AN ABSTRACT OF THE DISSERTATION OF

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Two interesting challenges have been created in the traditional transportation planning process through recent adoption of more interactive roles by Federal, State and local transportation agencies and of those representing the communities being impacted by proposed transportation projects. First, the decision-making groups that formerly included solely transportation and related professionals now consist of professionals from state and local agencies and other stakeholders impacted by those proposed projects. Furthermore, the economic justification methodologies commonly used, such as the benefit/cost ratio, no longer provide a sufficient means for evaluation since they now must take account of non-quantifiable or qualitative impacts, such as local quality of life and sustainable development. These new challenges require a new way of thinking, and a new methodology to handle them.

A new methodology is required not only to take qualitative performances into consideration, but also to accommodate the diversities created by those in the decision-making process. This research focuses on the alternative evaluation stage

as it often demonstrates the above challenges. The objective of the proposed methodology is to develop "a continuous process of learning and understanding through communicative means by virtue of a fair and open framework in developing the group consensus rather than relying solely on the STATUS QUO."

The new methodology that combines the advantages of three unrelated components is proposed to reduce the complexities in complex decision situations. The three components include the conflict resolution model (SANTA), the analytical method (AHP), and the group decision support system (GDSS). The proposed methodology also explores a new way to take advantage of the Internet which allows decision makers to make their decisions from any where at any time.

A small-scaled pilot study was set up to test the methodology and the software developed according to the framework outlined by the proposed methodology. Many benefits are discovered by the participants' observations without their prior knowledge about the methodology and the software. Those benefits include Flexibility, Accessibility, Transparency, and Efficiency, or FATE. There are two possible applications of this new methodology, i.e., in real-world problem-solving situations and as a learning tool.

FATE Group Decision Support System in Transportation Decision Making

by

Thaweesak Taekratok

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Thaweesak Taekratok, Author

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To Thai taxpayers who supported me financially so I could complete my study here in the US, I owe them my hard works and knowledge.

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FATE Group Decision Support System in Transportation Decision Making

CHAPTER 1 INTRODUCTION

Two interesting challenges have been created in the traditional transportation planning process, through recent adoption of more interactive roles by Federal, State and local transportation agencies and by those representing the communities being impacted by proposed transportation projects. First, the decision-making groups that formerly included solely transportation and related professionals now consist of professionals from state and local agencies and other stakeholders impacted by those proposed projects. Furthermore, the economic justification methodologies commonly used, such as the benefit/cost ratio, are no longer deemed to provide a sufficient means for evaluation; they now must take account of non-quantifiable or qualitative impacts, such as local quality of life and sustainable development. This change in the decision making process requires new methods.

This new methodology must not only take qualitative performances and impacts into consideration, but also accommodate the diversities among the decision-making groups, comprised by those with different, and sometimes conflicting agendas.

1.1 RESEARCH OBJECTIVES

The transportation planning process consists of several stages and phases that involve many participants and interest groups throughout the entire process. The evaluation stage of the planning process, in particular, is now complex, multifaceted, and involves many stakeholders. This research addresses an alternative evaluation process and procedures that accommodate both challenges identified above.

The overall goal of this research is to develop an integrated decision process for evaluation and selection of the optimal alternative that exhibits the following quality; <u>a continuous process of learning and understanding through communicative means by virtue of a fair and open framework to develop the group consensus rather than relying solely on the STATUS QUO.</u>

Specific research objectives include:

1. To identify the current practices and their limitations in handling the alternative evaluation process with complex decision situations,
2. To identify the proper methodology and necessary modifications to handle both quantitative and qualitative performances in evaluating different alternatives with a diverse group of decision makers,
3. To develop a framework based on the proposed methodology

3.1 Develop and implement procedures for evaluating, weighting, and integrating attributes (i.e., criteria and alternatives),

3.2 Develop and implement a network-based group decision support system,

4. To demonstrate the effectiveness and benefits of using the decision support framework to evaluate a set of alternatives in a transportation project,
5. To identify the issues concerning future research and development for implementation in the transportation planning process.

1.2 RESEARCH CONTRIBUTIONS

The selection of a single alternative for any transportation project could have profound impacts for those using and living along that facility. Those impacts include safety, livability, economic development, environmental impact, mobility, and sustainability.

Providing a methodology that creates not only a more thorough evaluation process, but also a well-organized group decision-making framework should dramatically increase the level of confidence by the group itself and will most likely create momentum toward the adoption of the recommended alternative. This will also have a positive impact on public confidence, especially those impacted by the proposed project, since the process itself will be transparent to the public's eye.

The proposed methodology is designed to support decision makers in conducting and making a decision with both effectiveness and efficiency in mind. Its simplicity and ability to include both quantitative and qualitative measures of the methodology make the group decision-making process more effective. The ability to work within the network environment, in this case the Internet, improves the flexibility for the working group to conduct their meetings and discussions. The provision of a more structured and task-oriented support system should benefit the group decision as well. Both will increase the group efficiency in making a quality decision.

According to Harsanyi (1977), there should be two separate circumstances in describing human rational behaviors in the group setting, i.e., Ethics and Game Theory. Ethics deals with a rational pursuit of the interests of the group as a whole, while Game Theory deals with individuals who rationally pursue their own self-interest. Most decision analysis techniques and decision support tools focus their interests in the first group as it is easier to identify the group optimal solution. It assumes a common acceptable threshold by the group or a social welfare function. The threshold could be the arithmetic mean of all individuals' utility levels in the group.

The second one will depend on the dynamics and interactions among group members. This means that there is no group acceptable threshold or optimal solution but the group consensus instead. The final outcome depends on the strategies being played among members within the group. Decision-making groups in transportation projects may consist of members who represent their own interests or groups with their own agenda. The proposed methodology from this research provides a decision support tool that can accommodate both types of group setting.

Finally, the actual applications of this proposed methodology are two-sided, i.e., for actual use and as a learning tool. The first one is already described above. Even though decision makers will exercise their judgments rationally, their rationale, however, is based on their own experiences and knowledge. Also, their judgments from time to time will reflect their own interests or that of the groups they represent.

A quality decision should be made with the full knowledge of the project with the balance among different group perspectives. The new tool could be used to facilitate the knowledge sharing and the understanding of the group members' perspectives. The better they understand the problem, the more the quality of their decisions improves.

1.3 DISSERTATION ORGANIZATION

Chapter 2 outlines the current practices and their limitations in the alternative evaluation process for complex decision situations. This chapter also provides details of a conflict resolution model called the SANTA model and an analytical method called the Analytic Hierarchy Process that could be used to reduce the current limitations in decision-making. Finally, the need to incorporate the Group Decision Support System (GDSS) into the research is described.

Chapter 3 identifies three key components and their relationships in the proposed framework for this research. Those three components include the conflict resolution model (SANTA), the analytical method (AHP), and the GDSS. This chapter also provides the expected benefits of the new framework in reducing the complexities in a complex decision situation. The last part explains the possible modification to extend the new framework to a network environment, in particular, the Internet.

Chapter 4 provides detailed descriptions on how the software is designed to accommodate the proposed framework in a network environment. The chapter also explains in detail the major modules needed in this GDSS tool.

Chapter 5 focuses on the pilot study including its study objectives, its performance, the participants, its findings and conclusions.

Finally, Chapter 6 presents the research conclusions and provides some suggestions for future research.

CHAPTER 2 BACKGROUND REVIEW

Recent encouragement by both Federal and State levels in a more interactive environment among different agencies and the public for decision-making for transportation planning provides an insight into the complexity of the process, required to accomplish the task. This chapter provides a background and review on those issues involved in complex decision situations in transportation planning, and how this complexity could be addressed.

First, the characteristics and different categories of decision situations described by Radford (1989) are introduced. Second, the characteristics of what Radford describes as complex decision situations are reviewed and used to demonstrate the complexity of decision making in transportation planning. The BOGSAT model traditionally used to resolve group decision making, such as any complex decision situation, does not provide a sufficient tool to handle this problem as described in Section 2.1.3.1. Then, the SANTA model developed by Radford is introduced, and why it is more appropriate than the BOGSAT model is explained. To implement the SANTA model, decision aides, such as GDSS and the AHP, are required as explained in the last two sections of this chapter.

2.1 COMPLEX DECISION SITUATION IN TRANSPORTATION PLANNING

There are several definitions for a decision involving human activity. One is defined broadly by Ofstad (1961) as, "the process of making a judgment regarding what one *ought* to do in a certain situation after having deliberated on some alternative course of action."

Churchman (1968) supports this definition by defining a decision maker as, "a person who decides among alternative courses of action and must decide which one will lead to a certain desired objective or set of objectives."

A similar definition is identified by Forman and Selly (2000) that describes decision making as, "a process of choosing among alternative courses of action in order to attain goals and objectives."

2.1.1 Characteristics and Categories of Decision Situation

There are four major factors that must be taken into account in the study of decision situations:

1. The nature and amount of the information that is available to form a basis for an approach to resolution of the problem,
2. Whether or not costs and benefits of taking a course of action can be described wholly in quantitative terms,
3. Whether those involved in the decision situation have a single objective or a set of multiple objectives,
4. Whether or not one or more participants have an interest in the resolution of the decision situation.

(Radford, 1989)

2.1.1.1 Certainty or Uncertainty

The decision with certainty can be viewed as the situation in which sufficient information can be gathered to obtain a complete specification of all of the alternatives and of their effectiveness in the situation under consideration. The decision with certainty can be relatively straightforward.

When there is a lack of sufficient knowledge, the decision situation is bound to be uncertain. According to Radford (1989), the uncertainty has three main effects in the decision:

1. It is usually impossible with incomplete information to construct a comprehensive model of the decision situation that includes all relevant factors and the relationships among them. With an incomplete model of the situation, those involved may feel that some of the more important aspects of the situation are beyond their immediate comprehension.
2. With limited information, different individuals involved in a decision situation may form different impressions of its characteristics, based on their previous experiences, competences, and motivations. In this circumstance, it is unlikely that complete agreement can be reached without certain processes to eliminate or reduce this uncertainty.
3. Without the certainty about the future environments, there is a risk that the actual outcome of a course of action will be different from that of the selection.

(Radford, 1989)

2.1.1.2 Quantitative and Non-quantitative Measures of Benefits and Costs

Many of the early efforts in developing a planning process were focused on the analysis and evaluation techniques that could provide quantitative estimates of the benefits and costs of those compared solutions. These quantitative values make the effort to make a decision easier and more objective-oriented. There is no need for communication, discussion, and conflict resolution. One methodology commonly used is the benefit-cost comparison. If the total gains or benefits over the total investment of one alternative is the highest, there is little difficulty in finding the most preferred alternative.

Because of its simplicity, many planners or decision makers are tempted to place quantitative values on all factors involved in evaluating the achievement of the objectives that form the background to the decision situation. This quantification process is often subjective, oversimplified, and unrelated to the rationality of the situation.

This leads to some questionable conclusions or recommendations when subjected to scrutiny by those impacted by the decision. As stated by Meyer and Miller (2000) on the early transportation planning process:

> Much of the early effort by engineers and planners to structure the planning process focused on the analysis and evaluation techniques that could provide quantitative estimates of the benefits and costs of alternative transportation project and system configurations. In the minds of many engineers and planners, the transportation planning process soon became synonymous with modeling methodology. Early research efforts aimed at improving transportation planning and decision-making focused almost exclusively on developing quantitative evaluation methodologies, often ignoring the question of what type of decision making process really existed and what type of information was needed for making decisions.
> (Meyer and Miller 2000)

The effective evaluation of quantitative measures that are the true representations of the decision situations and the required inclusion of non-quantitative measures, or often called qualitative, to balance the decision process are recognized in Categories 4 and 5 in Radford's Classification.

2.1.1.3 Single or Multiple objectives

Many terms have been used interchangeably to describe human decision-making and their assessment. Zeleny (1982) provided a common definition for three terms often used to describe the human assessment in decision-making. These three terms are "attributes", "objectives", and "goals", in which a fourth term "criteria" is used to encompass the other three. Zeleny described each term as follows:

> Attributes: refers to descriptors of objective reality. They may be actual objective traits, or they are perceived as characteristics of objects in the *outside* world. Thus, although they cannot be separated from the decision maker's values and model of reality, they can be identified and measured in relative independence from the decision makers' needs or desires.
>
> Objectives: are closely identifiable with a decision's needs and desires; they represent *directions* of improvement or preference among individual attributes or complexes of attributes. There are only two directions: more or less, i.e., maximize and minimize. Thus, height in itself is an attribute, but finding the tallest among the choices, or maximizing height, is an objective. Objectives are not themselves attributes, but they derive from one or more attributes. An attribute becomes an objective when it is assigned a purpose, a direction of desirability or improvement.
>
> Goals: are fully identifiable with a decision maker's needs and desires. They are a priori determined, specific values or levels defined in terms of either attributes or objectives. They can be a precise, desired level of attainment, or more fuzzily delineated, or vague ideals. Thus, while the distinction between attributes and objectives can sometimes become blurred due to their hierarchical nature, goals refer quite unambiguously to particular target levels of achievement that can be defined in terms of both attributes and objectives.

> Criteria: are measures, rules, and standards that guide decision-making. Since decision-making is conducted by selecting or formulating different attributes, objectives, or goals, all three categories can be referred to as criteria. That is, criteria are all those attributes, objectives, or goals which have been judged relevant in a given decision situation by a particular decision maker (individual or group).
>
> (Zeleny 1982)

Any decision situation can be identified by a single objective in which the decision maker/makers work with only one objective, and therefore, only one criterion of choice between courses of action, or as multiple-objective in which the decision maker/makers must attempt to satisfy more than one objective or criterion in their decision-making activities.

2.1.1.4 Single or more than one participant

In many decision situations, the responsibility for the decision may lie with one individual who decides according to his/her own interests or those of the organization that he/she represents. Also, a single-participant situation can emerge from a group setting if a preset group interest can be achieved first hand, and there is no conflict of interest. An example is to divide a hundred dollars among five persons when all of them priori agree to divide equally.

A much more complex situation arises if the individuals cannot arrive at an agreed position that represents the view of the group and a decision must be made by the members of the group. This type of situation arises when a number of independent participants with conflicting interests or an inter-organizational group with conflicting goals or responsibilities are involved.

For transportation planning and decision-making, there have been some changes in the institutional environment over the past 20 years (Meyer and Miller, 2000). Those changes started from a simple responsible organization, such as a state department of transportation, to a more conglomerated environment from different organizations or jurisdictions, both public and private. In addition to government agencies, participants in the planning process now include a variety of private sector organizations and community groups.

In recent years, transportation legislation and regulations have provided for a much more inclusive process that promotes participation by anyone who wants to be involved. For example, as stated in Oregon Highway Plan 1999 Policy 2D:

> It is the policy of the State of Oregon to ensure that citizens, businesses, regional and local governments, state agencies, and tribal governments have opportunities to have input into decisions regarding proposed policies, plans, programs, and improvement projects that affect the state highway system.
>
> (Oregon Highway Plan 1999)

Typical participants in a decision-making process include environmental groups, community associations, local business and real estate developers, local governments, and other interest groups. As one would expect with such a diverse set of actors involved in the planning and decision-making process, the progress is more cumbersome and tedious. A better approach to handle the complexities is required.

2.1.2 Definition of a Complex Decision Situation

Radford (1988) categorizes decision situations into two groups, i.e., well-structured and ill-structured, to describe the complex decision situations better. Well-structured decisions, as described by Radford, are commonly those in which:

1. There is no (or little) uncertainty
2. Benefits and costs can be measured in quantitative terms
3. A single objective is involved
4. A single participant has the power to make a decision.

Ill-structured decision situations are those in which one or more of the following conditions exist:

1. Uncertainty, caused by lack of complete information; the decision makers cannot therefore be certain that all aspects of the decision problem are known
2. Benefits and costs related to a course of action cannot necessarily be measured in quantitative terms; quantitative optimization models are not therefore a complete answer to the resolution of the decision situation
3. The decision maker must take more than one objective into account in searching for a means of resolution of the decision situation; there are no simple methods of optimization that are applicable to multiple-objective situations

4. More than one participant is involved in the resolution; the participants may have different objectives and different perceptions of the characteristics of the decision situation.

In these circumstances, it is not usually possible to obtain a uniquely optimal (and therefore objectively rational) resolution of a decision situation. The choices of a course of action under these circumstances are described as subjectively rational.

Complex decision situations have all the basic characteristics of ill-structured situations; namely, the existence of uncertainty, multiple objectives, more than one participant and the lack of quantitative measures of benefits and costs. It can be summarized as possessing the following characteristics:

1. Complex decision situations are normally centered around an issue, opportunity, venture, or threat that involves an individual or organizations,
2. Many complex decision situations occur within an inter-organizational setting,
3. It involves the interaction of participants in which each is trying to pursue his/her own interest or that of the group they represent,
4. It is seldom that the information available to the participants is sufficient to allow each to formulate a complete and exhaustive description of a complex situation,
5. Due to the incomplete information, each participant may base his/her appreciation of the nature of the problem on different perceptions and/or interpretations of different or the same information provided,
6. The most important characteristic of a participant with respect to the resolution of a complex situation is the power that he/she (or the organization they represents) can exert to influence the outcome.

(Radford, 1988)

2.1.2.1 Complex Decision Situation in Transportation Planning

Meyer and Miller (2000) summarizes the major characteristics of the decision making process in transportation planning as follows:

1. *Pluralistic.* Many "publics" are involved in decision-making, a reality that inevitably highlights conflicting objectives and leads to unquantifiable value judgments. One consequence of the pluralistic nature of decision making is that the number of public issues and problems brought before decision makers is so great and diverse that the time spent on one particular topic is often quite limited.
2. *Resource-allocative.* Of all the decisions facing decision makers, perhaps the most difficult is equitably allocating financial and organizational resources. The tradeoff between the need by the public and the limit in resources is very demanding.
3. *Consensus-seeking or constituency-building.* Due to limited resources and the diversification of stakeholders in the decision-making process, resolution of conflicts thus involves negotiated compromises, bargaining, and the formation of coalitions.
4. *Problem-simplifying.* As problems are complicated and involve several conflicting and fuzzy definitions, decision makers need to determine and develop proper methods that will help ascertain separable, well-defined problem definitions that can be handled much more easily. These must, however, avoid oversimplifying the problems.
5. *Uncertainty-avoiding.* The role for transportation planning or planners is to provide decision makers with the knowledge necessary to make informed decision.

(Meyer and Miller, 2000)

Furthermore, a traditional approach of evaluating transportation systems based solely on their monetary values such as cost-benefit analysis has drawn many criticisms over the year due to their limitations. According to Tsamboulas et al (1999), there are several considerable difficulties in measuring all relevant impacts of a project or plan in monetary terms. It seems to be improbable in practice to arrive at totally reliable and fully accepted monetary values by all parties for those relevant impacts. Also, there is no explicit way to take political impact and local groups' pressures into consideration within the scope of monetary evaluation.

From above characteristics, it can be objectively concluded that the decision-making process in transportation planning exhibits similar characteristics, explained by Radford, as a complex decision situation. It requires an in depth look into an effective resolution methodology that can minimize the drawbacks in complex decision situations as well as limitations exhibited in the monetary approach in an evaluation of transportation systems. A traditional model of decision-making resolution, its weaknesses, and a more effective model are discussed in the next section.

2.1.3 Resolution Methodology for Complex Decision Situation

2.1.3.1 BOGSAT Model

The most frequently used method for decision-making and conflict resolution today is sometimes referred to as a BOGSAT- a Bunch of Old Guys/Gals Sitting Around Talking (Forman and Selly, 2000). Even though there may be considerable preparation for a BOGSAT, including information-gathering, and detailed analyses (e.g., financial, technical, political, etc.), there are numerous problems with this approach. According to the discussion between Forman and Peter Beck of Decision Technology, Arlington, VA, in his book, Peter Beck was quoted as: "these sessions are often dominated by the leader and rarely facilitated. The leader sets the tone and is often not challenged. If the group starts down the wrong path, they rarely look back." This can be viewed as an ill-structured decision previously described by Radford. Other problems in BOGSAT are described as follows:

2.1.3.1.1 Cognitive Limitations

Psychologists have proven that the human brain is limited in both its short-term memory capacity and its discrimination ability (channel capacity) to about seven items plus or minus two (Miller, 1956). A BOGSAT discussion typically involves dozens of attributes/criteria, e.g., alternatives, their pros and cons, etc. This may have limited their abilities to make thorough comparisons among those attributes.

