very much possible for encountering a lack of consistency in the opinions of the people being approached. Though this phenomenon is unintentional but still it needs to be checked for validating the overall response of an expert. Having a similar cause-effect relationship at two different places with one being a direct relationship and another being an indirect relationship can check the consistency in the response.
- Another important point to keep in mind while formulating the causal relationship charts is that the level of consistency exhibited in developing the cause-effects for the different objectives must be more or less constant through out. In other words, explaining some of the objectives in a more detailed manner while the others being depicted with minimum level of steps in the causal relationship charts should be avoided. Though it is not a limitation, but it should be implemented to ensure that unnecessary information or uncertainty does not creep into the formulation of the analysis. Though this has not been proved mathematically but it is an interesting issue to be considered for future study.
- The formulation of the subsystems of the transit project can be developed in different formats. The three objectives of socio-economic impact, environmental impacts and mobility improvements can act as the variables that influence the cost effectiveness. In other words there can be hierarchy among the objectives themselves. Such a representation might be more practical way of representing the actual scenario. But, it

might be difficult for the experts to analyze such interrelationships between the project objectives.

8.4 Interpretation of the Confidence Measure

The expression between uncertainty and confidence is given by

$$U = log\ (1/c) \qquad (8.1)$$

as explained in section 3.2.4.2. The graphical representation for just the positive values of confidence being considered in the proposed analysis is shown in Figure 8.1

As the figure indicates, at high confidence levels, even a small increase in the uncertainty would correspond to a significant decrease in the confidence level. However, at low confidence levels, only a very large increase in the uncertainty would result in a considerable decrease in the confidence level. The relationship shown in the figure indicates that for large confidence level values, even a minute level of difference in the values should be looked at carefully. While on the other hand, for low confidence levels, the difference between the confidence levels can be assumed to more or less imply a same significance level.

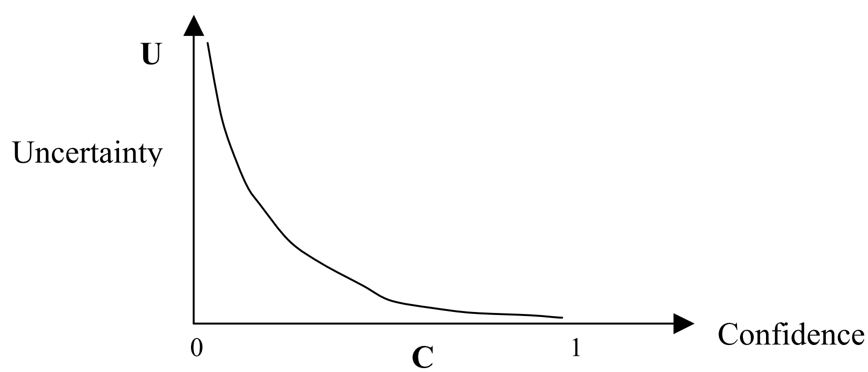


Figure 8.1 Uncertainty and Confidence

The interpretation of the confidence measures about the satisfaction of the achievement of the objectives from the implementation of a given alternative obtained from the analysis process should be done carefully. The confidence measure values are ordinal in nature and are not proportional. For example a confidence of 0.8 for a causal relation does not mean that it represents twice as much confidence with a value of 0.4. The confidence measures signify only the order.

Consider two alternatives that have to be evaluated, one alternative being the implementation of a transit service and the other being status quo. Suppose the transit service has a confidence value of 0.2 and the status quo has a value of 0.5, then it doesn't mean that status quo should be recommended. In fact the values reveal that the strength in agreeing to the achievements from the transit service is very less. This implies that there should be more studies undertaken. Also the performance indicators of the transit service need to be changed such that the objectives of the project are more feasible and achievable.

The final values present the degree of feasibility of each alternative achieving the objectives, as expressed by the different stakeholders involved in the project. The alternatives with low confidence values imply that the stakeholders are doubtful about the achievement of the objectives. The FTA can then send the project back to the local planning agencies for modifying the project specifications and improve the performance parameters of the alternative such that the benefits of the service are more predictable.

The proposed method analyzes the performance of different alternatives under a given set of project characteristics and performance indicators to determine the possibility of attaining the desired outcome in terms of mobility improvements, environmental benefits etc.