2.1.3.1.2 Bounded Rationality

Bazerman (1986) points out that the economist's model of the rationality assumes that decision makers following these logical steps with perfect judgment:

1. Perfectly defining the problem
2. Knowing all relevant information
3. Identifying all criteria
4. Accurately weighing all the criteria according to his/her goals
5. Accurately assessing each alternative on each criterion
6. Accurately calculating and choosing the alternative with the highest performances or values.

(Bazerman, 1986)

However, Herbert Simon defines human judgment in complex decision situations as bounded rationality (Hogart, 1987). He believes that decision-making in complex situations takes place under constraints of human information-processing limitations. Humans lack both the knowledge and computational skills necessary to make decisions in a manner compatible with economic notions of rational behavior.

2.1.3.1.3 Unorganized Information Sharing and Resolution Seeking

The most common way to seek any resolution in the BOGSAT setting is through a meeting or discussion. As described by Forman and Selly (2000), the information sharing and resolution seeking in the meeting or discussion are relatively unstructured or unorganized, and the discussion jumps from topic to topic in a haphazard way. Some relevant points are discussed several times, some not at all. Frustration comes into play as strong members of the group dominate the discussion, often far beyond the level justified by their knowledge and experience. Shy members of the group may fail to exert their influences in the group, even though they have important information to convey. A decision is made (or forced to be made) either when it appears that no progress is forthcoming, or when it is time to go to another meeting, or it is reaching the project deadline. This haphazard approach to decision-making is far too common in BOGSAT.

2.1.3.1.4 Number Comparison Biases

In order to determine the final outcome, the number of pros/cons or the number of members in the group are counted and then compared. Certainly, it would be wrong to calculate the net numbers of pros over cons for each alternative, and then select the alternative with the largest net number since the relative importance of each pro and con may differ.

It also is sensitive to how the group is formed. Selecting more partisan members in favor of a particular alternative could lead to the decision advantageous to those members.

2.1.3.2 General Theory of Rational Behavior

Harsanyi (1977) categorized human rational behavior and decision theory into two cases, i.e., individual decision theory and theory of rational behavior in a social setting.

According to Harsanyi, individual decision theory deals primarily with rational behavior in situations in which the outcome depends on an individual's (the decision maker's) own behavior. But, it can also handle situations where the outcome does depend on other individuals' behaviors as long as it is assumed that their behaviors are governed by well-defined deterministic or probabilistic laws rather than by their own rational strategy choices and by their own rational expectations about other participants' behaviors.

Table 2-1 General Theory of Rational Behavior (Ref: Harsanyi, 1977)

A. Individual Decision Theory (Utility Theory)
Deals with rational behavior of an isolated individual under:
A1. Certainty
The outcome of any possible action is fully predictable.
A2. Risk
The objective probability of any possible outcome is known.
A3. Uncertainty
Some or all of these objective probabilities are unknown or even undefined.
B. Theory of Rational Behavior in a social setting
B1. Game Theory
Rational pursuit of self-interest and of personal values against other individuals rationality pursuing their own self-interest and their own personal values
B2. Ethics
Rational pursuit of the interests of society as a whole.

An individual decision maker has to deal with three different conditions or expectations in his/her decision-making process, i.e., certainty, risk, and uncertainty. Some techniques that are commonly used to satisfy the individual decision theory are classified by Randhawa and West (1992) as shown in Table 2.2.

In a social setting or a group decision making, Hersanyi believes that there should be two separate circumstances in describing human rational behaviors in the group setting, i.e., Game Theory and Ethics. According to Harsanyi, Game Theory deals with individuals who rationally pursue their own self-interests (as well as the group they represent) against other individuals who just as rationally pursue their own self-interest (or groups their represent). Some examples of Game Theory in a social setting includes:

- Two-person simple bargaining games,
- Two-person cooperative games,
- N-person simple bargaining games,
- N-person cooperative games,
- Noncooperative and Almost-non-cooperative games,
- Strategic/Tactical model or SANTA model.

Table 2-2 Classification Scheme for Justification Techniques (Modified from: Randhawa and West, 1992)

Certainty Quantitative Attributes

- Economic Non-discount – Payback Period
- Economic Discount – Net Present Value, Internal Rate of Return
- Optimization (Programming) – Linear and Integer Programming
- Analytic Hierarchy Process
- Utility Theory
- Goal Programming

Risk

- Markov Analysis
- Simulation
- Expert System
- Decision Trees

Uncertainty

- Optimistic-Pessimistic Models

As contrast to Game Theory, Ethics deals with a rational pursuit of the interests of the group as a whole. It assumes a common acceptable threshold by the group or a social welfare function. The threshold could be the arithmetic mean of all individuals' utility levels in the group, or the optimum solutions, criteria, or weights. Therefore, the majorities of the techniques apply in the individual case could be modified to work in Ethics case as they already use statistical analysis and optimization algorithm. Those techniques include simulation, markov analysis, linear and goal programming, and so on. Another popular methodology commonly used is the Delphi method.

Delphi is an iterative forecasting procedure originated by Rand Corporation in early 50's. Delphi allows participants to remain anonymous through out the process to avoid dominance by strong personalities within the group. It usually uses a questionnaire or interview by a facilitator to elicit ideas or opinions of the group members. All the judgments are compiled and reviewed anonymously by an appointed person, and the results were sent back to each member for review. The process continues until the consensus is reached. Often the criteria are limited in number to make the questionnaire manageable. Some examples of questions asked in a questionnaire were:

"What action could be taken to provide faster response to the emergency call?"

"From the five ideas listed, please assign a five-point scale while five means the most favorable idea and one means the least favorable idea?"

The development of a questionnaire is a critical step in Delphi. The questions should be clear and reflect information groups try to measure. Asking the wrong question or the right one in the wrong way could undermine the benefits of Delphi.

This research is interested in the alternative evaluation and selection process consisting of a group with conflicting interests, agenda, and backgrounds. This should be more suitable with Game Theory approach in Harsanyi classification. This is because some members of the decision-making group will gain benefits from a selected alternative in favor of them and others could lose their benefits. This is described in Game Theory as a zero-sum game. It is unclear as an optimum point could be attained which is defined in Ethics approach.

The next section introduces a conflict resolution model based on Game Theory approach called the Strategic/Tactical model. It allows each participant or player to exchange his/her developed strategy in order to satisfy his/her own interest and to determine the group final outcome.

2.1.3.3 Model of Resolution for a Complex Decision Situation

A common agreement in decision-making process is that the process evolves through a number of interwoven stages, rather than a single isolated act, like BOGSAT. In his 1910 work, John Dewey proposed that the process could be thought of as consisting of three phases, namely answering these three questions (Dewey, 1910): 1) What is the problem? 2) What are the alternatives?, And 3) Which alternative is best?

A more general and widely accepted model was proposed by Herbert A. Simon in his book "The New Science of Management Decision" (Simon, 1960). His model consists of three stages that can be described as follows:

> Intelligence: The internal and external environments of the decision maker are searched for conditions requiring a decision, and information is gathered about these conditions.
>
> Design: The courses of action available to the decision maker are determined and analyzed as possible solutions to the problems that have been detected.
>
> Choice: One of the available courses of action is selected for implementation on the basis of an evaluation of their effectiveness relative to the achievement of objectives.
>
> (Simon, 1960)

Eilon (1969) provided a more detailed description based on Herbert's model consisting of eight steps. The eight steps were as follows:

1. Information input
2. Analysis of the available information
3. Specification of measures of performances and costs
4. Creation of a model of the decision situation
5. Formulation of alternatives (or strategies) available to the decision maker
6. Predictions of outcomes of the alternatives
7. Specification of criteria of choice between alternatives
8. Resolution of the decision situation.

(Eilon, 1969)

The above models are more suitable to explain a well-structured decision situation in which a single participant and a single objective are involved. However, a complex decision situation requires some modifications to handle the dynamics of an ill-structured problem.

Radford (1988) proposed a modified three-stage model of decision-making to better describe a complex decision situation called the strategic/tactical model, or SANTA model. The model contains three stages of activity (see Figure 2.1) that can be briefly described as follows:

> Stage 1 Information Gathering consisting of an examination of the environment of the decision situation and the seeking out of details by the participants and of all of the factors that might bear on or affect the outcome of the situation.
>
> Stage 2 Analysis consisting of two parts: strategic analysis, which is concerned with possible final outcomes of the situation and with participants' preferences for them; and tactical analysis, which is concerned with the choice of courses of action that a participant might use in order to bring about an outcome that is most preferred.
>
> Stage 3 Interaction consisting of communication between the participants with the purpose of bringing about a final outcome; the objective of each participant in this stage is to persuade or coerce the other participants to agree to an outcome that he/she most prefers.
>
> (Radford, 1988)

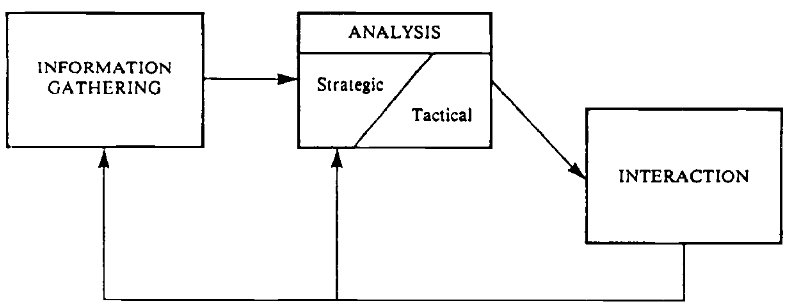

Figure 2-1 Three-stage SANTA Model (Radford, 1988)

2.1.3.4 SANTA Model and its Rationality

The key contribution of the SANTA model that distinguishes it from other decision models is the interaction stage. The most important activity in the interaction stage is communication because it is by this activity that participants become aware of the views and possible actions of the other participants involved. Habermas (1987) emphasizes the importance of communicative interaction in the planning and decision-making process in his proposed concept of communicative rationality that can be described as follows:

> Under the functional aspect of *mutual understanding*, communicative action serves to transmit and renew cultural knowledge; under the aspect of *coordinating action*, it serves as social integration and the establishment of solidarity; finally, under the aspect of socialization, communicative action serves the formation of personal identities.
>
> (Habermas 1987)

Communication in this sense can be achieved by direct oral exchanges, by exchange of written material, by other actions designed to convey a message, or by a combination of all three. The communicative interaction in a group setting with conflicting interests, such as a complex decision situation, can be in the form of negotiation and bargaining. The content of the message exchanged is usually designed to influence the recipients in some way or to change their perceptions of: 1) the decision situation; 2) the possible outcomes; and 3) preferences between the outcomes. The pure communication tactic as described by Feldmen (1983) is one of the most commonly used in the SANTA model.

The pure communication is appropriate in situations where mutual understanding and unforced agreement are desired. Each decision maker or actor responds with new analyses, arguments, or judgments as other actors presenting their points of views. The actors are aware of the whole or some incomplete information about the alternative courses of actions among participants, and counteract by exchanging knowledge of calculations and impact assessments. Each decision maker has the information base for judging what change represents generalizable interests. The acceptable alternative emerges through a mutual exchange of views where nobody yields to other pressure than that inherent in a valid argument.

The eventual outcome under the SANTA model is one to which all participants agree, some possibly reluctantly. In some cases, participants agree to proceed to an outcome in the face of the overwhelming power of one or more participants. In other cases, a participant may agree to an outcome that is not initially his or her most preferred, in order to dispense with a time-consuming or costly argument, and to proceed to other matters that are considered to be more important or have an influence on the final outcome. The key difference from a model, such as BOGSAT, is that the SANTA model is a continuous process of learning and understanding through effective communications by virtue of a fair and open framework in developing group consensus rather than relying solely on STATUS QUO.

According to Radford (1988), the final decision can be viewed as a result of meta-equilibrium in Game Theory. The meta-equilibrium is defined as a solution to a situation from which no participants can gain by moving as long as the other participants do not. Figure 2.2 shows the model of the process of interaction and solution-seeking of a complex decision situation. Strategic and Tactical analysis is performed by each of a number of participants, and is represented by a series of boxes placed down the page in time sequence under each participant. The input of information and perceptions from the participants' individual information gathering activities is indicated by the arrowhead to the left of each box. From time to time, the participants communicate with one another concerning their perceptions of the situation or with regard to any actions that they have decided to take after analysis of the situation. This exchange is represented by the boxes labeled "interaction."

The SANTA model by Radford is very useful in organizing or structuring how the group discussions and resolutions of ill-structured decision situations should take place. The SANTA model provides a sense of purpose and direction to accomplish the complicated tasks in a complex decision situation.

Even a small change in the decision process to a structured discussion would be a vast improvement over the BOGSAT model. Time would not be wasted by jumping back and forth, discussing some points over and over again and inadvertently failing to discuss some issues at all. Also, it helps decision makers recognize their positions in the group and be able to move along more efficiently. One person's preference and its failure to be accepted within the group is more likely to be contributed to the group points of views and the tactics used to resolve the conflicts rather than the failure in communications, information sharing, or

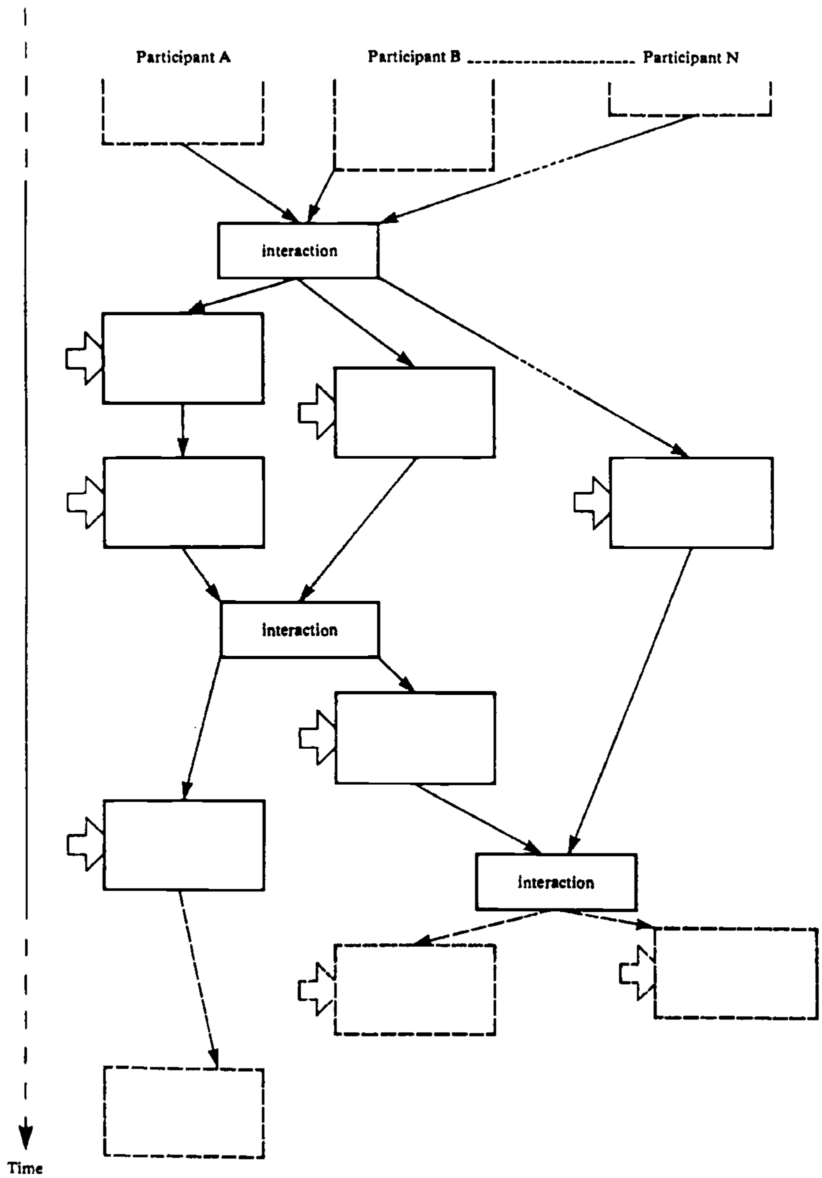

Figure 2-2 SANTA Resolution Process (Ref: Radford, 1988)

failure to recognize other participants' roles in the group. This model improves group performance in making a decision, such as group cohesiveness, cooperation, coordination, and confidence.

To make the SANTA model applicable would require decision aids to help decision makers gathering information about group's values and judgments about the decision situation, comparing those values, and apply their strategic/tactical analysis in order to achieve their final goals or group consensus. These new decision aids should be simple to construct, adaptable to different decision situations, natural to users, intuition and general thinking, encourage compromise and consensus building, and not require inordinate specialization to master the new tool. The next section describes possible tools that can be used to implement the SANTA model in real world problems.

2.2 GROUP DECISION SUPPORT SYSTEM

Sage (1991) defined a decision support system, DSS, as a system that supports technological and managerial decision-making by assisting in the organization of knowledge about ill-structured, semi-structured or unstructured problems.

Thierauf (1988) provides a broader definition for DSS to be as follows:

> Decision Support Systems allow the decision maker to combine personal judgment with computer output in a user-machine interface to produce meaningful information for support in the decision-making process. Such systems are capable of solving all types of problems (structured, semi-structured, and unstructured) and use query capabilities to obtain information by request. As deemed appropriate, they use quantitative models as well as database elements for *problem solving*. From an enlarged perspective, decision support systems are an integral part of the decision maker's approach to *problem finding*, which stresses a broad view of the organization by employing the 'management by perception' principle.
> (Thierauf 1988)

Some observed characteristics of DSS that has evolved from the early research and implementations include the following:

- They tend to be aimed at the less well structured, under specified problems that upper-level managers typically face,
- They attempt to combine the use of models or analytical techniques with traditional data access and retrieval functions,
- They specifically focus on features that make them easy to use by non-computer people in an interactive mode,
- They emphasize flexibility and adaptability to accommodate changes in the environment and decision-making approach of the user.

(Sprague, 1982)

According to Spraque (1982), six performance requirements should be satisfied from the user point of view. The first three pertain to the type of decision-making task that decision makers face for which DSS should provide support. The latter three relate to type of support that is needed. Six requirements include:

1. DSS should provide support for decision-making, but with emphasis on semi-structured and unstructured decision situations.
2. DSS should provide decision-making support for users at all levels, assisting in integration between the levels whenever appropriate. This is to recognize

that any tough decision problem involves several people or groups, and requires integration and coordination.

3. DSS should support decisions that are interdependent as well as those that are independent. Hackathorn el al (1981) suggested three decision types involving in DSS, i.e.,
   - Independent: A decision maker has full responsibility and authority to make a complete implementable decision.
   - Sequential interdependent: A decision maker makes part of a decision, which is then passed on to someone else.
   - Pooled Interdependent: The decision must result from negotiation and interaction among several decision makers.
4. DSS should support all phases of the decision-making process such as those suggested by Simon (1960).
6. DSS should support a variety of decision-making process, but not be dependent on any one. In other words, a very important characteristic of DSS is to provide decision makers with a set of capabilities, but be adaptable to each person's cognitive style, i.e., process independent and user driven.
7. DSS should be easy to use.

2.2.1 Definition of Group Decision Support System

Desanctis and Gallupe (1987) defined a decision-making group as:

> Two or more people who are jointly responsible for detecting a problem, elaborating on the nature of the problem, generating possible solutions, evaluating potential solutions, or formulating strategies for implementing solutions. The members of a group may or may not be located in the same physical location, but they are aware of one another and perceive themselves to be a part of the group which is making the decision.
> (Desanctis and Gallupe, 1987)

Desanctis and Gallupe (1985) also defined a group decision support system, or GDSS, as: "an interactive, computer based system that facilitates the solution of unstructured problems by a set of decision makers working together as a group."

A GDSS aims to improve the process of group decision making by removing common communication barriers, providing techniques for structuring decision analysis, and systematically directing the pattern, timing, or content of discussion (Desanctis and Gallupe, 1987). Dennis el al (1988) provided a broader definition of GDSS as follows:

> GDSS are social, information technology-based environments that support intellectual group activities either within or across geographical and temporal boundaries, where:
>
> - Information Technology environments encompass communication, computing, and decision support technologies, and include, but are not limited to; distributed facilities, computer hardware and software, audio and video technology, procedures methodologies, facilitation, and applicable group data, and

- Intellectual group activities include, but are not limited to, planning, idea generation, problem solving, decision-making, issue discussion, negotiation, conflict resolution, and creative or collaborative group activities such as document preparation and sharing.

(Dennis el al, 1988)

2.2.2 Research Studies on GDSS

The main interest in GDSS studies is to answer the question of whether or not this new technology is effective when compared to traditional techniques. Effectiveness has been evaluated for GDSS in three ways: quality of the decision, time to make the decision, and effect on group processes, such as domination by one or more group members, and the distribution of power. Several studies have shown that decisions using a GDSS are better than those made by non-GDSS-supported groups (Gallupe 1985, Lewis 1982, Steeb and Johnston 1981).

Gallupe (1990), however, reports many cases, especially those that were tested in a laboratory setting, in which GDSS-supported groups did not produce better decisions than non-GDSS-supported groups.

This finding leads to the question, "under what conditions is GDSS effective and ineffective?". Dennis el al (1989) have summarized some of the conditions under which GDSS-supported groups will be effective and ineffective.

They noticed that most GDSS-supported groups generally are effective in field settings, but not in laboratory experiments, and they speculated on the characteristic differences between laboratory settings and field settings. One of the important differences is that field settings tend to use larger groups (10-30 participants) and the participants usually have non-overlapping knowledge. A subsequent experiment by Dennis el al (1990) examined the size of a group that could be supported by a GDSS.

In a non-GDSS-supported environment, the effective size of a group for making decisions is about five to six people. Because the GDSS allows participants to operate in parallel, the size of the effective groups can be increased. The experiment studied three sizes of groups: 3-member, 9-member, and 18-member. They found that the larger groups generated more ideas and were more satisfied with their work than were the smaller groups. It should be emphasized, though, that the idea generation per person did not increase with larger groups (it stayed around 11 for the session), but the fact that there were more people in the larger groups meant more total ideas. In a non-GDSS environment, larger groups would cause the participation per group member to decrease.

The complexity of the problem is also important to the effectiveness of the GDSS. Gallupe (1985) found that GDSS-supported groups were effective when solving complex problems and not when solving simple problems. This could possibly be related to the size of the group. Simple problems could be solved by fewer people, which would mean that a GDSS would not be needed in the support of a larger group. More complex problems require the use of more people, some with specialized knowledge, so that GDSS support would be needed.

In terms of group processes, Dennis el al (1989) found that participants made only one verbal comment about every 94 minutes and that most of the time was spent interacting with the computer with comments inputted in a range from once every 1.75 minutes to once every 5.5 minutes. From the study by Lewis (1982) and Nunamaker el al (1989), it suggests that GDSS tends to equalize participation so that the most dominant members do not control the decisions of the group.

2.2.3 Analytical Methods in GDSS

2.2.3.1 Reviews of Analytical Methods in GDSS

The most important parts of DSS and GDSS are the analytical methods used to convert decision problems into easily identifiable and comparable frameworks or structures.

Andriole (1989) classified the analytical methods used in DSS and GDSS into four groups as follows:

- Decision analytical methods
- Operation research methods
- Computer Science methods
- Management Science methods

According to Barcley el al (1977), decision analytical methods can be characterized as:

> ...in the application of decision analysis a problem is decomposed into clearly defined components in which all options, outcomes, values, and probabilities are depicted. *Quantification* is in the form of the value for each possible outcome and the probability of those values (or costs) being realized can be in terms of objective information or in the form of quantitative expressions of the subjective judgments of experts. In the latter case, the quantitative expression serves to make explicit those subjective qualities which would otherwise be weighted in the decision process, albeit in a more elusive, intuitive way...
>
> It should be emphasized that in no sense does decision analysis replace decision makers with arithmetic or change the role of wise judgment in decision making. Rather, it provides an orderly and more easily understood structure that helps to aggregate the wisdom of experts on the many topics that may be needed to make a decision, and it supports the skilled decision maker by providing him with logically sound techniques to support, supplement, and ensure the internal consisting of his judgment.
>
> (Barcley et al, 1977)

Some example of decision analytic methods include the Analytic Hierarchy Process, Multiattribute Utility method, Decision Tree method, and so on.

Contrasting to the subjective nature of analytical data in decision analytical methods, Operation Research (OR) methods are quantitative-empirical data analysis (Andriole, 1989). OR models are highly structured and frequently mathematical. There are a variety of tools and techniques that comprise OR methods. Some of the most recognized include linear and dynamic programming, Game Theory, Simulation, Econometric methods, and other mathematical models.

In Andriole's view (Andriole, 1989), methods such as Artificial Intelligence, Expert Systems, Knowledge Based Models, draw much of their interest from

Computer Science community and should be classified differently from the previous two. The applications of Computer Science in decision analysis have their roots in Information Theory that has interest in linking electronic data processing with data and models for data storage and problem-solving purposes. The tools and techniques of Computer Science make it possible to develop a successful DSS and GDSS.

There are some methods frequently used to monitor and manage projects or manpower for management purposes only. Those include Gantt chart, Precedence Diagram, CPM, Time-Scale Charting, etc., which can be classified as Management Science methods.

2.2.3.2 Selection of Proper Analytical Methods for Complex Decision Situations

According to Andriole (1989), there are five characteristics that should be examined to determine the proper analytical method for each decision situation. They are:

- Epistemology
- Ease of Use
- Degree of Structure and Flexibility
- Transparency and Safety
- Evaluability

2.2.3.2.1 Epistemology

Epistemology is the study of knowledge. It deals with the sources of knowledge and the various forms it can take. It distinguishes between knowledge that is discovered empirically via sensory means, and knowledge discovered intuitively. Decision analytic and many AI methods process information that is intuitive (Andriole, 1989). They collect, quantify, and manipulate subjective information based on the wisdom, judgment and experience of experts. These two methods should be more suitable for a complex decision situation in which both quantitative and qualitative information, or data, are required.

2.2.3.2.2 Ease of Use

Decision analytic methods are preferred over other methods when multiple participants are involved in the decision-making process. Decision analytic methods are intuitively more appealing than OR methods because their models are more representative of the way humans solve problems in a group setting. It is easy to understand the general concept of divide-and-conquer commonly used in some decision analytic methods. Also, the ability to compare among each criterion separately helps reduce the workload of those involved in the process. It is not easy for those who have no solid background in mathematics to understand or question the outcomes derived from dynamic programming or mathematical models. Many of the methods anchored in inferential statistics require a statistical background. Both would be difficult to control in a complex decision situation since each group is formed by people with different backgrounds.

2.2.3.2.3 Degree of Structure and Flexibility

As previously mentioned, the SANTA model requires a highly flexible method to accommodate the interaction process. The "What-If" scenario and sensitivity evaluation are always a key part of strategic/tactical development for each decision maker. In terms of structure and flexibility, decision analytical methods provide a great deal of both (Andriole, 1989). They allow decision makers to test alternative hypotheses, the sensitivity of group acceptance for a particular alternative, and changes in value judgment through coalition and coercion using the previously agreed criteria/objectives hierarchical structure.

2.2.3.2.4 Transparency and Safety

Many analytical methods are powerful and at times deceptive. In many complicated mathematical models, a solution may be accepted even though users may not understand or have no tool to verify the solution. As a general rule, Andriole suggests that regardless of what methods are being used, it should always be possible for users to access information about the characteristics of the embedded method as well as the analytical assumptions that underlies them. Under no circumstances should users be expected to accept blindly the system's conclusion. Most decision analytical methods allow users to keep track of every part of the decision process and any computational results given by those methods.

2.2.3.2.5 Evaluability

The application of decision analytical methods in a group setting are difficult to evaluate compared to more precise quantitative-empirical methods in OR. The literature on the evaluation of decision analytical methods is voluminous, but far from conclusive. Andriole (1989) concluded that the internal logic of many decision analytical methods can be measured easily, but internal logic does not shed much light on whether or not the method produces "good" outcomes. This is why most decision makers prefer to structure decision situations as well-structured decision situations, as previously described by Radford. However, most decision situations in transportation planning are complex decision situations and should not be evaluated as well-structured situations. The final outcomes of complex decision situations are always imprecise and difficult to be evaluated. Those outcomes are always subjectively rational.

2.2.4 Ideal Engineering Decision Support System

Ullman described an ideal engineering decision support system as having eleven important attributes, based on his work (Ullman, 1995) and that of Cook (1993). The eleven attributes are as follows (Ullman, 2001):

1. Support **inconsistent** decision-making information
2. Support **incomplete** decision-making information
3. Support **uncertain** decision-making information
4. Support **evolving** decision-making information
5. Support the building of a **shared vision**
6. Calculate alternative **ranking, rating, and risk**
7. Suggest direction for additional work, **what to do next**
8. Require low **cognitive load**
9. Support a **rational strategy**
10. Leave a **traceable logic** trail
11. Support a **distributed** team

(Ullman, 2001)

The next section discusses each attribute as compare to a complex decision situation in more details.

2.2.4.1 Support Inconsistent Decision-making Information

Ullman (2001) identifies three possible causes of information inconsistency in the decision-making process, i.e., viewpoint inconsistency, data variation or inconsistency, and abstraction inconsistency.

In a common group setting such as those in transportation planning, the group is formed by members from different agencies with different responsibilities as well as representatives from different interest groups. This could create conflicts or inconsistency in Ullman's term of viewpoints among group members. This lack of consistency can be handled by either averaging the viewpoints to generate a single, consistent viewpoint, such as those described by Harsanyi (1977) as Ethics class, or by exploring the group diversity in Game Theory.

The data variation or inconsistency is created by the differences in interpretation or evaluation among group members about certain alternatives relative to certain criteria. These differences are based on members' experiences, knowledge, and interests about these issues.

A complex decision situation involves both quantitative and qualitative measures that could create an abstract inconsistency when trying to combine the two in the decision-making process.

2.2.4.2 Support Incomplete Decision-making Information

In engineering decision problems such as machine and software designs, defined alternatives and criteria may evolve throughout the entire process. Information about these alternatives and criteria, therefore, are considered incomplete. However, this is not the case in transportation planning and decision-making process, especially, in the alternative selection stage. The entire process consists of several groups of people in which people come in and out throughout the process to participate in just a particular task or stage. Public participation may only occur during the preliminary discussion to address their concerns. Other groups or representatives may participate to oversee that those concerns are addressed properly during the design stage. Criteria and alternatives are screened and refined through several long and arduous stages prior to the actual selection stage by a decision-making group. These original alternatives and criteria may come from the decision-making group, public participation, or an assigned group of experts. The final set of the alternatives and criteria, however, are limited into manageable numbers for easy and thorough comparison by the decision-making group. Therefore, all the alternatives and criteria are known prior to the alternative selection stage, and could be considered complete information.

Another cause of incompletion, however, may occur when different subgroups of the decision-making group are assigned to evaluate alternatives against specific criterion or criteria based on their expertise of those subgroups, e.g., a subgroup of economists may be assigned to evaluate all alternatives under the Economic Viability criterion. An ideal decision support tool should allow this incomplete information to be aggregated back into the final decision-making process.

2.2.4.3 Support Uncertain Decision-making Information

Uncertainty is always a part of a complex decision situation as described by Radford (1988).

2.2.4.4 Support Evolving Decision-making Information

A common agreement about the decision-making process is that the process evolves through a number of interwoven stages. Radford (1988) recognized and established a three-stage model to support these learning and evolving aspects of the decision-making process called the SANTA model. The SANTA model consists of information gathering, strategic analysis, and interaction.

2.2.4.5 Support the Building of a Shared Vision

Ullman (2001) suggests, "A decision support system should be a mechanism to foster the sharing of information". The system should provide a transparent, fair, and open framework for developing a group consensus. This could lead to the development of group trust and their willingness to support and put forward the group's final decision.

2.2.4.6 Provide Alternative Ranking, Rating, and Risk

The objective of the alternative selection process is to identify the group's preferred alternative. Therefore, the system should help users rate and rank those alternatives in order to choose the most preferred one. A complex decision situation is also involved risk created by its uncertainty.

2.2.4.7 Provide Direction for Additional Work, What to do next

According to Ullman (2001), support for what to do next comes in the form of a sensitivity analysis. The analysis provides information about the sensitivity of the group in accepting or rejecting the recommended alternative as well as the sensitivity of each alternative in retaining its ranking.

2.2.4.8 Require Low Cognitive Load

Psychologists have proven that the human brain is limited in both short-term memory capacity and its discrimination ability (channel capacity) to about seven items plus or minus two (Miller, 1956). Also, Herbert Simon defines human judgment in complex decision situations as bounded rationality (Hogart, 1987). He believes that decision-making in complex situations takes place under constraints of human information-processing limitations. Therefore, an ideal decision support system should help minimize these limitations and improve group capabilities.

2.2.4.9 Support a Rational Strategy

According to Ullman (2001), an ideal decision support tool "should encourage the careful evaluation of the alternatives against the criteria, allowing the decision-maker (s) to work with the information in a manner that is both rational and flexible". The traditional engineering evaluation process provided a rational strategy by using measures, such as the benefit/cost ratio, but excluded important qualitative factors and unquantifiable variables.

2.2.4.10 Leave a Traceable Logic Trail

An ideal decision support system should keep the history of all the progress being made throughout the evaluations, discussions, information sharing, and the changes in members' viewpoints for later use by the group members or by the public. The transparency and its accessibility to the public should have a positive impact on public confidence about the decision made by the group. This attribute would not only provide a chronicle of the effort, but would assure that hidden agenda did not dictate the final solution.

2.2.4.11 Support a Distributed Team

An ideal decision support system should provide flexibility of scheduling and reduce travel costs and times by allowing members to access the system from anywhere at any time.

2.3 THE ANALYTIC HIERARCHY PROCESS

2.3.1 Development of the AHP

The Analytic Hierarchy Process or AHP was developed by Thomas L. Saaty. It allows decision maker/makers to model a multiple-objectives decision problem in a hierarchical structure showing the relationships of the goals, objectives (criteria), and alternatives. Uncertainties and other influencing factors can also be included.

According to Forman and Selly (2000), the AHP allows for the application of data, experience, insight, and intuition in a logical and thorough way. The AHP enables decision makers to derive ratio scale priorities or weights as opposed to assigning them arbitrarily. In so doing, the AHP not only supports decision makers by enabling them to structure complexity and exercise judgment, but also allows them to incorporate both objective and subjective considerations in the decision process.

According to Saaty (2000), the reasons users find the AHP easy to use are as follows:

- People find it natural and are usually attracted rather than alienated by it,
- It does not need advanced technical knowledge and nearly everyone can use it. In the Saaty case, it only takes about an hour to introduce the AHP to his students, and they can go on to do substantial examples,
- It takes consideration of judgments based on people's feelings and emotions as well as their thoughts,
- It deals with intangibles as well as tangibles. What we perceive with the senses is dealt with by the mind in a similar way to what we feel,
- It derives scales through pairwise comparison rather than by assigning numbers pulled from the mind directly,
- It does not take the measurements on scales for granted, but asks that scale values be interpreted according to the objectives of the problem,
- It relies on simply elaborated hierarchical structures to represent decision problems. With such appropriate representation, it is able to handle problems of risk, conflict, and prediction,
- It can be used to make direct resource allocation, to do benefit/cost analysis, resolve conflicts, and to design and optimize systems,
- It is an approach that describes how good decisions are made rather than prescribes how they should be made. No one living at a certain time knows what is good for people for all time,

- It provides a simple and effective procedure to arrive at an answer, even in group decision-making where diverse expertise and preferences must be considered,
- It can be applied in negotiating conflicts by focusing on relations between relative benefits to costs for each of the parties.

2.3.2 Steps in the AHP

The AHP consists of three major steps:

2.3.2.1 Step 1

This consists of breaking down the decision problem into a hierarchical structure. Figure 2.3 shows a basic hierarchical structure of a hypothetical transportation project. The structure consists of two levels under the general project goal. The first level represents the criteria relevant to this goal, i.e., speed control, accident reduction, and economic development. The BOTTOM or second level represents the project alternatives, i.e., alternative A, B, and C. For greater precision, the criteria may be divided into sub criteria, creating an additional level in the hierarchy.

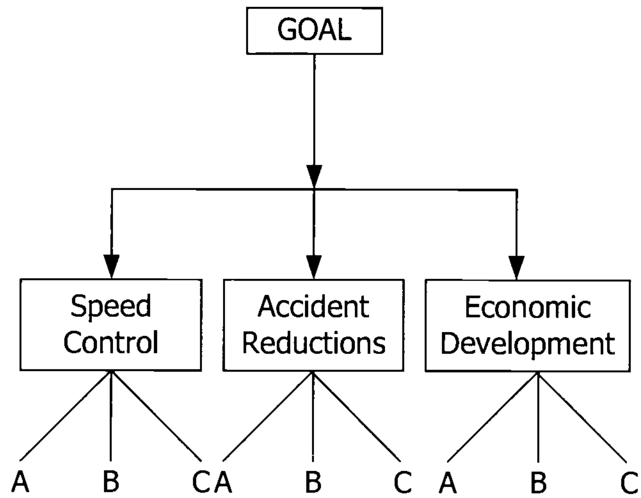

Figure 2-3 Hierarchical Structure of Hypothetical Project

2.3.2.2 Step 2

The second step involves evaluating the alternative priorities and weighting the criteria. The alternatives are compared in pairs to assess their relative performance with respect to each of the criteria. Similarly, the criteria are compared in pairs to define their importance with respect to the general project goal. The comparisons are based on hard data, as well as experience and expertise of the decision makers.

The fundamental scale presented in Table 2-2 is used to elicit the comparisons. The use of verbal comparisons facilitates the weighting of criteria, as well as the evaluation of the alternative priorities in terms of non-quantifiable criteria. Once the verbal comparisons are made, they are translated into the numerical values of the fundamental scale. Each set of comparative judgments is entered into a separate matrix to define the so-called "local" priorities, i.e., the preferences of the alternatives with respect to a specific criterion. The weights of the criterion are derived in a similar fashion.

Table 2-3 Preference Scale (Ref: Saaty, 2000)

Scaled Value	Definition
1	Equally Important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very Strongly more important or preferred
9	Extremely more important or preferred
2,4,6,8	Intermediate value to reflect compromise
Reciprocal	Used to reflect dominance of the second alternative as compared with the first

Figure 2-4 depicts the type of matrix used to enter the pairwise comparisons. The comparison of alternative A with B, for instance, is expressed by a participant as slightly better, which yields the numerical value of 3 from Table 2-2. For obvious reasons, the diagonal cells always contain the value of 1. Also, the cell of the opposite comparisons, for instance, alternative B with A is a reciprocal of the one comparing A with B. In this example, the numerical value of B with A would be one third.

	A	B	C
A	1	3	6
B	1/3	1	2
C	1/6	½	1

Figure 2-4 Pairwise Comparison Matrix

If the judgments were perfectly consistent, any column of the completed matrix could simply be normalized to yield the respective "local" priority of the project, i.e., its relative performance regarding criterion A. However, the judgments may not be consistent, therefore the Eigen Vector method is proposed to determine these local priorities and weights. Appendix A summarizes the Eigen Vector Method as proposed by Saaty.

Aside from the method of determining priorities using the Eigenvalue and Eigenvector suggested by Saaty, other methods has been proposed such as the Row Geometric Mean (or the Logarithmic Least Square), the Column Geometric Mean, and the Harmonic Mean (Zhou, 1996). The Row Geometric method has been widely used due to its simplicity and to bypass the once criticized idea of the measure of inconsistency by many researchers. Some argued that the limited range of numbers from 1 to 9 made it impossible for users to be consistent even though they wanted to be (Belton 1986, Schoner 1989, Salo 1993).

This could simply be illustrated as follows. If A is slightly less important than B or on numerical scale A is one-third of B, and A is strongly more important than C or A is 5 times more important than C. To be consistent, B should be 15 times more important than C. However, even though the decision maker decided to choose B is extremely more important than C, the numerical value would only be 9 based on the preference scale. Therefore, the inconsistency as expressed by Saaty's computation is due solely on the limitation of the preference scale not the decision maker's intent.