Chapter 9

CONCLUSION

The issue presented in this analysis is that the proposed decision-making method can incorporate the uncertainty without compromising the efficient use of available information. The motivation for the study of this thesis was to present a decision-making paradigm that can incorporate the three sources of uncertainty in the analysis of large-scale public projects namely presence of large number of interactions in the system, the subjective nature of the objectives, and the diverse set of benefits and concerns of the stakeholders.

Through the example of a transit investment project, the proposed method for evaluating an alternative has been described. The choice of an alternative from a set of possible alternatives in the case of public projects is very much influenced by the political decision. But it is the analyst's duty to advise the decision-maker regarding the performance of a given alternative by providing useful and reasonable findings about the performance of each alternative. The proposed method presented in this thesis has achieved this aim to a considerable level.

The method can analyze the problem from the perspective of different possible dominant groups of stakeholders involved in a given decision-making scenario. The proposed method measures the consistency of the opinions expressed by the respondents, which is important for the credibility and believability of the study results. The method does not provide directly the final alternative, as seen in the traditional decision-making methods, but instead provides numbers that represent the confidence of achieving the desired outcome from the project and alternatively the degree of uncertainty. This will help the decision makers understand the opinions of different groups of the people concerned with the implementation of the project.

The approach presented in the study can be considered as a combination of multicriteria decision-making under uncertainty and group decision-making. Apart from the transit investment projects, the method can be implemented for evaluating the alternatives of private sector projects that have the characteristics of a large-scale public project. It is hoped that the study has shed some light in the techniques to be adopted for the analysis of uncertainty in the large-scale public systems.

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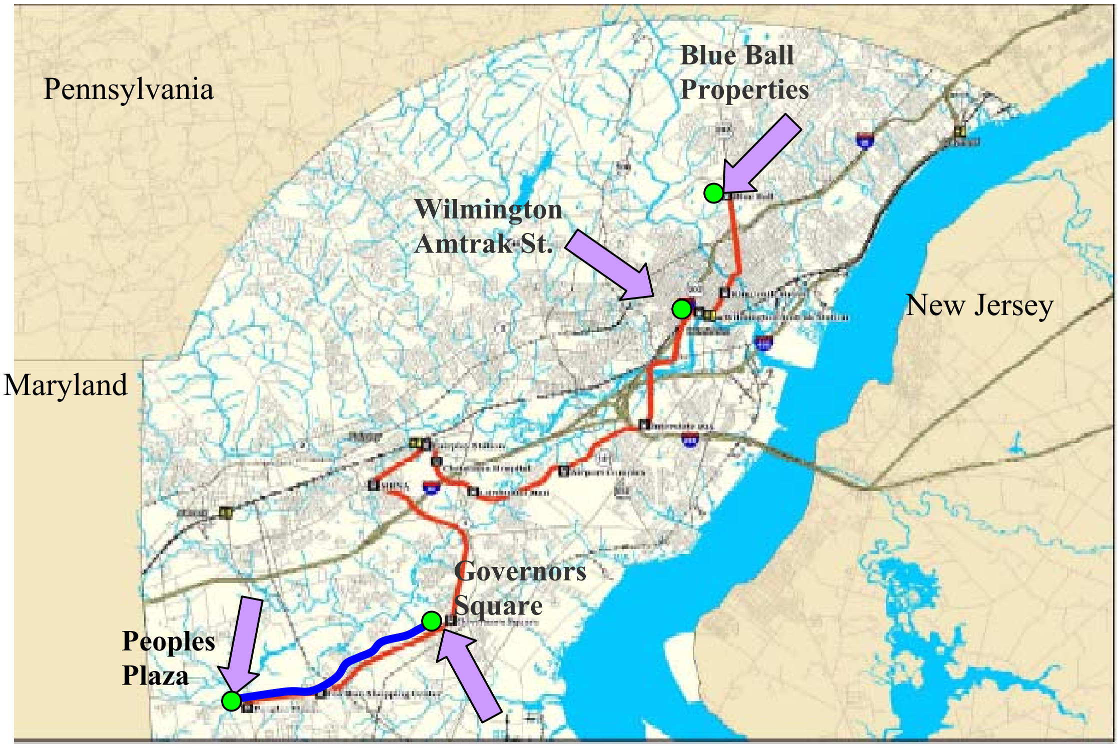
APPENDIX A