2.3.2.3 Step 3

The third step consists of synthesizing the local priorities throughout the hierarchy, in order to compute the global priorities of the alternatives. The principle of hierarchical composition is applied for this task (Saaty, 2000). The principle simply states that, for each alternative, the local priorities are multiplied by the corresponding criterion weight, and the results are summed up to obtain the global priority of that alternative with respect to the goal stated at the top of the hierarchy. Thus, the global priorities for three alternatives are shown as follows:

Global Priority for:
Alternative A = Σ (Weight of the criterion*local priority of Alternative A under that criterion)

Global Priority for:
Alternative B = Σ (Weight of the criterion*local priority of Alternative B under that criterion)

Global Priority for:
Alternative C = Σ (Weight of the criterion*local priority of Alternative C under that criterion)

2.3.3 Absolute and Relative Measurement in the AHP

Cognitive psychologists have recognized for sometime that there are two kinds of comparisons that people are able to make, i.e., absolute and relative (Forman and Selly, 2000). In absolute comparisons, alternatives are compared with a standard in one's memory that has been developed through experience. In relative comparisons, alternatives are compared in pairs according to a common attribute. When users create a pairwise comparison in the AHP, all relative measurements of priorities and weights are computed by comparing the elements one to another.

In contrast, an absolute measurement (sometimes called Rating) is used to gauge the alternatives against an established scale and not against each other. The absolute measurement is very common in our daily lives. A good example is the academic grading system where an A grade is represented by a numerical values of 4.0. A person who gets an A would get an assigned numeric value of 4.0.

This absolute measurement or Rating approach makes it easier to rate many alternatives in a short period of time. In the Rating approach, the objectives are pairwise compared against one another as usual, but the alternatives are evaluated using a pre-established scale (called intensity by Saaty) instead of being compared to one another. This intensity scale, in a sense, serves as surrogates for the alternatives. Instead of deriving priorities for the alternatives with respect to each objective, users can derive priorities for the intensities through a pairwise comparison.

2.3.4 Useful Research Findings of the Uses and Limitations of the AHP

The main benefit of the AHP is not the mathematical solution itself, but its rationality and the ability to present human judgment and problem of conflicts numerically and graphically.

The use of pairwise comparison instead of direct rating helps provide the redundancy in evaluating human's judgment. This is partly due to the limited ability of human short-term memory to compare seven objects consistently plus or minus two (Miller, 1956). In their study, Leake and Dix (1979) found that the method of pair comparisons was more acceptable than other selected methods for obtaining the relative importance of a set of transport objectives.

Recent study by Al-Akhras (1997) which compared three methods of assessing weights used in evaluating transportation alternatives, i.e., the AHP, the Anchored Rating Scale, and Direct Rating, found that the AHP performed better than the other two in his first experiment and all performed equally well in his second experiment.

A similar finding was found from the study by Millet (1997). Millet studied five different preference elicitation methods, i.e., Direct Estimation, Graphical Multiple Bars, Graphical Pairwise, Numeric Pairwise, and Verbal Pairwise. In Direct Estimation, the user simply produces a set of values reflecting the relative preference for the compared elements. The graphical multiple bars (GMB) method depicts the set of compared elements as light bars and allows the user to directly change the relative lengths of these bars to reflect relative preferences. The graphical pairwise bars (GPB) method depicts each pair of compared elements as two light bars and allows the user to change the relative lengths of these bars to reflect relative preferences. The numeric pairwise comparison (NPC) mode allows the user to provide pairwise comparisons using numerical ratios. The verbal pairwise comparison (VPC) method provides a translation layer above the NPC method by accepting verbal judgments from the user and converting them to numeric values. It allows the user to provide pairwise comparisons on a verbal scale with five major gradations: Equal, Moderate, Strong, Very Strong, and Extreme. From these five methods, the Verbal and Numerical Pairwise methods were the most accurate, and the pairwise comparison modes were more accurate than the non-pairwise modes.

Many researchers also found that people prefer to use verbal phrases rather than numerical probabilities when conveying uncertainty, but prefer to receive it numerically (Wallen et al, 1993, Erev, and Cohen, 1990, Budescu and Wallsten, 1990, Rapoport et al, 1987). However, these research studies also found that humans attach different probabilities to individual phrases, and they overlap the meaning between them. In order to determine the impact of this difference in value elicitation, Huizingh and Vrolijk (1997) conducted a study to compare the verbal and numerical judgments in the AHP. They confirmed that there is overwhelming evidence in which people have very different numerical interpretations of the same verbal expressions. The study also found that the 1-to-9 conversion table, as is often used in the AHP, tends to overestimate differences in preference. However, as suggested by Huizingh and Vrolijk, given the preference of many people for the verbal mode, they conclude that if accuracy is not of the highest importance, the ease and comfort of verbal expressions may be worth the small loss in decision quality. The optimal solution would be to include a personal conversion table for each decision maker. Although optimal, it may not be practical.

2.3.5 Applications of AHP in Transportation Planning

Holguin-Veras (1995) conducted a comparative study of AHP and the multiattribute value (MAV) functions in highway planning. Two different decision makers were selected to evaluate a case study of the road from Santo Domingo to San Cristobal, an 18-km road project built in the Dominican Republic from 1987 to 1989. The criteria used in the study included economic benefits, project life, and added land value. After applying both methodologies, both decision makers were not fully satisfied with the results. However, both thought that the methodologies helped them conducted their evaluation in a more systematic manner, and should be useful in transportation decision-making process.

Tsamboulas et al (1999) conducted a comparative analysis of five of the most commonly used multicriteria methods in the assessment of transport projects. Those five methods include: (1) REGIME; (2) ELECTRE; (3) AHP; (4) Multiattribute approach; and (5) ADAM Type. Details of each method can be found in Tsamboulous's article (Tsamboulas, 1999). These methods were assessed from four perspectives, i.e., transparency, simplicity, robustness, and accountability. The main conclusion drawn from this study can be summarized as follows:

- The theoretical background of each method is philosophically consistent with the decision-making framework of transport planning,
- The methods are capable of receiving inputs concerning preferences of the actors involved, and they can generate outputs permitting the evaluation of direct impacts as well as the assessment of indirect effects on social and physical environment,
- The methods are relatively easy to use by the decision makers and have the potential to be a decision support tool for the selecting among different transport initiatives.

(Tsamboulas, 1999)

Raul (1994) described the decision-making context in common transportation planning in two distinct situations: a) when a simple decision maker (or a group of decision makers that share similar objectives) must make a decision about a problem involving multiple and often conflicting objectives or b) when many decision makers or interest groups (each of which has his own conflicting objectives) are involved in the final decision. This is similar to the one described as Ethics and Game Theory in Harsanyi's classification.

Raul focused his research on the application of the AHP to solve the alternative selection problem in transportation planning in the first situation while this research try to address both situations.

In Raul's research, he proposed the modification of the AHP technique in a group setting by adjusting criteria weights based on members' personalities and knowledge. Each member is evaluated by questionnaires prior to actual decision-making process using the AHP. Then, those answers are analyzed and determine overall adjustment factors, i.e., $\mathrm{K}a$, $\mathrm{K}b$, $\mathrm{K}c$. These three factors are intended to express an individual's perception about his/her knowledge, initial judgmental consistency, and perceived bias in his/her pattern of choices.

After the adjusted individual weights are determined, an overall group weight for each criteria, then, can be determined through the use of geometric means as proposed by Saaty. This technique does not take into account the possible changes in opinions or attitudes through interactions among group members.

Guegan et al (2000) studied the use of the AHP to prioritize traffic-calming projects in comparison to existing point scoring systems. Two point scoring systems were selected for comparison in the study, i.e., Portland's point scoring, and Canberra's point scoring schemes. The most important aspect as mentioned in the study was the ability of the AHP to incorporate qualitative decision factors that were specific to the problem under consideration. These qualitative factors are difficult to take into consideration under the point scoring systems. The major disadvantage was the number of pairwise comparisons required by the AHP. If there are n alternatives, then $n*(n-1)/2$ pairwise comparisons are needed. The study recommended that alternatives and criteria should be limited to a reasonable number. The study did not clearly identify the result of the comparison as further testing was needed. The study did not mention how the AHP could be implemented in groups with conflicting interests that are commonly found in projects such as traffic-calming improvements.

Mouette and Fernandes (1996) evaluated goals and impacts of two alternatives for the third Metro line in Sao Paulo using the AHP. They found that:

> The AHP is an effective procedure in the analysis of different impacts of transportation systems and in the decision-making process, since it allows it to be placed into hierarchy, to order and to retrain the impacts and its consequences, to analyze several criteria simultaneously, as the operational and social impacts, and to provide a large quantity of information in a comprehensive and clear way for the multidisciplinary team that must act at the planning and decision-making process.
>
> (Mouette and Fernandes, 1996)

In Taiwan, the AHP was used to evaluate nine accessible transportation alternatives for four transportation handicapped groups as identified by the government (Lan, 1996). The four handicapped groups included: (1) impaired ambulation: with difficulty in walking, needing wheelchairs, crutches, or walkers for movement; (2) visually impaired: blindness or weak vision, with difficulty in reading external messages such as maps, bus stops, and route information; (3), aged: slow movement or any disabilities due to age (e.g., difficulty in movement caused by the reduction of cardiovascular capacity), and others (including hearing, speaking impaired, mentally retarded, and multiple disabilities): with difficulty in communicating, with public announcements at stations or on boards, or in learning or understanding external information. Based on the AHP, it was found that the most appropriate accessible alternative for the impaired ambulation, the aged, and others would be a demand-responsive lift-equipped specialized van, while half-fare subsidized taxi would be the second best. The half-fare subsidized taxi, however, seemed to be the best alternative for those with visual impaired and conventional bus with broadcast equipment is the second best.

Three transportation systems were proposed for one of the newly planned towns in Kansai Cultural and Academic Research Complexes (Pak et al, 1987). The three systems were:

1. Monorail Car (MRL-G) which is made to be small and light by moving its speed controlling equipments down to the ground,

2. Linear Motor Car (LMC-G) with steel wheels which is made to be small and light by placing the heavy and complicated primary coil on the ground, and
3. Magnetic levitation Car (MGLC) that is small and light and can run in a levitated state, and can reduce noise and vibration completely.

The AHP was used to evaluate these three systems. All the major criteria necessary for evaluating transportation systems in general were considered. Based on the assessment, the MRL-G was evaluated in favor of the best system in the economy-oriented scenarios, and the MGLC in both environment-oriented and convenience-oriented scenarios. The LMC-G was shown to be relatively good in both economy and convenience. The evaluation was done by the technical experts from five different manufacturers. The AHP made it easier for these experts to agree upon the outcomes, even though they had their own opinions and thoughts.

Two important points could be made from the above literature reviews of the Applications of AHP in Transportation Planning:

1. The AHP is suitable for the evaluations of several types of transportation planning and alternative selection process,
2. Most of the applications are either focused on the implementation by a single decision maker or a group of experts. This is more fitted to the description of Ethics in Harsanyi's classification of rational behavior. However, many transportation-planning environments are decided by groups of different interests or agenda as described in Harsanyi's

classification as Game Theory. The implementation of the AHP in this environment would require a further modification such as how to handle the group conflicts, and how games should be played within the decision environment while still continuing to support a fair and open process. This is already suggested in the previous section by incorporating SANTA's model and the Group Decision Support System.

2.3.6 Decision Support Software Using the AHP or similar methods

There are many decision support software package for individual and group environment that are either in use or under development. However, most of them focus on solving group problems in the Ethics class as described by Harsanyi (1977). This research is more interested in a decision support system that can handle both Ethics and Game Theory. None seems to be suitable for the second situation, i.e., Game Theory.

Two decision support software systems seem to provide some useful background in the development of the methodology as proposed in this research. One is Expert Choice and the other is Engineering Decision Support System.

According to its website http://www.expertchoice.com, Expert Choice is a group meta decision support software product based on the AHP. Dr. Thomas Saaty, who developed the AHP, partnered with Professor Ernest H. Forman in 1983 to produce Expert Choice. Five key features of Expert Choices include:

1. The flexibility to build and analyze various sizes and types of hierarchies of criteria,
2. The amplification of the option to identify value elicitation, i.e., original pairwise comparison process using verbal associations, numerical statements and graphical comparisons with bar charts. Also, it allows users to bypass the pairwise comparison and directly assign his/her preferred values,
3. The graphical user interface making the process easier to use,
4. The sensitivity graphs making the what-if scenarios easier to conduct and report,
5. The use for both individual and group decision.

Engineering Decision Support System or EDSS was developed by Derald Herling (Herling, 1997) under the supervision of Dr. David Ullman to provide a decision support method that matches the structure and kind of information in alternative-criterion pair evaluation observed in engineering conceptual design activities. The concept of EDSS is similar to the one proposed by Raul (1994) in that both believed that their proposed analytical technique should be adjusted to human imperfection in decision making. The EDSS adjusts for the lack of knowledge about particular issues and confidence about his/her own judgment. Instead of using empirical adjustment factors as proposed by Raul, the EDSS uses an analytical technique called Bayesian mathematics.

The two software packages demonstrate the values of computer-decision support tools, the use of graphical user interface to convey human opinions or beliefs into something recognizable, and the possible improvement of analytical techniques to accommodate actual human' characteristics such as the lack of knowledge, confidence or conflicting agenda.

2.4 AHP, SANTA, AND GDSS

In Simon's model of decision resolution, i.e., intelligence, design, and choice, the AHP is a process that focuses on the choice phase. It can provide a suitable analytical method to help decision makers structure complex decision situations, developing measures of utility, and synthesizing both quantitative and qualitative measures with respect to numerous competing objectives inherent in the problems. This emphasizes two of the five basic characteristics, i.e., Epistemology and the Degree of Structure and Flexibility, for proper analytical methods in GDSS as previously described by Andriole. The use of the AHP is growing rapidly, and the AHP is a widely used decision analytic method in the United States in many disciplines and many organizations (See Golden, 1989, and Zahedi, 1986). This increases the credibility of the methodology and provides a good evaluation of its performances.

In terms of transparency and ease of use, Bard and Souskin (1990) found from their observation of the use of the AHP as follows:

> From the standpoint of consensus building, the AHP methodology provides and accessible data format and a logical means of synthesizing judgment. The consequences of individual responses are easily traced through the computations and can be quickly revised when the situation warrants.
> (Bard and Souskin, 1990)

Saaty proposes the use of the geometric mean to determine the representation of the group values, but this may create unwillingness to accept the solution by the group members since no information or learning process has been exchanged among decision makers.

One possible solution to improve the group aggregation is to apply the SANTA model in the AHP process. The interaction stage of the SANTA model can be used to aggregate individuals' judgment. During the SANTA process, each member will have his/her own opportunity to state his/her opinions and to take part in a partisan discussion on the issue under consideration. The information, both provided and hidden, can be exchanged among participants. Each can freely develop his/her own strategy/tactic to determine possible group weight for each criterion that will benefit his/her own agenda. The final outcome could be the single dominate alternative that the group could agree on, some reluctantly, or to achieve the meta-equilibrium in Game Theory underlining the concept of the SANTA model. The equilibrium occurs when no participants can gain by moving as long as the other participants do not. This provides the information about the sensitivity of each alternative being accepted by the group. At the equilibrium, no weight can be modified without having an impact on one of the alternatives. This can be viewed as a true measurement of sensitivity analysis.

More importantly, the ability to convert those verbal expressions by each participant into comparable numbers that are not obvious to them should help illuminate another dimension of the group decision-making process and can be used to guide the various participants to understand better the magnitude of their differences and the impact of increasing or reducing those differences. This can be an important advantage when applying the AHP to the SANTA model. The side-by-side comparison of each objective can be used to develop a strategy/tactic that satisfies each participant. One person may describe the difference as "strongly", while another may prefer "moderately" even though both may describe the same numerical value. As the information is being exchanged, both then can determine the proper verbal expression.

It can be used to reduce the impact of verbal differences in the AHP, as previously mentioned. The differences can be identified through comparison and information exchange in the interaction stage.

Hamalainen and Poyhonen (1996) conducted a study using the preference programming (The modified version of the AHP by Raimo Hamalainen) in the group decision support. The preference programming is a decision support technique that allows decision makers to give preference statements of weight ratios in terms of intervals instead of single numbers in a value tree. Individual preferences can be combined into an interval model, and the negotiation proceeds by focusing on decreasing the width of intervals. The preference programming approach was evaluated with a realistic traffic planning problem by using the

HIPRE3 + group link software. The results from nine test groups indicate that preference programming is an operational group decision support technique that initiates negotiations and efficiently directs the discussion towards issues that are relevant in reaching a consensus.

This study illustrated the possible use of the AHP in GDSS for transportation planning. However, the study did not provide a direction on how the discussion and group consensus should take place, and how the conflict should be minimized. This can be handled more effectively by the SANTA model as previously described.

2.5 SUMMARY

Complex decision situations consist of all the basic characteristics of ill-structured decision situations including the existence of uncertainty, multiple objectives, more than one participant and the lack of quantitative measures of benefits and costs. Alternative selection in transportation planning is a complex decision situation since it includes all those characteristics.

A traditional model to resolve decision situation called BOGSAT possesses several drawbacks, i.e., cognitive limitations, bounded rationality, unorganized information sharing and resolution seeking, and number comparison biases. An improved model developed by Radford, called the strategic/tactical model, is reviewed and its advantages over BOGSAT are explained.

In order to implement the SANTA model, a Group Decision Support System, or GDSS, is required and the analytical method called the Analytic Hierarchy Process, or AHP is proposed as the proper analytical method for GDSS in the SANTA model.

The new development that combines the SANTA model, GDSS, and the AHP should provide several improvements over the BOGSAT model. The new model is a continuous process of learning and understanding through communicative means by virtue of a fair and open framework in developing group consensus rather than relying solely on the STATUS QUO.

The final outcome could be the single dominated alternative that the group agrees on or to achieve the meta-equilibrium in Game Theory underlining the SANTA model. At the equilibrium, no weight can be modified without having an impact on one of alternatives. This can be viewed as a true measurement in sensitivity analysis.

CHAPTER 3 SYSTEM DESIGN AND IMPLEMENTATION

3.1 OVERVIEW

The alternative evaluation procedure exhibits all the basic characteristics of an ill-structured decision situation as described by Radford (1989). The alternative evaluation procedure in most transportation projects has more than one objective and more than one decision maker in the evaluation and selection of the preferred alternative. Furthermore, those objectives are not just quantitative, but also non-quantitative or qualitative impacts, benefits and costs, such as local quality of life or sustainable development.

The decision in most traditional settings is made through the conflict resolution model called the BOGSAT model, i.e., a Bunch of Old Guys/Gals Sitting Around Talking (Forman and Selly, 2000). This model exhibits several drawbacks including cognitive limitations, bounded rationality, and the lack of qualities in the group decision. As observed by Forman and Selly (2000), the discussions in most group meeting are relatively disorganized. The discussions jump from topic to topic in a haphazard way. Some points are discussed several times with no real contribution to the final decision. Many relevant points may be ignored or avoided. Frustration comes into play as a dominant member press other members to agree with his preference. Shy member may be reluctant to present their positions, even though they have important information to convey. Members lacking in knowledge about particular issues may lag behind in the discussions, which are continuous processes. The final agreement, or disagreement, is made (or forced to be made) when it appears there is no progress or a single member in the group takes control of the whole process and dictates the outcome. This lack of control over the group decision leads to poor quality in the decision and could lead to the lack of effort to adopt the recommended alternative.

Based on the Habermas' concept of communicative rationality (Harbermas, 1987) and the observation by Forman and Selly (2000), the qualities of the group decision in this research are defined as follows:

1. The resolution process to determine the preferred alternative is a continuous process
2. The decision is reached through effective communications that allow information gathering, sharing and understanding within the members of the group
3. The acceptable outcome emerges through a mutual exchange of views where nobody yields to other members' pressures than that inherent in valid arguments
4. The decision process provides an equal and open framework for developing group consensus
5. The acceptable outcome reflects the group sensitivity.

3.2 RESEARCH REQUIREMENTS

With this background stated to assist understanding, the purpose of this research is to develop a group decision support system that:

- Promotes a continuous process of learning and understanding through effective communications by virtue of a fair and open process to develop group consensus rather than relying solely on STATUS QUO,
- Accommodates both quantitative and qualitative measures of benefits and costs,
- Reduces the impact of cognitive limitations that limit human abilities to make thorough comparisons among multiple objectives and alternatives simultaneously,
- Eliminates the haphazard nature in group conflict resolution process as discovered in the BOGSAT model.

From the above requirements, it is suggested that there are three key components needed to satisfy them, i.e., the group conflict resolution model, the analytical method, and the software application as shown in Figure 3.1.

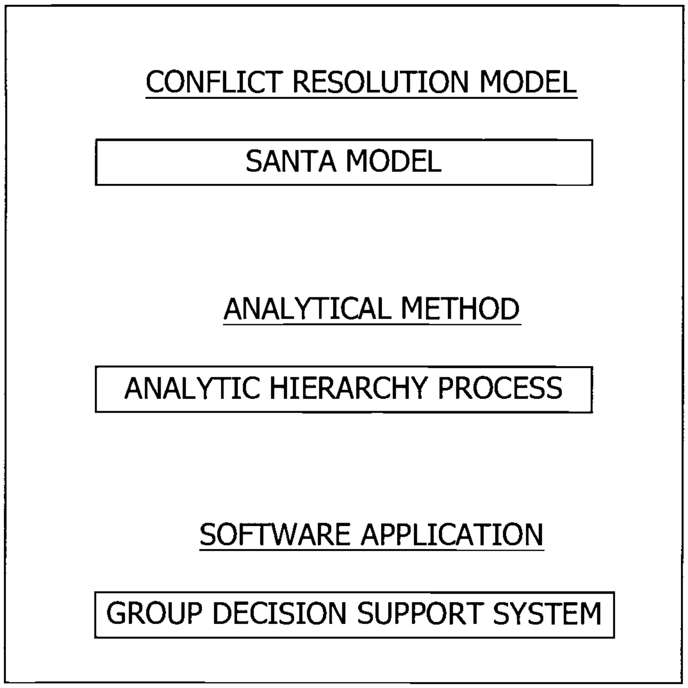

Figure 3-1 Three Key Components for the Proposed Framework

3.2.1 Group Conflict Resolution Model

Radford (1988) proposed a modified three-stage model of decision making to solve the ill-structured problems in a complex decision situation called the strategic/tactical model or the SANTA model. The most important activity in the SANTA model is the interaction stage. At this stage, each decision maker responds freely with his/her own arguments or judgments as others present their points of views.

Each member is aware of the differences in other members' opinions and counteract by exchanging knowledge of analysis results or assessments. Each member has the information base for judging what changes represent group interests or responses. The acceptable alternative emerges through a mutual understanding of each member. According to Radford (1988), the final decision can be viewed as a result of meta-equilibrium in Game Theory. Meta-equilibrium is defined as a situation in which no participants can gain by moving as long as the other participants do not accept or agree. At this equilibrium stage, the actual sensitivity of the acceptable alternative is reached. The SANTA model is very useful in organizing or structuring how the group conflict resolution of a complex decision situation should take place. The SANTA model provides a sense of purpose and direction to overcome the haphazard nature in reaching the group consensus. It also provides an equality and openness within the proposed framework.

3.2.2 Analytical Method

The Analytic Hierarchy Process or AHP developed by Thomas L. Saaty (2000) allows decision makers to model a multiple-objective decision problem in a hierarchical structure showing the relationships of the goals, objectives, and alternatives. The AHP not only supports decision makers by enabling them to create a better structure and exercise their judgments, but also allows them to incorporate both quantitative and qualitative measures in the decision process. The pairwise comparison in the AHP helps reduce the impact of cognitive limitations in human judgment. It also provides redundancy that improves the consistency in human judgment.

3.2.3 Software Application

Software that helps decision makers gather needed information to develop their strategies or tactics is required to make the SANTA model and the AHP applicable. This software should be simple to construct, adaptable to different decision situations, natural to users, and not require specialization to master the software. This is implemented by the use of the Group Decision Support System or GDSS.

3.3 CONCEPTUAL FRAMEWORK

Figure 3.2 illustrates all the steps required in the proposed framework. As goals, objectives, and alternatives of an alternative selection project are established by the decision-making group, the AHP is used for value elicitation for each member.

With these values or judgment information, each member then can gather necessary information about the problem and other members' opinions so he/she can develop his/her strategy or tactic to convince other members to agree on his preferred direction in the next stage. These strategies or tactics are exercised in the interaction stage.

In the interaction stage, values are changed or aggregated as members convince others to change their minds through their strategies or tactics. This iterative process continues until equilibrium is achieved. No one can convince any members to change their preferences. The preferred alternative is the one that is ranked first by the majority of the group. However, the system also provides the information about how likely the preferred alternative can be changed, and who are the most likely candidates to do so. This helps provide the measure of sensitivity of the selected alternative.

This system is an improvement over a common voting process in two senses. First, the system uses the benefits of communicative activities as explained in the theory of the communicative rationality by Harbermas (1987). Second, the system eliminates the haphazard nature of group discussion and resolution by providing a direction and structure of how the process should proceed.

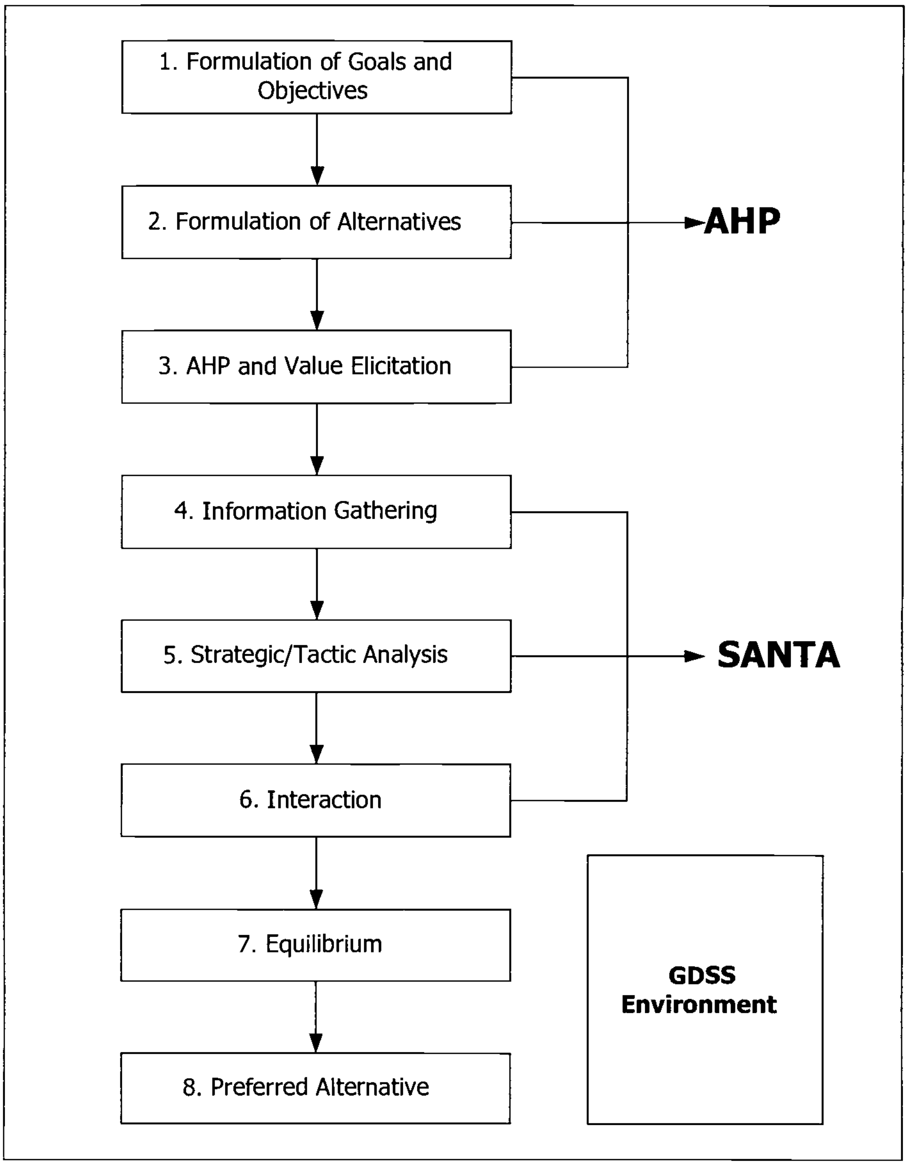

Figure 3-2 Steps in Proposed Framework

3.4 BENEFITS OF THE PROPOSED METHODOLOGY

By implementing the AHP as the proposed analytical method, humans' verbal judgments can be converted into comparable numerical values that are not obvious to the group members at the beginning. Each member could identify the directions and the magnitudes of the conflicts pair-by-pair. Most importantly, however, they can easily observe the changes of those directions and magnitudes, and their impacts on the final alternative ranking.

The side-by-side comparisons of the group members' values should also eliminate the problem in which one member tries to dominate the discussion as the group trend on that issue is very obvious to him/her. Since the methodology provides the instant value elicitation that leads to the final outcome, it should eliminate group members' attempts to hide their own agenda during the discussion while waiting for the normal voting process. The methodology bypasses the voting process by using the final ranking given by the methodology directly. The recommended alternative is the one with the highest percentage of being ranked first from all members.

The SANTA model is very useful in organizing or structuring how the group discussions and resolutions should take place. The SANTA model provides a sense of purpose and direction to resolve the group conflicts. The interaction stage provides a communicative means that is vital to the group learning and understanding about members in the group. The continuing process of information sharing and values adjustments should develop a knowledge and better-understanding working environment.

The implementation of the GDSS helps converting individual ideologies into something tangible to the group members. The graphical representation of the group conflicts conform those conflicts into something manageable by the group. By keeping all individuals judgments in a computer format, this allows the interaction process to stop and resume as the group deems convenient without having to start the discussion from the beginning again, such as those in the BOGSAT.

Finally, the proposed methodology should improve quality of the decision-making, increase the group confidence in their decisions, and create momentum toward the implementation of the recommended alternative. This will also have a positive impact on the public confidence, especially, those impacted by the project since the decision process is transparent to the public's eye.

3.5 USES OF THE PROPOSED METHODOLOGY IN A GROUP SETTING

There are two possible uses the proposed methodology in a group setting, i.e., a single conflicting-group environment, and in a mixed group environment.

3.5.1 Single Conflicting-group Environment

In this environment, only one member or more than one but all with conflicting interests are assigned to evaluate and select the group preferred alternative given criteria and AHP hierarchical structure similar to that shown in Figure 2-3. If there is only one group, the group could start by comparing those alternatives under a selected criterion first, then providing group priorities through the use of the proposed framework and the software.

Since this is a conflicting group, a single priority for each alternative is not required, i.e., there can be more than one priority based on members' judgments and their strategies and agreements. The process continues until all alternatives are evaluated, and then move on to the weighting-of-criteria stage. The final score or the global priority will include all priorities from all members, then the percentage of each alternative being ranked first is computed and displayed.

Another scenario is when conflicting groups are assigned to work under different criterion/criteria to determine the priorities of those alternatives under these criterion/criteria. The final score is an aggregate of those priorities and weights from every group. This scenario is more appropriate with a large group and not a single member would agree on a single issue. By dispersing into smaller subgroups, each subgroup only focus on a particular task or issue without impeding or interrupting the entire group decision-making process.

3.5.2 Mixed-group Environment

One of the advantages of using the AHP is its hierarchical nature. The AHP allows decision-making groups to break down problems into levels and assign different levels to different working groups as already explained in the single conflicting-group environment. This makes the AHP far better than other techniques such as Delphi as it does not have a synthetic rule to aggregate responses from different groups. The difference between the mixed-group and the first one is the way the group is assembled. In the mixed-group, not only members with conflicting viewpoints, but experts in particular professionals can also be chosen to work in part of the process.

The experts could be assigned to assess and assign priority of each alternative deemed suitable based on their expertise. For example, a group of economists could be assembled to provide an evaluation of all alternatives under the impact of economic development for those alternatives. Also, local representatives could be assigned to work on the impact of neighborhood livability. This allows experts' opinions to be taken into account without allowing those opinions to dominate the entire decision-making process. This is similar to common practice of decision making in the real world as decision makers listen to pros/cons of each alternative from experts, take those into consideration, weigh those pros/cons and critical objective/objectives before selecting the preferred course of action.

Since experts' opinions are more likely to be just differences in opinions rather than differences of interests or agenda, it could be considered an Ethics approach in Harsanyi's classification and could use those techniques that are suitable for the approach, such as Delphi, Linear Programming, and simulation, to determine proper priorities for those alternatives.

Some applications of the proposed methodology in transportation fields include alternative selection in access management, roadway improvements, traffic-calming projects, public transportation adoption, resource allocation, and so on. The main advantage of the proposed methodology for those applications is that the methodology can be implemented in both Ethics and Game Theory group setting under the Harsanyi's classification of rational behavior.

3.6 METHODOLOGY EXPANSION

Due to the recent explosion of the use and access to the Internet, many software applications have been adapted or newly developed to take advantage of this new medium. The Internet makes those applications easily accessible any time from anywhere. It also allows users from geographically dispersed areas to access the same information simultaneously. Furthermore, it allows users to communicate and/or to exchange information among those users via text or voice messages, or both.

This should provide a good avenue for the research to expand and take advantage of this new medium. The open nature of the proposed framework makes it a viable candidate for the possible expansion. The software could be developed to work on the Internet or in a network environment. The group members can access the software application from anywhere at any time. This could also be expanded to allow the public to access information, and observe how the decision progresses and is finalized.

The benefits of the expansion include the:

- Flexibility for the group to collaborate without scheduling and traveling constraints,
- Reduction in travel costs,
- An increase in productivity as the travel times are reduced, and the group schedule is more flexible,
- The selection of the communicative modes, i.e., text versus voice or both.

CHAPTER 4 SOFTWARE DESIGN

This chapter provides an overview of the client-server model for a web-based application. Two types of systems, i.e., thin-client and thick-client are explained. Finally, the application development based on the thick-client system is proposed, and the key modules required by the software are described.

4.1 CLIENT-SERVER WEB-BASED APPLICATION

The implementation of the web-based software as proposed in this research is very important in providing easy access to those involved in the decision-making process. The majorities of government agencies and the public now have access to the Internet. This allows participants in different locations to access the same content without having to travel. Each user can use his/her web browser and assigned authentication information to access his/her project either synchronously or asynchronously. Members of a project can schedule either in pairs or the whole group to discuss and exchange their strategies in order to revise other members' ratings or priorities.

According to Scott Mann (2002), a server is a network node that makes computing or data resources available. A client is a network node that utilizes server resources. Client-Server systems, upon which web-based applications can be built, require a network and at least two machines to operate: a client computer and a server computer that serves requested information to the client computer (Nguyen, 2001). With the current familiarity of users, a web browser is a default tool for the User Interface on client computers to access web-based applications.

In the client-server model, either clients or servers can handle the processing works required by those web-based applications. Since both clients and servers can handle the program execution, they are categorized by the amount of processing work handled by either clients or servers.

With thin-client system, the client PC does very little processing work only to display and submit required information. All the main processing power is done on the server side. This approach centralizes processing on the server and eliminates most client-side incompatibility concerns. A thick-client system, on the other hand, processes some portions of the applications on client machines. In this system, the browser which works as a User Interface tool not only has to format the HTML page, but it also has to execute other components such as Java Applet and ActiveX. The server machine houses the database that processes data requests from the client. The processing work is shared between client and server. Some client-side compatibility may need to be addressed in developing the thick-client system.

The web-based application developed from the proposed methodology is best suited with the thick-client system. This is shown in Figure 4.1. In this figure, the process starts with all users completing all pairwise-comparison questions among those selected criteria or those alternatives under those criteria. After everyone completes and submits to the database, they can log in and view all the answers from all participants question by question.

If all priorities of every criterion are already completed prior to the criteria-weight evaluation, the program will determine the final score of each alternative using those priorities and submitted weights from each user. Then, the program determines the ranking order of the alternative for each user and computes the percentage of alternative being ranked first. The program displays the elicited weight of each user for each criteria and the percentage in bar-graph form to those users.

Each user, then, browses through his/her own answers, and those from others so that he/she can identify differences and develop proper strategies. Each user can evaluate the impacts of weights and percentages changes by modifying his/her answers or other members. This will provide necessary information for them to develop proper strategies to achieve an individual goal of the game. It is similar to playing a chess game except more than two persons involved in the game. Each user engages in exchanging his/her own strategy in order to convince his/her opponents to modify their answers that will benefit the user. If the levels of payoff in particular questions, i.e., gaining higher percentages of their preferred alternatives, are low, they can ignore those questions and pay more attention to those with higher payoff, i.e., the ones that have impacts for the changing of individual weights and percentages.

When a user agrees to modify his/her answer, he will need to submit his/her changes to the database and the program will re-compute and re-display those new changes. The process continues until no change can be made without objection by a user. The alternative with the highest percentage of being ranked first will be the group preferred alternative. Figure 4.2 shows the prototype of the client display and layout. The next section describes all necessary modules for the program in details.