The Study Project

The project studied in the thesis is an extension of a hypothetical Monorail alignment along the Rt.40 corridor in the State of Delaware. The monorail project was actively pursued about two years ago, as a viable transit alternative to meet the future travel needs in the Northern New Castle County region. The Wilmington Area Planning Council (WILMAPCO) had undertaken the task of conducting a comprehensive study for the monorail project in the Wilmington region. As part of this effort, a Regional Monorail Exploratory Study was prepared in September 2003, which was conducted in partnership with DelDOT, Delaware Transit Corporation, City of Wilmington, New Castle County and elected officials in the region. The objective of this study was to investigate the feasibility of the monorail transit in Northern New Castle County. The study incorporated only the initial Systems Planning phase of the standard procedure to be followed by any FTA New Starts project. The project was not pursued beyond this stage due to local administrative reasons. The map below illustrates the alignment of the proposed monorail project (see red line on the map).



Extension of the Monorail alignment along Route 40 corridor.

Original Monorail alignment.

Map showing the alignment of the Monorail and the Route 40 corridor

The one end of the alignment, the Blue ball properties is home to the upcoming North American headquarters of the pharmaceutical company Astra Zeneca. This project is bound to increase the employment in the region. The State of Delaware has lobbied aggressively to bag this prestigious project and has acquired the blue ball properties to address the environmental, recreational and transportation needs of the citizens in the region. The alignment of the monorail project connects other high-density employment areas in the region like MBNA, Christiana Mall, and the hub for economic activity in the region, the Wilmington City downtown that houses many residential units also. The alignment proposed in the exploratory study of monorail in the region originates from Blue Ball properties and culminates in Peoples' Plaza on Route 40.

The scope of the study in the thesis is to analyze the transit scenario of the monorail project along the Route 40 corridor. A hypothetical transit scenario of extending the monorail alignment existing from blue ball properties to Governors Square further along Route 40 corridor to the Peoples' Plaza is assumed as the transit scenario for study in the thesis. Please note that the area of interest for this study is the alignment along Route 40 corridor alone. This transit scenario is undertaken with an aim of applying the proposed method of large-scale systems analysis to the process of evaluating the transit alternative in a given local region. The blue line on the map starting from the Governor's Square to the Peoples' Plaza is the region of interest.

The Rt. 40 corridor region in New Castle County has been extensively studied as part of the corridor improvement plan. Rt. 40 corridor is an increasingly congested area that has been a subject of discussion in the last few years. With 75% of the land being either developed or proposed for development and about 47% increase in population expected by year 2020, this corridor features prominently in the list of transportation development plans to be identified and implemented in near future. As part of these efforts, a long-range 20 year Route 40 corridor improvement plan has been created and is already being implemented in stages. The vision of the project is to deal with the major issues along this corridor namely providing a safe, community friendly and less congested Route 40. The facts and other related information related to each chart have been provided below.

I hope that this fact sheet put together for your reference helps you in giving an educated, and informed guess about the integrity of each link of the logical chain of reasoning. For further information please check the following web sites:

For Monorail exploratory study:

http://www.wilmapco.org/Monorail/MONORAIL%20FINAL%20REPORT.pdf

For Route 40-corridor study:

http://www.deldot.net/static/projects/rt40/pages/about40.htm

Instructions to the respondents

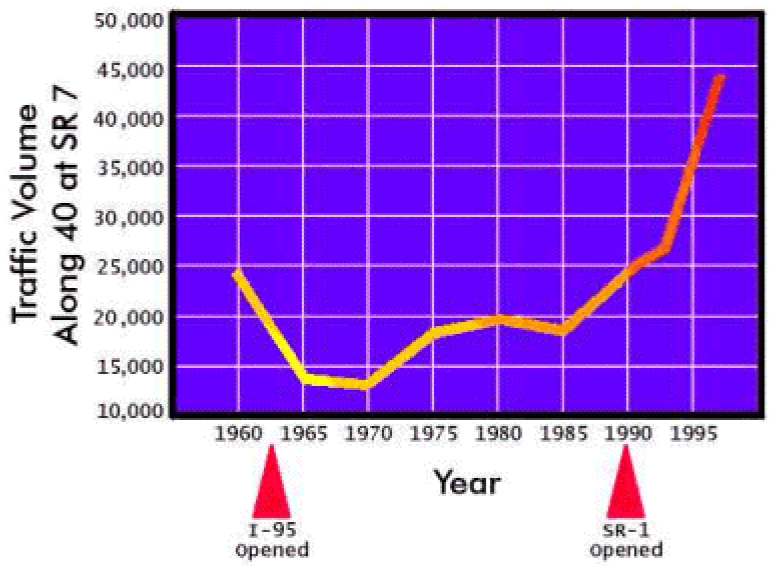
Please assign a number between 1 and 10 that relates to your strength of agreement for each arrow representing a cause effect relationship. Note that 1 represents very little agreement about the causal effect and 10 represent total agreement of the relationship. The respondent is encouraged to freely express his opinion based on his knowledge and exposure to similar projects and the survey is aimed purely to capture the unique perspective of an experts.