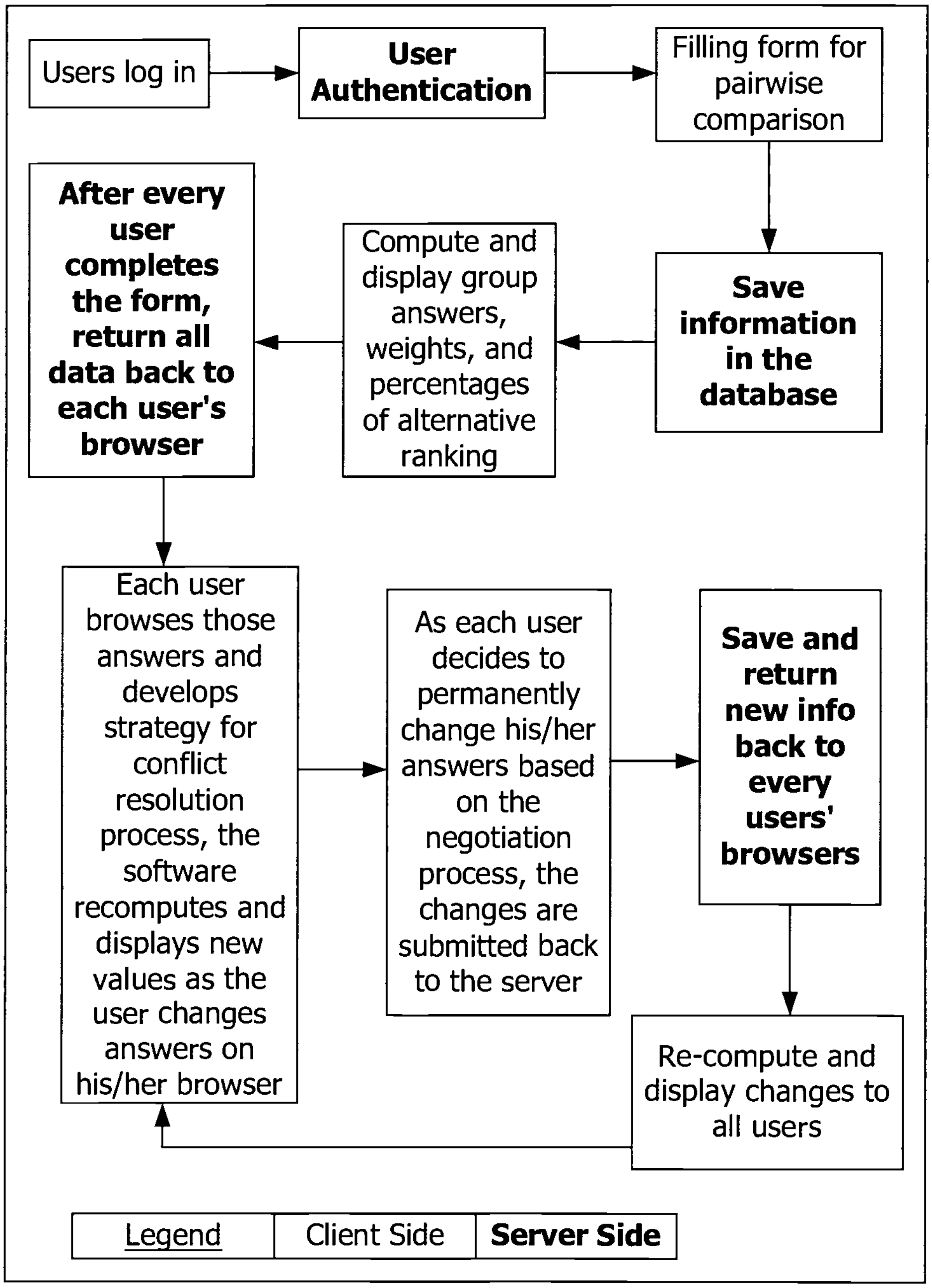

Figure 4-1 Thick-client System Design

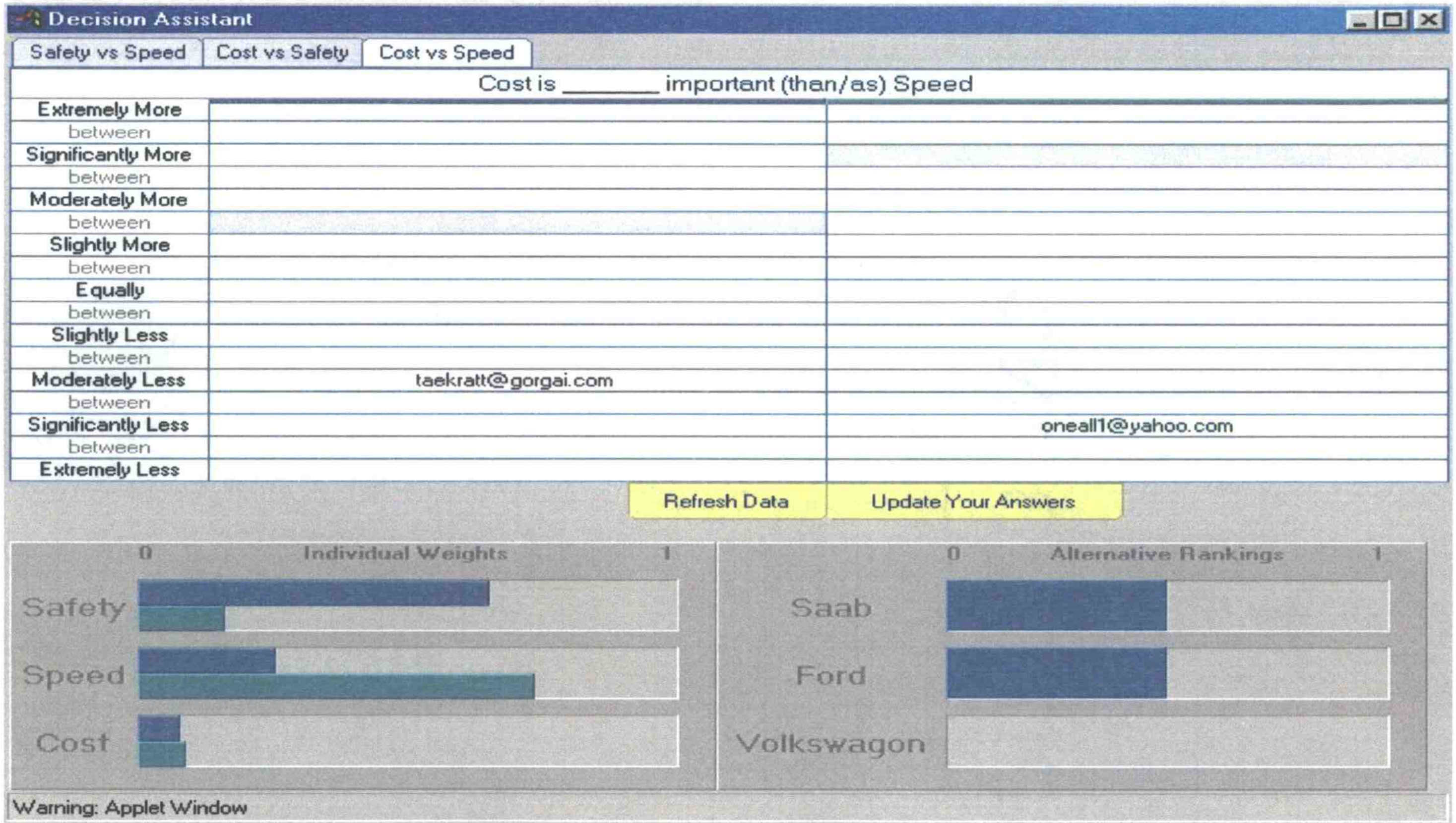

Figure 4-2 Design Prototype

4.2 KEY MODULES

4.2.1 User Authentication Module

Figure 4.3 shows an example of the login window that could be used for authentication purposes. The project administrator will set up and provide login names and passwords for all users. This module is used to identify information given by each user and to authorize the changes.

4.2.2 Client Display and Interface Module

The function of this module is to provide the results of all users' pairwise comparisons in an easy-to-compare style. It also helps users navigate through each pair and allows each user to see the possible impacts of individual weights and alternative ranking based on the changes in answers. This is useful for each user to develop his/her strategy/tactic in the conflict resolution process.

Figure 4.4 shows an example of the possible design. The users can navigate around from one pair to another by selecting the preferred tab, e.g., Cost vs. Speed. The actual answers on the server database are displayed in shaded-color cells directly aligned with the actual responses by each user. Each column represents an individual user. The user can move around from cell-to-cell and from column-to-column to see possible impacts due to the changes of other users' answers. When users decide to change their answers after the discussions with other members, they can move their answers to those new ones and click "Update Your Answers" tab.

This sends the new changes back to the server database. Only the answers of the person logging in can be changed, which is verified by the User Authentication module. Each participant, then, needs to click the "Refresh Data" tab to retrieve the new data from the server and the client browsers, then re-compute and display the new values.

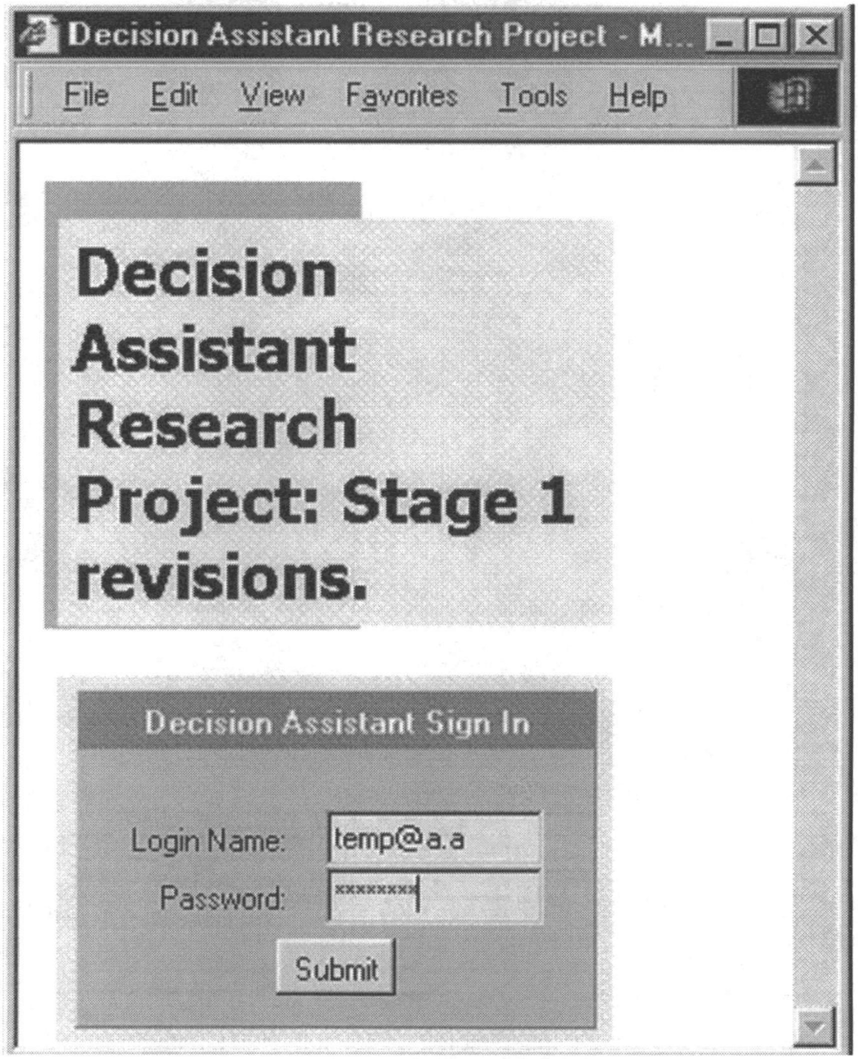

Figure 4-3 User Authentication Module

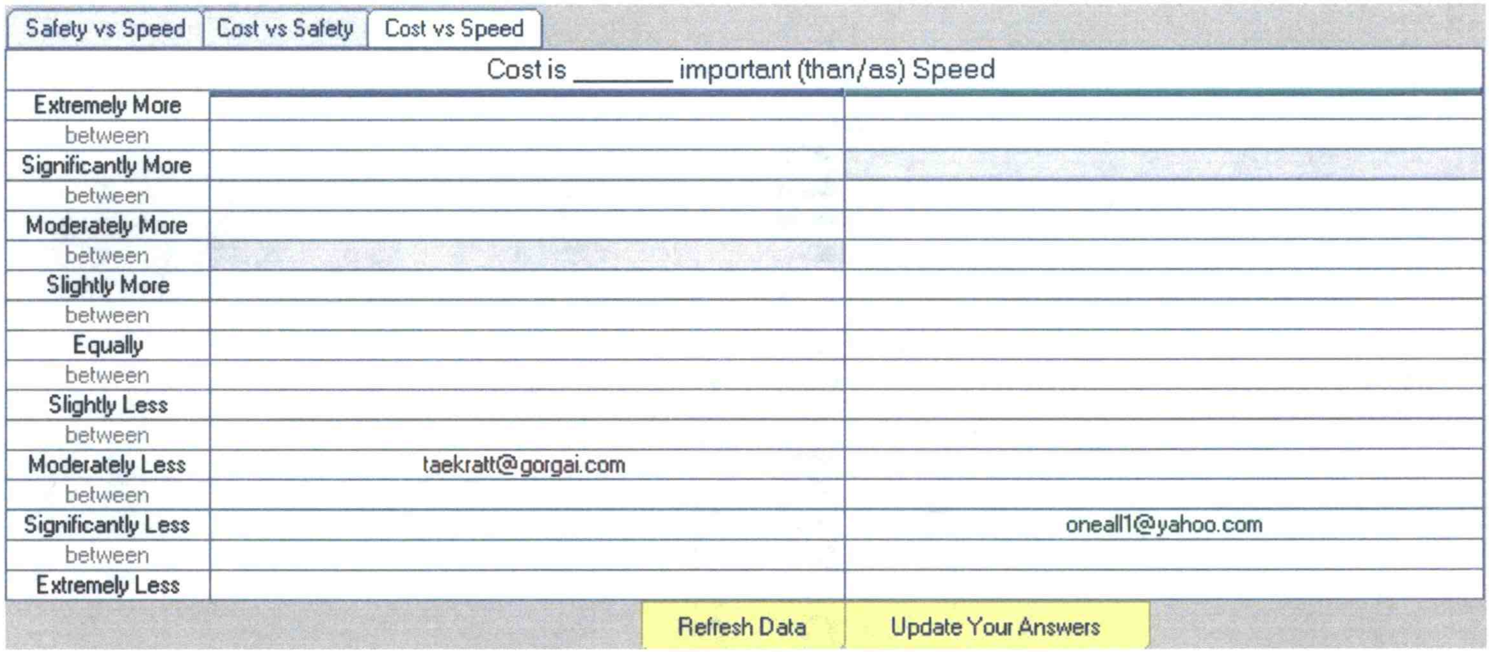

Figure 4-4 Client Display and Interface Module

4.2.3 Weights and Alternative Ranking Display Module

The function of this module is to display the individual weights ranging from 0 to 1 and the percentages of alternative ranking in a discernable and easy-to-understand fashion. Figure 4.5 shows an example of the possible design. The criteria weights are displayed in a bar graph ranging from 0 to 1 for each individual. As the answers change in the previous module, the sizes of the bar will be changed accordingly. A similar bar graph is used to display the percentages of each alternative being ranked first. Any changes in the answers that have impacts on the ranking are reflected in the changes of those bar sizes.

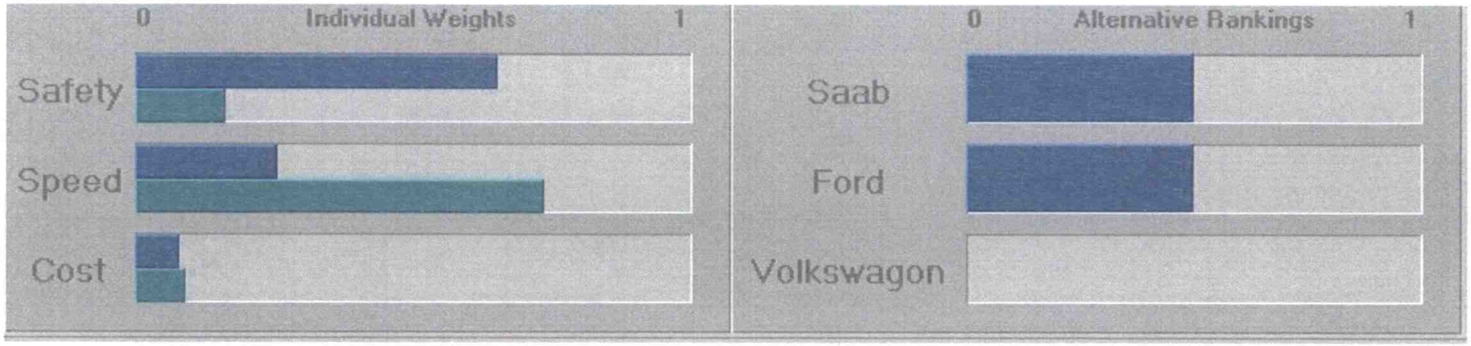

Figure 4-5 Weights and Alternative Ranking Display Module

4.3 SOFTWARE BENEFITS AND COMPARISONS

4.3.1 How Software Benefits Group Decision

Figure 4-4 shows the client Display and Interface as proposed in the prototype. The verbal expressions are used instead of the numerical values to avoid the confusion of scale conversion. The users are told to evaluate each pair of criteria without their knowledge about the conversion table. Therefore, it would be more consistent to have them use the same verbal scale.

The side-by-side comparison of each criteria pair should provide the magnitudes and directions of the differences among group members as well as help establish the base for comparison. Each user uses his/her own personal scale for evaluation. One described as "Strongly" could mean "Moderately" by others. However, if five members describe the same level as "Moderately" and only one chooses "Strongly", then either that member disagrees with the others or he/she uses a different personal scale for comparison. The software allows each user to adjust his/her personal scale so it is comparable to others. As found by Huizingh and Vrolijk's study (1997), there is overwhelming evidence that people have very different numerical interpretations of the same verbal expressions. This allows the adjustment to be made without using a personal conversion table for each user as suggested by Huizingh and Vrolijk.

Also, the side-by-side comparison could help identify users who may intend to inflate his/her values or weights by providing unusually high or low scores. For example, by choosing "Extremely More Important" on every pair comparing Cost with the other criteria, where the Geometric Mean is used to determine the group average, the mean value will be shifted toward Cost without other members noticing why. With the side-by-side display, this tactic could be exposed easily, and that member will be forced to re-evaluate those values.

Figure 4-5 shows the weights as provided by each user for each criterion, and the percentage of each alternative being ranked first. As the answers are modified, the weights are changed. However, the ranking may not change, as those alternatives may be insensitive to particular weights or within particular ranges. This should help reduce the number of unnecessary arguments or conflicts among group members since it would be futile to argue on those issues. The users can choose to discuss only those that will have impacts on the change in ranking.

The interaction stage continues from one pair to another until no answer can be modified without forcing any user to do so, or it is at equilibrium. The final recommended alternative could be viewed as the most sensitive solution of being accepted or rejected by the group. The ranking can only be changed by forcing a member or members to change their answers unwillingly. This should be a better measurement of sensitivity than the traditional sensitivity analysis.

In the traditional sensitivity analysis, the group member must agree on a single weight for each criterion either by using the statistical analysis, such as the Geometric Mean, or through forceful discussions. Then, each weight is gradually increased or decreased until the ranking of the alternatives is changed. The wider the range of those weights, the less sensitive it is for the recommended alternative, and vice versa.

This method of analysis has two drawbacks. First, it is very difficult to identify a single value that all members could agree on, especially when each may have different viewpoints about this issue. The alternative is to use the Geometric Mean that could lead to the value inflation tactic as previously described. The analysis itself also discards all the valuable information about the group members. The analysis only identifies the values that cause the ranking to change. However, it does not provide the information on how likely these values could occur within the group, and under what condition, i.e., willingly or unwillingly.

In this software, the sensitivity analysis is conducted during the interaction stage. The pairwise comparisons that have no impact to the ranking are ignored, and only those with impacts are discussed. The process continues until it reaches equilibrium. This means that those answers, as well as weights, are likely to occur in this group, and they can only be changed by forcing users to change their answers.

By keeping all individuals' judgment in a computer format, this allows the interaction process to stop and resume as the group deems convenient without having to start the discussion from the beginning again. Also, it allows the group to conduct their discussions either synchronously or asynchronously.

As a conclusion, the software offers a new group decision support system with the following benefits:

- It uses verbal expressions rather than numerical values,
- It provides a rough correction for difference in personal scale conversion,
- It eliminates the possible bias or value inflation as introduced by any group member,
- It proposes a new and more accurate way of measuring the sensitivity of the recommended alternative,
- It allows discussions to stop and resume at any convenient time,
- It works with both synchronous and asynchronous meetings.

4.3.2 How Software Compared to the Ideal DSS

Table 4.1, shows the comparison between the GDSS developed in this research and the ideal DSS as proposed by Ullman (1995). The details for each one are discussed in the following section.

4.3.2.1 Support Inconsistent Decision-making Information

Ullman (2001) identifies three possible causes of information inconsistency, i.e., viewpoint inconsistency, data variation or inconsistency, and abstraction inconsistency. The developed software and the proposed methodology not only satisfy, but encourage all three of them. The software allows each user to express his/her opinion freely through the pairwise comparison and verbal expressions. All of the differences in members' interpretation or evaluations are not discarded or averaged, but incorporated directly into the alternative ranking. Both quantitative and qualitative measures are handled by the AHP.

4.3.2.2 Support Incomplete Decision-making Information

As suggested in Section 2.2.4.2, the criteria and alternatives considered in the alternative selection process in transportation planning are screened and refined into a set of manageable numbers through several long and arduous stages prior to the actual selection stage. Therefore, it is considered complete and does not require handling incomplete information.

4.3.2.3 Support Uncertain Decision-making Information

The AHP is designed to handle uncertainties and other influencing factors by incorporating them into the hierarchical structure of the problem.

Table 4-1 Software Comparisons to Ideal DSS

Ideal Decision Support System	Software
Support inconsistent decision-making information	Satisfy all three causes of inconsistency
Support incomplete decision-making information	Not Required
Support uncertain decision-making information	Handle through the AHP
Support evolving decision-making information	Progress through communication and mutual understanding
Support the building of a shared vision	Encourage sharing of information, knowledge, and ideas
Calculate alternative ranking, rating, and risk	Allow individual value elicitation, individual alternative ranking, and group recommended outcome
What to do next, or Sensitivity Analysis	Provide a new and better measurement of sensitivity
Require low cognitive load	Reduce through pairwise comparison, separation of criteria and alternatives
Support a rational strategy	Support through the use of the SANTA model
Leave a traceable logic trail	Create a log file to keep track of all changes
Support a distributed team	Take advantage of the Internet

4.3.2.4 Support Evolving Decision-making Information

The key contribution of the SANTA model in the proposed methodology is the interaction stage. The most important activity in the interaction stage is communication. Based on the concept of communicative rationality proposed by Habermas (1987), communication helps develop mutual understanding within a group by serving to transmit and renew cultural as well as personal knowledge and characteristics.

The software encourages the exchange of ideas and knowledge in order to resolve differences. The users may change their answers willingly through mutual exchange of knowledge and viewpoints, and valid arguments.

4.3.2.5 Support the Building of a Shared Vision

The software provides a fair and open framework for developing group consensus. The methodology encourages the sharing of information, knowledge, and ideas that could help develop group trust, increase confidence, and create momentum toward the implementation of the group recommended alternative.

4.3.2.6 Calculate Alternative Ranking, Rating, and Risk

The software allows users to rate each criterion or alternative against each other, and compute individual weight and alternative ranking. The recommended alternative is the alternative with the highest percentage of being ranked first.

4.3.2.7 What to do next

The interaction stage provides a true measure of the sensitivity of the final recommended alternative. The final outcome is viewed as the most sensitive solution of being accepted or rejected by the group.

4.3.2.8 Require Low Cognitive Load

The pairwise comparisons and the hierarchical structure of criteria and alternatives help reduce cognitive load.

4.3.2.9 Support a Rational Strategy

The SANTA model allows each user to develop and apply his/her strategy in pursuit of his/her own interest as described in the class of Game Theory in the rational behavior of Harsanyi (1977).

4.3.2.10 Leave a Traceable Logic Trail

A log file can be created to keep track of all the changes by the users during the interaction stage.

4.3.2.11 Support a Distributed Team

The software is designed to work in a network environment, especially the Internet. It also provides instructions on how to keep the software and the data secure under the use of the Internet.

4.4 SOFTWARE SECURITY ON THE INTERNET

The common use of software applications on the Internet is through the World Wide Web. It is important that the software application as proposed in this research should have web security in mind. In a simple term, the Internet or the Web connection consists of three parts, i.e., web browser on user side, web server, and the connection between the two. A user connects to a remote server and requests a document, data, or applications. The requested server sends back that information which is displayed on the user's web browser on his/her own machine. To guarantee safe and secured connections, web security concerns about three parts, i.e., client-side security, server-side security, and Document or Information Confidentiality (Stein, 1998).

4.4.1 Client-side Security

There are concerns about the security of users' computers connecting to either the Internet or the server. Some security risks include computer viruses, malicious software, such as a worm or the Trojan horse, and stolen information about users or their computers. To prevent these security risks, organizations should prevent employees from browsing through high-risk websites, downloading or installing unauthorized software, and educate them on how to prevent their personal information such as passwords from being exposed on the Web.

4.4.2 Server-side Security

Security of the web or database servers that are used to keep important information about the projects is also of concern. Some risks on the server-side include break-ins by hackers, denial-of-service attacks (which prevent users' computer from connecting to the servers), and computer viruses and malicious software. To minimize these risks, some technological solutions including a firewall or server authentication could be implemented to prevent outside break-ins. Also, security updates of both software and operating system should be done as frequently as possible and high-risk vulnerabilities should be fixed promptly.

4.4.3 Document or Information Confidentiality

This is to ensure the privacy and the integrity of those documents or information being transmitted through the Web. Some of the risks include eavesdropping (an unauthorized person or persons can gain access to the information being transmitted), content hijacking or content tampering, and fraudulent identity (when someone pretends to be the authorized person). The preventive strategies include encrypted information while transmitting, using virtual private network, content validation, and user authentication.

Another possible security risk is programming errors. This is created by inexperienced or unintentional overlook by programmers. Also, some programming languages may contain security holes that could be exploited by experienced hackers. It is important that the software should be tested thoroughly and frequently. Any software or program bugs should be fixed immediately.

CHAPTER 5 PILOT STUDY

This chapter outlines the common difficulties faced by researchers in evaluating new methodologies in group decisions and group decision support systems. To satisfy the research study that requires an evaluation and validation process, a small group pilot study was conducted. The criteria for evaluation, the case study and the experimental setup are explained in Section 5.2 and 5.3, respectively. Finally, the pilot study findings and the conclusion from the pilot study are discussed at the end of the chapter.

5.1 DIFFICULTIES IN EVALUATING THE NEW METHODOLOGY

There are several difficulties in conducting a research study to evaluate a new methodology for group decision and the group decision support systems, such as the one proposed in this research. Those difficulties include:

- The methodology is developed from the integration of several unrelated components as described in Chapter 3. Each component is designed to solve a particular shortcoming, but not all of them at the same time. This makes it difficult to identify the component or components that do not work as intended,
- There is very limited information about other comparable methodologies prior to the development since the methodology itself is new,

- The new methodology is designed to improve the qualities of the process, i.e., objectivity, group confidence in the outcome, and equality in a group working environment rather than the final product itself, i.e., the selected alternative. Therefore, there is no previously-known optimal solution or product to be gauged against,
- The lack of commitment from participants in the case study using actual projects because they are more interested in finding the solutions under tight schedules rather than conducting research
- It takes a long time to complete a thorough evaluation in a complex decision situation, such as selection of alternatives in a transportation project
- Some traditional evaluation criteria, such as cost-benefit analysis, do not apply to the methodology, such as the one proposed here in this research. Evaluation criteria need to consider broader issues that truly reflect the actual use of this new methodology, such as the quality of the group decision making itself, particularly, the satisfaction with the methodology and the increase in collaboration.

5.2 CRITERIA FOR EVALUATION

Rubin (Swap and Associates, 1984) proposed six quality indicators for group decision-making: efficiency, careful development and analysis of alternatives, fairness, group satisfaction, teamwork effectiveness, and growth over time. These indicators are developed from a group process point of view, and cannot be measured and compared directly. To apply in this research, they need to be translated into something measurable, such as in a form of a questionnaire.

Figure 5.1 shows the questionnaire that is used to evaluate the proposed methodology. In terms of Careful Development and Analysis of Alternative, this is already part of the AHP design as described in Chapter 2.

Efficiency of the methodology can be viewed as the ease of use of the software developed in this research based on the proposed methodology. This is measured in Question 3 of the questionnaire. Fairness or Equality is measured in the first question. Group Satisfaction in this research can be measured in terms of the usefulness of the methodology as expressed in Question 2. Teamwork Effectiveness is described as the ability of the team members to work in a collaborative fashion as shown in Question 5. Growth over Time is a product of information sharing and learning process. As the learning process continues, each member will have a better understanding of other members' points of view, which is measured in Question 4.

Questionnaire

Involvement means that your input in the direction of the decision making process as a team member was equally considered with other members and there was no forms of inequality in the decision making process. Which one of the following best represents your involvement in the decision making process

a) I was unable to get any involvement as a team member
b) I was able to get a little involvement as a team member
c) I was able to get a moderate involvement as a team member
d) I was able to get a large involvement as a team member
e) I was able to get a nearly unlimited involvement as a team member

Rate the usefulness of the methodology

a) The GDSS was completely useless
b) The GDSS was somewhat useless
c) The GDSS was neither useful nor useless
d) The GDSS was somewhat useful
e) The GDSS was completely useful

Rate the difficulty or ease of using the software during the problem-solving activity

a) The GDSS was extremely difficult to use
b) The GDSS was difficult to use
c) The GDSS was neither difficult nor easy to use
d) The GDSS was easy to use
e) The GDSS was extremely easy to use

Which one of the following best describes your opinion toward other members' points of view

a) I did not learn anything about other members' points of view
b) I had less overall understanding of other members' points of view
c) My opinion about other members' points of view did not change
d) I had better overall understanding of other members' points of views
e) I had a full knowledge about other members' points of view

Which one of the following best describes your observation about the ability of the team members to work in a collaborative fashion

a) I observed an extreme lack of teamwork
b) I observed a moderate lack of teamwork
c) I am neutral about the level of teamwork
d) I observed a moderate cooperation of teamwork
e) I observed fully-cooperative teamwork

Figure 5-1 Questionnaire

5.3 CASE STUDY

Based on the Dennis el al (1990) experiment, the effective size of a group for making decisions in a non-GDSS-supported environment is about five to six people and a GDSS-supported environment is more effective as the number of group members increases. In order to verify the benefits of the proposed methodology over a non-GDSS-supported environment, i.e., BOGSAT model, a six-member group is proposed. Six students from different disciplines (two with backgrounds in transportation planning) were paid to participate in the study. The reason for selecting participants from different disciplines is in hope that this would generate the conflicts of opinions. The case study was modified from the actual transportation project called the Aurora Corridor Project, City of Shoreline, Washington. Appendix B provides the brief summary of the actual project and experiment.

The participants assumed the roles of the Citizen Advisory Task Force. The task was to identify the group preferred alternative from three possible choices using the software developed in this research. The three alternatives were compared against six criteria, i.e., Economic Development, Capital Cost, Air Quality and Energy Implications, Neighborhood Spillover Traffic, Transit Operation Improvement, and Traffic Safety Improvement. Figure 5.2 shows the hierarchical structure of the criteria/alternatives comparison as explained in the AHP.

Due to the time and budget constraints, the alternative values for each criteria are pre-determined using the recommendations suggested by the actual project participants. The research participants are only required to elicit weight priorities of all criteria, and then proceed with the conflict resolution phase. The objective of each participant in the resolution phase is to identify the differences and their impacts on the final ranking of each paired comparison, and then apply his/her strategic/tactic or negotiation skill to convince other participants to change their values. Not all pairs need to be changed, as they may not have any impact on the change in the alternative ranking. This phase ends when the meta-equilibrium underlining the SANTA model is reached, i.e., no participant can gain by moving as long as other participants do not. The group recommended alternative is the one with the highest percentages of being ranked first.

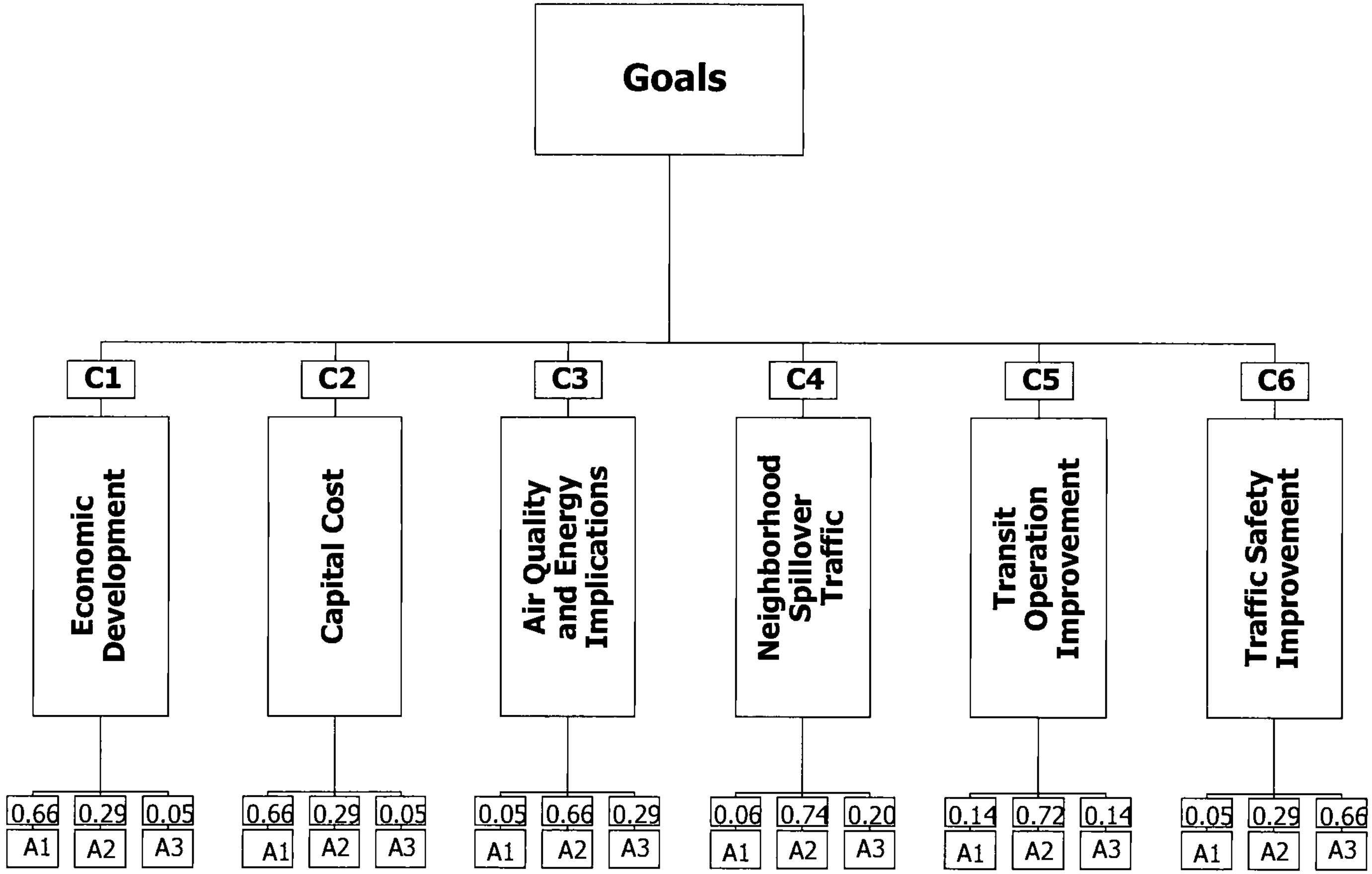

Figure 5-2 Hierarchical Structure of Criteria and Alternatives

5.4 RESEARCH EXPERIMENT AND FINDINGS

5.4.1 Experiment Setting

Due to the high values given to Alternative 2 in the alternative priorities' assignments, the final ranking is dominated by Alternative 2 with no impact from the changes in weights from participants. This is understandable since Alternative 2 is the preferred alternative in the actual project, and the priorities were derived directly from the actual project.

To study the use of the software and methodology, the alternative priorities have been reassigned randomly while controlling the sum of each alternative to be the same. This ensures that the changes in the ranking are the direct product of the changes in participants' assigned weights.

The experiment began with each member completing the pairwise comparison of the six criteria. Each participant needed to answer fifteen questions. After all participants completed the questions, the software displayed the answers of all participants including the weights and the ranking percentages of all three alternatives. Each member, then, developed his/her strategy/tactic and applied to the conflict resolution process. The participants discussed among themselves to determine the suitable verbal expression for each criteria pair. The participants continued to the next pair when either a single verbal expression was reached or no more changes could be made via the negotiation. When modifications were needed, the participant submitted his/her changes back to the database and the software recalculated and displayed the new results on each participant's browser. The process continued until no more changes could be made.

In addition, the group was assigned to work in two different modes in the conflict resolution phase. The first mode was to pair up the participants for discussions, and then switch their partners until every participant met all other participants. Later, the problem was reset and the alternative priorities were modified. Then, the group worked simultaneously to resolve conflicts pair-by-pair.

5.4.2 Experimental Results

5.4.2.1 Questionnaire Responses

Table 5.1 summarizes the results of the participants' responses to the questionnaire. The follow-up oral interview after the study also expressed several interesting findings observed by the participants.

5.4.2.2 Positive Comments

- The software eliminates the emotional influence during the discussions and focuses on the group task which is to identify the group preferred alternative,

Table 5-1 Questionnaire' s Responses

Question 1	Four members believed that they were able to get a moderate involvement as a team member while two believed that they were able to get a large involvement.
Question 2	The majorities believed that the methodology was somewhat useful and only one thought it was completely useful.
Question 3	The group unanimously believed that the software was easy to use.
Question 4	Four members believed that they had better overall understanding of other members' points of view, while two believed that they had a full knowledge about other members' points of view
Question 5	One member was neutral about the level of team work, four observed a moderate cooperation, and one thought that he/she observed fully-cooperative team work

- The software allows the community to get more involved because it is designed to work on the Internet. Even though the public may not be the actual decision makers, they can contact those decision makers to tell them whose positions they support. The decision process is transparent to the public,
- The methodology helps convert human's thinking into something visualizable,
- The methodology eliminates members' attempts to hide their agenda or motivations until the final decision. The final decision is made as an aggregated result from explicit information sharing and conflict resolution process,
- The decision is no longer decided based on the monetary benefit and cost alone,
- The methodology allows other members to see what other members think, and what would be the best way to approach those members,
- The methodology allows the group to stop or resume the process at any convenient time,
- Members do not have to discuss or agree on every issue to reach the final decision. Members can select the issues and persons with whom they want to discuss the issues.

5.4.2.3 Other Comments

- One of the research participants who has an experience working with people with disabilities suggested that the software may not be able to accommodate these groups,
- Some people may not familiar with computers and the Internet,
- The text and bar sizes in the software were too small and clustered,
- The methodology may not be practical for a large decision-making group, such as a fifty-people group.

Finally, the advantage of the alternate pair discussion over the simultaneous group discussion is inconclusive. One participant suggested that the alternate pair created an environment in which compromises seems easier to obtain. This is due to a more cordial and personal interactions. Another participant thought on the contrary. This participant thought that the second one was better since all participants could see the group trend, and those who did not follow the trend seem to be willing to compromise. However, all subjects agree that the first one is more flexible in terms of scheduling since only two people need to be available at the same time.

5.5 PILOT STUDY CONCLUSIONS

There are several difficulties in evaluating a new methodology, such as the one proposed in this research. The most appropriate way to evaluate this methodology would be to assess the improvements of the decision process itself, rather than the output of the process that is the recommended alternative. For group decision-making process, six quality indicators can be used to measure or assess the improvements. The six indicators as explained by Rubin (Swap and Associates, 1984) include efficiency, careful development and analysis of alternatives, fairness, group satisfaction, teamwork effectiveness, and growth over time.

From the pilot study, the participants identify several benefits of the new methodology as well as some useful suggestions or concerns.

CHAPTER 6 DISCUSSIONS OF PILOT STUDY AND RESULTS

Due to research constraints in which the study would be better suited for a large-scaled and fully-funded research project, the pilot study is very limited in terms of extending its scope of inference as to draw any valid conclusions. Any conclusions drawn from the six-person non-randomized group with very limited time of participation could only reflect on what those participants perceived about the study, but may not be viewed the same by others.

6.1 LIMITATIONS OF PILOT STUDY AND SOFTWARE

6.1.1 Pilot Study and Results

Several limitations of the pilot study and its results include:

1.) There was only one experimental unit,

2.) The group was volunteered rather than being randomized,

3.) There was only one case study which may not represent real-world problems and complexities,

4.) To compensate for the time limits, many values were pre-defined by the evaluator which may simplify the experiment, 5.) The experiment made an assumption that students from different disciplines should have different backgrounds and interests to simulate the conflicts generated in real-world situations,

6.) Subjects were not familiar with the location of the case study and had no attachment, interests, or knowledge about the case study,

7.) The methodology is developed from three unrelated components in which each component was designed to solve a particular shortcoming, not all of them at the same time, so it is difficult to identify the component or components that do not work as intended,

8.) The methodology has no comparable analytical techniques or exact solutions to validate the outcome,

9.) Even though subjects were paid as an incentive to participate in the experiment, there was no way of measuring their levels of commitment.

6.1.2 Software Testing

In common software testing, there are two processes, i.e., verification and validation (Sommerville, 1996). Verification is intended to show that a program meets specification. Validation is intended to show that the program does what users require. The purpose of software testing is to establish the presence of defects in a program and to ensure the program is usable in practice. In this research, the verification was done by testing the AHP algorithm against manually computed outputs. Also, the software was tested on the Internet to see if it would display the correct results. However, the web security has not been tested as it was not the main interest of the research.

The subjects showed no difficulty in using the software. They thought the software was easy to use. However, this may not be a true representation of normal users in the real world since the subjects were students who were more likely to be familiar with computers, a web browser, and spreadsheet software. The software developed for this research is intended to be used by various groups of users who may or may not be familiar with particular aspects of the software, such as how to access them from the Internet or how to use web browser. Also, it could be used by people with disabilities.

The number of criteria, alternatives, and users should have an impact on how the software should display the results as well. It was found during the pilot study that the text and bar sizes cold have an impact on the usability of the software. The testing can be improved by testing a wide range of the number of criteria, alternatives, and users as well as different designs of graphical displays to determine the most suitable interface.

6.2 IMPLICATIONS FOR METHODOLOGY IMPLEMENTATION AND FUTURE RESEARCH

Even though the pilot study was limited, restricting statistical validation of the final conclusions, however, the findings do provide an encouraging result. Many benefits as designed into the methodology are discovered by the participants' observations without their prior knowledge about the methodology and the software. Those benefits include Flexibility, Accessibility, Transparency, and Efficiency, or FATE. The new methodology provides the flexibility, as decision makers can stop and resume discussions as their convenient times. The use of the Internet improves the levels of participation, as the decision-making process is more accessible by more parties, and also reduces the costs of travel to required meetings. Transparency was discovered by the participants as no agenda could be hidden from group discussions, since the methodology provided the instant value elicitation that led to the final outcome. In terms of efficiency, the SANTA model provides a sense of purpose and direction to resolve the group conflicts. It eliminates the haphazard nature in group conflict resolution process as discovered in the BOGSAT model.

This implies that the concept, the design, and the benefits of the methodology could be identified just by the actual use of the methodology and software. The next step in future research would be to test the methodology on an actual project, and to observe if the same benefits or responses could be identified.