Fact Sheet

General information:

- In the monorail feasibility study, the management and steering committee evaluated different segments of the initial proposed alignment. Among the 7 segments that were evaluated based on the criteria contained in the Purpose and need statement of the monorail project, the Route 40 corridor segment obtained the maximum ratings in favor of the implementation of the monorail.
- The regional monorail exploratory study opinionated that the monorail service in Route 40 corridor would supercede the bus service enhancements contained in the 20 year plan for this corridor and also that it would need more park and ride activities than contained in the current plan.
- 4 out of 5 most congested intersections identified in the Route 40 20 year implementation plan feature in the corridor segment studied in this thesis as an extension to the monorail alignment.

- More than a quarter of the trips have their origin and destination within the corridor. Thus the local traffic is much higher than the through traffic on the corridor.



*All values are average daily traffic

Source: About Route 40 extracted from the website about Route 40 Improvement Plan

http://www.deldot.net/static/projects/rt40/pages/about40.htm

Improve Mobility/Accessibility:

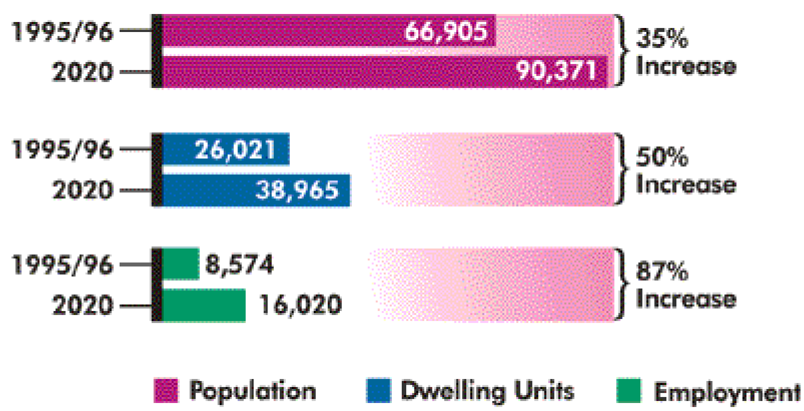
- Currently there are three bus routes operating in this congested corridor. Over 1,000 riders use these busses daily.
- The travel time along the corridor from Governor's square to Peoples' plaza on bus is 16 to 18 minutes. The monorail would cover the same distance in about 8 minutes.
- The travel time on the corridor is expected to increase 2-3 times by 2020.

- The monorail is proposed to run at headway of 5 minutes during peak hours and 16 minutes during off peak hours. The bus routes run at headway of 30 minutes during the peak hours and 1 hour in the off peak hours.
- Currently about 25 % of the intersections are congested, and in 2020 at least 70% of the intersections will be congested with the level of service F at peak hours.

Socio-economic impacts:

- The existing development in the Route 40 corridor is on 55% of the land and the proposed development is on another 20% of the land in the region. The no development activity area is around 25%.

The demographics are represented by the following bar chart.



Source: About Route 40 extracted from the website about Route 40 Improvement Plan

http://www.deldot.net/static/projects/rt40/pages/about40.htm

Note: The operating and maintenance costs and the capital costs mentioned are for the whole corridor length of 24 miles of the proposed alignment for monorail. The Route 40 corridor part of the alignment is just 5.3 miles.

Operating cost efficiency:

- The estimated total annual operating and maintenance cost is about $18 million. The key constituents being $ 6 million for labor, $ 2 million for materials, and $ 7 million for utilities.
- The total ridership along the whole alignment for the monorail is estimated to be 12,800 boardings per weekday.
- The current ridership in the buses along just the Route 40 corridor is 1000 per day.