Furthermore, future research based on the results of this dissertation would lead in a number of interesting directions. First, It suggests of a study of the effectiveness and benefits of the alternate pair discussion over the simultaneous group discussion. From the pilot study, the result is still inconclusive. One factor that might dictate the selection of each mode is a time-constraint to complete the decision. It also suggests the possible influence between synchronous and asynchronous meeting to exchange strategies among group members. It is interesting to know whether or not the two modes will have an impact on strategies development and executions. Prolonged games may make it difficult to convince others to change answers as they have longer time to think everything through and develop better arguments. On the other hand, the synchronous mode reduces the potential of prolonged or endless discussions, as some members may not want their non-preferred alternatives to be selected.

Second, even though the AHP can be applied to most alternative-selection problems, it may not be the most effective method when the SANTA model is added. The SANTA model is intended to facilitate the conflict resolution part of the problem under group setting with Game Theory. However, the use of the SANTA model in a non-Game Theory, such as the Ethics case, may complicate the process and take longer time to complete. This may make the use of the AHP alone or other analytical techniques become more attractive. Further investigation may be useful in developing a guideline to identify when the proposed methodology becomes most effective. In addition, it may be necessary to provide instructions on how to identify Game Theory problems from non-Game Theory as some people may not accept the remarks that they exercise their judgments based on their interests rather than valid arguments.

Third, the methodology also suggests two environments for implementation of the methodology, i.e., in a single conflicting group and in a mixed group. The second one may introduce some complexities. For example, some members may not feel comfortable or confident about their selection as the problem is broken down into different parts and worked on by different groups. Future research may be useful to see if there is a difference in perception between a single group and a mixed group environment.

Fourth, Saaty suggested that there are two types of measurement in the AHP, i.e., absolute and relative. An absolute measurement has a potential to help reduce alternative pairwise comparisons to a more manageable set by establishing sets of priorities for commonly used criteria in transportation planning and decision making. For example, Level of Service is commonly used to evaluate roadway performance. A group of traffic experts could be appointed to establish appropriate priorities for different Levels of Service to be used in those projects that consider Level of Service as part of their evaluation criteria. Other potential commonly used criteria include Safety Index, Level of Carbon Monoxide, Level of Noise, and so on.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

A recent shift from traditional planning methodology in which only quantifiable measures are taken into consideration by a group of transportation and related professionals has been made to be more inclusive, but complex, decision-making system situations. New challenges created include:

- The groups of impacted stakeholders are involved in the decision-making process
- More issues and often conflicts are taken into consideration, and some of them are not quantifiable

A new methodology is required not only to take qualitative performances into consideration, but also to accommodate the diversities created by those in the decision-making process. This research focuses on the alternative evaluation stage as it often demonstrates the above challenges.

The new methodology that combines the advantages of three unrelated components is proposed to reduce the complexities in complex decision situations. The three components include the conflict resolution model (SANTA), the analytical method (AHP), and the group decision support system (GDSS). The proposed methodology also explores a new way to take advantages of the Internet which allows decision makers to make their decisions from anywhere at any time.

The objective of the proposed methodology is to develop "a continuous process of learning and understanding through communicative means by virtue of a fair and open framework in developing the group consensus rather than relying solely on the STATUS QUO."

A small-scaled pilot study was set up to test the methodology and the software application developed according to the framework outlined by the proposed methodology. From the pilot study, the participants identified several benefits, as well as some useful suggestions and concerns.

Even though, the pilot study was small, generated findings and conclusions do provide encouraging results. Many benefits are discovered by the participants' observations without their prior knowledge about the methodology and the software. Those benefits include Flexibility, Accessibility, Transparency, and Efficiency, or FATE. The new methodology provides the flexibility, as decision makers can stop and resume discussions at any convenient time. The use of the Internet improves the level of participation, as the decision-making process is more accessible by more parties, and also reduces the costs of travel to required meetings. Transparency was discovered by the participants as no agenda could be hidden from group discussions, since the methodology provided the instant value elicitation that led to the final outcome. In terms of efficiency, the SANTA model provides a sense of purpose and direction to resolve the group conflicts. It eliminates the haphazard nature in group conflict resolution process as discovered in the BOGSAT model. This implies that the concept, the design, and the benefits could be identified just by the actual use of the methodology and the software. This suggests that the next step in future research would be to test the methodology in actual projects with actual decision makers to observe if the same benefits or responses could be repeated and identified.

7.2 RECOMMENDATIONS

7.2.1 Actual Applications

There are two possible applications of this new methodology, i.e., in real-world problem-solving situations and as a learning tool. The methodology can be implemented in actual alternative evaluation problems. The hierarchical structure in the AHP allows those problems to be separated and assigned to those who have full knowledge in those particular areas. For example, the evaluation of proper values of different alternatives under the Local Economic Impact criteria can be assigned to a group formed by local business owners and transportation economists. Similarly, the evaluation of proper values under the Regional Traffic Impact can be evaluated by a group of State transportation agencies.

The decision-making groups then only need to evaluate the weights given to each criterion as demonstrated in the pilot study. This not only simplifies the decision process, but also eliminates the limitations of bounded rationality as described by Herbert Simon (1960). A quality decision is made with the full knowledge about the problem through the aggregation of experts' knowledge in those issues related to the decision.

The new methodology could also be used to facilitate the learning and understanding about the complexities involved in complex decision situations. As described above, the shift to more inclusive but complex decision situations only occurred recently. Many involved in the process are still unaware of how the complexities should be handled while focusing on completing their tasks. The proposed methodology can be used to inform those groups on how other members comprehend the problems, and understand how different positions can be dealt with to reach quality decisions. The methodology allows decision makers to see that not all conflicts have impacts on the final outcomes.

7.2.2 Software Improvement

One of the concerns from the pilot study is that the use of the software may exclude the people with disabilities from the decision-making process. This may be due mainly to the limitations of computers and the Internet themselves rather than the software. However, this needs to be addressed if the actual implementation is to succeed.

Another concern is the graphical layout of the prototype seems to be too clustered and difficult to read. A new user interface study may require improved software.

Another possible future expansion is to integrate existing Internet communicative means such as email, instant messenger, chat, web board, or voice communication into the program. This should enhance the communicative capabilities and information sharing among remote users.

7.2.3 Future Research Study

The next step in future research is to test the methodology in actual projects with actual stakeholders impacted by those proposed projects. The goal of the research would be to observe if the same benefits or responses found by the participants in the pilot study could be repeated and identified.

Another question of interest is to study the advantages between the two different setups of the discussion, i.e., the alternate pair and the simultaneous group discussion.

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APPENDICES

Appendix A Brief Overview of Analytic Hierarchy Process

Calculation of Maximum Eigen Value and Eigenvector

Part of this Appendix is modified from an example in the book "Decision Aids for Selection Problems" by David L. Olsen (1996).

For the matrix

$$\begin{bmatrix} 1 & 5 & 9 \\ .2 & 1 & 3 \\ .111 & .333 & 1 \end{bmatrix}$$

The eigenvector technique would require solution of:

$$\begin{bmatrix} 1 & 5 & 9 \\ .2 & 1 & 3 \\ .111 & .333 & 1 \end{bmatrix} - \lambda \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Yielding

$$\begin{bmatrix} 1-\lambda & 5 & 9 \\ .2 & 1-\lambda & 3 \\ .111 & .333 & 1-\lambda \end{bmatrix}$$

This can be solved by determinants, yielding the formulation:

$(1-\lambda)^3 + 5/3 + .6 - 3(1-\lambda) = 0$

which simplifies to $\lambda^2(3-\lambda) = -.266667$

This is in a cubic form, meaning that there are three solutions for λ. Not all of these solutions have to be real numbers, but Saaty established that the **maximum** value for λ ,or λ_{max}, will be a real number, and will also be $\geq$ n, which is the number of elements. For perfectly, consistent matrices, $\lambda_{max} = n$. For this problem, a search will yield $\lambda_{max} = 3.02906$. The consistency index is (λ_{max} - n)/(n-1). For this matrix, that would yield .015, a very consistent matrix as suggested by Saaty with 0.1 cutoff point. The other two solutions for λ are complex numbers.

Once λ_{max} is determined, the eigenvector of weights can be obtained by solution of set of n simultaneous equations. For each row of the pairwise comparison matrix A, $Aw = \lambda_{max} w$.

$$1w_1 + 5w_2 + 9w_3 = 3.02906\, w_1$$

$$.2w_1 + 1w_2 + 3w_3 = 3.02906\, w_2$$

$$1/9w_1 + 1/3w_2 + 1w_3 = 3.02906\, w_3$$

An additional requirement is that $w_1 + w_2 + w_3 = 1$. Because any two of the first three equations (in general, n equations) contain all the necessary information, one of them can be deleted, and replaced with the additional requirements, thus yielding a system of n equations in n unknowns, which can be solved many ways, including linear programming. In this case, the eigenvector of the weights is: $w_1 = .751$, $w_2 = .178$ and $w_3 = .070$.

Using the row geometric mean

$$\text{Row nth} = \sqrt[n]{s_1 * s_2 * s_3}$$

$$\text{First row} = \sqrt[3]{1 * 5 * 9} = 3.557$$

$$\text{Second row} = \sqrt[3]{.2 * 1 * 3} = 0.843$$

$$\text{Third row} = \sqrt[3]{.111 * .333 * 1} = 0.333$$

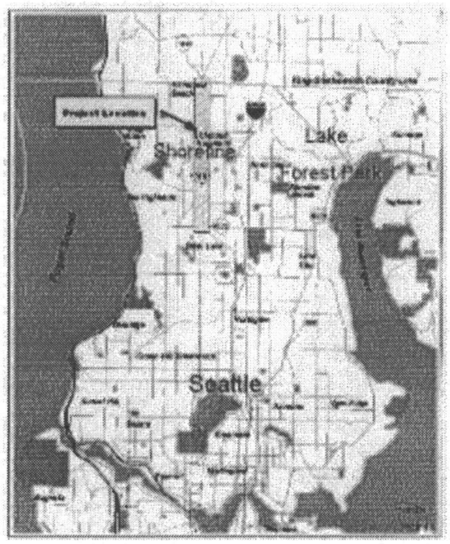
$$\text{Sum} = 4.733$$

And the normalization yields: $w_1 = 3.557/4.733 = 0.751$, $w_2 = 0.843/4.733 = 0.178$, and $w_3 = 0.333/4.733 = 0.070$, which are the same as those computed by the Eigen method.

Appendix B Pilot Study Case Project

Overview of the Case Study, the Aurora Corridor Project

In 1998, the City of Shoreline, State of Washington, began the Aurora Avenue North Multi-modal Corridor Study. This study was the first phase in the redevelopment of aurora Avenue North along the segment within the City of Shoreline.



Existing Transportation Conditions

The roadway is currently configured as a five-lane arterial with a continuous two-way left-turn lane for the length of the segment (some channelization is provided at intersections). Property access is defined for only 20 percent of the parcels fronting

Aurora Avenue North. The majority of properties along this corridor have continuous shoulder access without defined driveways.

Average daily traffic volumes range from 35,000 to 42,000. Traffic volumes on this roadway are growing at a rate between three and five percent per year. Many of the signalized intersections along the corridor are over capacity during the peak commute periods.

Safety conditions along the corridor are among the worst in the state for a facility of its type. 1,500 accidents occurred along the 3-mile segment over the past five years. Washington State Department of Transportation (WSDOT) estimates that this translates to over $61 million in social costs due to the high number of crashes, injuries, and fatalities.

In addition to traffic congestion and high accident rates, Aurora Avenue North currently experiences poor pedestrian and transit conditions, and unsightly commercial "strip" development. The City's goals for the project, as stated in their Comprehensive Plan, are to support economic stability along the corridor and provide multi-modal transportation services.

Goals for the Aurora Corridor Transportation Solution Project

- Improve the safety of all users along and across the corridor
- Enhance the use of alternate modes such as transit, carpools and bicycles through the development of strategies to make these modes more attractive to the public.
- Optimize the ability of the roadway to move people and goods safely and effectively
- Meet both the short- and long- term transportation needs of users of Aurora, including access and impacts to adjacent properties.
- Enhance and provide travel mode choices as alternatives to driving alone
- Support both local and regional economic development
- Preserve the character of adjacent neighborhoods along the corridor.

Based on the above goals, six objectives are established as a guideline to identify possible alternative solutions. Also, these objectives are used to evaluate those proposed alternatives to identify the group-preferred alternative. These six objectives include:

1. Economic Development

Qualitative evaluation of the extent to which alternatives further the City's economic development objectives of pursuing a strong and diverse economy while maintaining and improving the quality of life. In particular, the Comprehensive

Plan calls for recognizing the Aurora Corridor as the economic core of the City with potential for revitalization, providing services, jobs, opportunities, and becoming an activity center for Shoreline.

2. Capital Cost

Quantitative "order-of-magnitude" measure of capital cost in dollars based upon conceptual definition for alternatives.

3. Air Quality and Energy Implications

Assessment of the relative air quality impact expressed in terms of measures derived from anticipated traffic conditions in the year 2015 for each of the design alternatives. The quality of traffic operations improvements is evaluated as a combination of Carbon Monoxide and Nitrous Oxides by vehicle type.

4. Neighborhood Spillover Traffic

Assessment of the quantity and location of traffic diverted due to design and capacity features of each design alternative. The magnitude of Neighborhood Spillover Traffic Impacts is evaluated as a combination of total volume diverted and the number of streets affected by diverted traffic.

5. Transit Operations Improvements

Assessment of the quality of transit facilities included with the alternative in terms of measures of transit speed and reliability, rider comfort, and accessibility to transit service. The quality of transit improvements is evaluated as a combination of service reliability, travel time, waiting environment, and the quality pedestrian connectors to provide access to transit stops.

6. Traffic Safety Improvements

Assessment of the relative improvement of traffic safety based upon geometric design, operational and environmental characteristics of the alternatives.

After the long comprehensive planning process by the Citizen Advisory Task force, the Interagency Technical Advisory Committee and the general public, three design alternatives are developed for the preliminary evaluation by the Citizen Advisory Task Force. The three alternatives are as follows:

Alternative 1: Local Access

This alternative is oriented to providing local access to businesses and properties along the corridor. It maintains a five-lane cross section in the area between intersections, and includes some sections of landscaped median, but for the majority of its length retains the center-left-turn lane. It has generous sidewalks and landscaping along the edges of the roadway. This alternative includes bus pullouts, and queue jump lanes at intersections (that is, transit lanes at intersections which allow transit vehicles to get to the "head of line" or through the intersection first). This alternative could include some on-street parking pockets.

Alternative 2: People Mover

This alternative is oriented to moving people. It includes adding a business access transit lane in each direction, and a landscaped median island with left and u-turn pockets. The business access transit lane is available for bus movement and for general-purpose vehicles for right turning movements. Landscaping would be provided between the sidewalks and the street as a buffer.

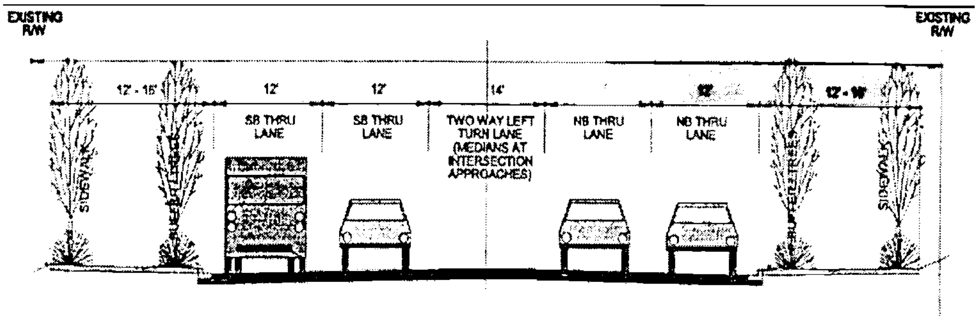
Alternative 3: Regional Design

This alternative is oriented to providing for regional through traffic. It consists of two general-purpose lanes in each direction, and one-way frontage/access roads for each direction. The general-purpose lanes and frontage roads are each separated by a solid barrier. Left or U-turning movements occur only at intersections. The major intersections have grade separation (diamond-like interchanges) for through traffic. Landscaping could be provided as components of the barriers. It is assumed that transit would share the through lanes with general-purpose traffic and use the transit flyer stops at interchanges. Transit access could be provided to frontage roads, and bus turnouts would be created.

Experiment Task

There will be six persons in the experimental group. Each person will assume a role as a member of the Citizen Advisory Task Force. The task is to identify the final recommendation of the group preferred alternative using the GDSS program. The three alternatives will be compared against six criteria, i.e., Economic Development, Capital Cost, Air Quality and Energy Implications, Neighborhood Spillover Traffic, Transit Operations Improvements, Traffic Safety Improvements. After the evaluation is completed, the group will be asked regarding the usefulness of the GDSS program and the ease of use in the layout and the user interface design.

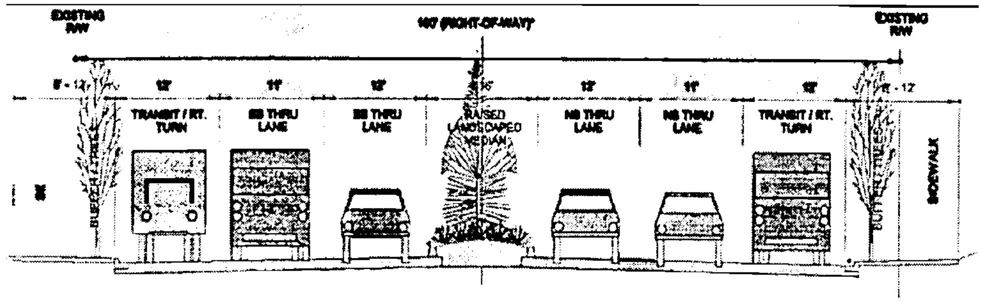
Alternative 1



This alternative focuses on the existing 4-lane plus two-way left-turn lane section with some medians. Extra lanes and signal improvements would be provided at intersections. Transit lanes would be provided at major intersections. Buses would load and unload passengers in the queue jump lanes and at bus turnouts.

Extensive landscapes, streetscape and pedestrian improvements would be made along the corridor. Sidewalks and signalized pedestrian crossings would be added. Frontage streets would be provided where possible. Most parking needs would be provided on private properties off-street. On-street parking pockets could be provided in higher density sections. This alternative would rely Dayton, Meridian, and 15th Avenues as well as Interstate 5 to accommodate excess traffic demand not served on Aurora.

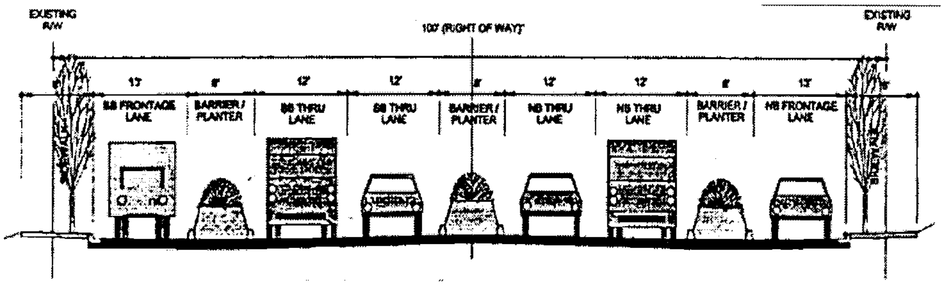
Alternative 2



This alternative provides a people-movement orientation and is designed to balance transportation modes. Six lanes would be provided throughout the corridor including two general traffic lanes and one transit/right-turn-only lane in each direction.

Some intersection improvements would be provided as well as spot network improvements to improve safety and pedestrian access. Continuous transit/right-turn-only lanes would be provided in each direction. Buses would load and unload passengers in the transit lanes. A continuous, landscaped center median would be constructed that would include some access breaks for high volume driveways. U-turns would be accommodated at intersections and at median breaks. Streetscape, landscape and pedestrian amenities would be improved. Parking would be provided in private off-street lots.

Alternative 3



This alternative focuses on through traffic with roadway design based on vehicle movement. A four-lane section is assumed with two general-purpose lanes in each direction. Grade-separated interchanges would be developed at highly congested intersections. Parallel frontage roads would be developed adjacent to Aurora Avenue to provide local access to properties.

Pedestrian crossings would be provided via overpasses. There would be full access management with a continuous barrier/planter median down the center of the roadway. Some consolidated access to properties would be developed with right-in/right-out connections. Some local street development would be included to support local access. Buses would utilize turnouts and flyer stops. Landscaping would be added in each barrier/planter.