Cost effectiveness:

- The guideway structure and equipment cost of $ 635 million is the major constituent of the estimated total capital costs of the monorail.
- The add-on costs for the monorail project are estimated to be around $ 330 million.
- The system wide costs are estimated to be around $ 300 million with the vehicles alone costing about $ 66 million.

Environmental impact:

- Monorail is propelled by electric power and is less dependent upon petroleum than buses.
- The current state of Route 40 needs improvements in its aesthetic appeal. The 20-year plan for Rt. 40 corridor considers aesthetics as one of the 5 objectives in its vision statement along with safety, congestion, land use planning and mobility.
- Route 40 comes under the New Castle County, which is located within the Wilmington Area Planning Council (WILMAPCO) region and is in a severe non-attainment area for ground-level ozone. The CAAA requires this region to reach

attainment of the National Ambient Air Quality Standard (NAAQS) for Ozone by 2005

- Transportation conformity is a major issue for this region. The harmful emissions of concern in the WILMAPCO region are two ozone precursors: Volatile Organic Compounds (VOC) and nitrogen oxide (NOx) which if not reduced to acceptable levels prescribed by the State Implementation Plan's emission budget by 2005, the region will lose significant Federal transportation funding.

APPENDIX B

The following is the code for the calculation of group opinion obtained by aggregation of the individual opinions. (Refer Section 7.3.1).

```
clear;
G1 = [  0.73    0.9     0.154   0.58    0.56    0.28    0.624;
        0.95    0.9     0.3     0.94    0.9     0.99    0.06;
        0.86    0.98    0.126   0.89    0.7     0.8     0.45;
        0.98    0.99    0.867   0.95    0.91    0.94    0.95 ];

G2 = [  1       1       0.25    1       0.96    0.96    0.25;
       0.98     0.95    0.51    0.98    0.82    0.95    0.31;
       1        1       0.03    0.96    0.72    0.77    0.00];

G3 = [  0.96    0.73    0.07    0.9     0.66    0.82    0.02;
        0.68    0.6     0.01    0.47    0.1     0.3     0;
        0.97    0.99    0.4     0.97    0.9     0.96    0.91];


t=0.001;
tol = 0.005;

%The following sequence is for combining the opinions of experts in Group 1

  for j=1:7
     count = 0;
     z(j,1) = 1;
     for k=(min(G1(:,j))+t):t:(max(G1(:,j))-t)
        if z(j,1)<=tol
           break;
        end
        count = count +1;
        C0 = k;
        y1 = 0;
        y2 = 0;
        for i=1:4
           if  G1(i,j) >= C0
              y1 = y1 + G1(i,j) -C0;
           else
              y2 = y2 + C0-G1(i,j);
           end
```

```
        end
        x = (1-C0)/(1+C0);
        y = y1/y2;
        z(j,1) = abs(x-y);
     end
     c(j,1) = C0 ;
     end
  end

  clear i,j,k;

%The following sequence is for combining the opinions of experts in Group 2

  for j=1:7
     count = 0;
     z(j,2) = 1;
     for k=(min(G2(:,j))+t):t:(max(G2(:,j))-t)
        if z(j,2)<=tol
           break;
        end
        count = count +1;
        C0 = k;
        y1 = 0;
        y2 = 0;
        for i=1:3
           if  G2(i,j) >= C0
              y1 = y1 + G2(i,j) -C0;
           else
              y2 = y2 + C0-G2(i,j);
           end
        end
        x = (1-C0)/(1+C0);
        y = y1/y2;
        z(j,2) = abs(x-y);
     end
     c(j,2) = C0 ;
     end
  end

  clear i,j,k;

%The following sequence is for combining the opinions of experts in Group 2
```

```
for j=1:7
   count = 0;
   z(j,3) = 1;
   for k=(min(G3(:,j))+t):t:(max(G3(:,j))-t)
      if z(j,3)<=tol
         break;
      end
      count = count +1;
      C0 = k;
      y1 = 0;
      y2 = 0;
      for i=1:3
         if  G3(i,j) >= C0
            y1 = y1 + G3(i,j) -C0;
         else
            y2 = y2 + C0-G3(i,j);
         end
      end
      x = (1-C0)/(1+C0);
      y = y1/y2;
      z(j,3) = abs(x-y);
   end
   c(j,3) = C0 ;
   end
end
```