UNIVERSITY OF CALIFORNIA,
IRVINE

Decision Theory for Performance Evaluation of New Technologies Incorporating Institutional Issues: Application to Traffic Control Implementation

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in Civil Engineering

by

Stephen Peter Mattingly

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2000

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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A member of the university team that evaluates two federally sponsored Field Operation Tests (FOTs). Co-authored evaluation plans, developed and implemented individual evaluation test plans, conducted an institutional analysis, and organized, coordinated, and managed data collection teams. Co-authored institutional and technical reports. Collected data, completed analysis, and co-authored a report on the effects of the Northridge Earthquake on the Los Angeles transportation network.

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Developed two surveys, one for distribution to members of the North Central Texas Council of Government Bicycle Committee and another for distribution to bicyclists that use roadways on a weekly basis. Organized and led focus

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Mattingly, Stephen P., R. Jayakrishnan and Michael G. McNally, "Integrated Multiple Objective-Attribute Methodology to Determine the Overall Value of Implemented New Technology in Transportation." Accepted and forthcoming in *Transportation Research Record*.

Conference Presentations

Mattingly, Stephen P., "Decision Theory for Performance Evaluation of New Technologies Incorporating Institutional Issues: Application to Traffic Control Implementation." Presented at the Seminar on Doctoral Student Research at the Transportation Research Board 79th Annual Meeting in Washington, D.C., January 2000.

McNally, Michael G., Stephen P. Mattingly, James E. Moore, and C. Arthur MacCarley, "Evaluation of the Irvine Integrated Ramp Metering/Adaptive Signal Control Field Operational Test: Post-Mortem for MOU 65315." Presented at PATH Program-Wide Research Meeting, Richmond, CA, November 1999.

McNally, Michael G., Stephen P. Mattingly, James E. Moore, Hsi-Hwa Hu, C. Arthur MacCarley, and R. Jayakrishnan, "Evaluation of the Anaheim Adaptive Control Field Operational Test: Technical and Institutional Issues." Presented at the Transportation Research Board 78th Annual Meeting in Washington, D.C., January 1999.

Mattingly, Stephen P., R. Jayakrishnan and Michael G. McNally, "Integrated Multiple Objective-Attribute Methodology to Determine the Overall Value of Implemented New

Technology in Transportation." Presented at the Transportation Research Board 78th Annual Meeting in Washington, D.C., January 1999.

Mattingly, Stephen P., Michael McNally, James E. Moore, C. Arthur MacCarley, and R. Jayakrishnan, "Evaluation of the Anaheim Adaptive Control Field Operational Test." Presented at PATH Program-Wide Research Meeting, Richmond, CA, November 1998.

Mattingly, Stephen P., R. Jayakrishnan, Michael McNally, and James Moore, "Evaluation of the Advanced Network Traffic Control System." Presented at the Institute for Operations Research and the Management Sciences 1998 Fall Meeting in Seattle, Washington, October 1998.

Mattingly, Stephen and R. Jayakrishnan, "A Decision-Theoretic Framework for the Field Evaluation of Network Traffic Control Schemes." Presented at the Institute for Operations Research and the Management Sciences 1997 Fall Meeting in Dallas, Texas, October 1997.

Jayakrishnan, R., Michael McNally, and Stephen Mattingly, "Evaluation of Traffic Control Field Test." Presented at the Transportation Research Board 75th Annual Meeting in Washington, D.C., January 1996.

McNally, Michael G., R. Jayakrishnan, Stephen Mattingly, Rick Komerska, and Andrew Nickerson, "Impacts of the Northridge Earthquake on Traffic Network Performance." Presented at the Transportation Research Board 75th Annual Meeting in Washington, D.C., January 1996.

Mattingly, Steve and Sia Ardekani, "Detection of Roadway Hazards for Urban Cyclists." Presented at TexITE 1994 Winter Meeting in Austin, Texas, February 1994.

Reports

McNally, M.G., et. al. *Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Executive Summary*. Final report prepared under project RTA-65V313 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR-99-18), July 1999.

Moore, James E.,et. al. *Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Introduction and Task A: Evaluation of SCOOT Performance*. Final report prepared under project RTA-65V313 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR-99-26), July 1999.

McNally, M.G., et. al. *Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Task B: Assessment of Institutional Issues*. Final report prepared under project RTA-65V313 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR-99-27), July 1999.

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ABSTRACT OF THE DISSERTATION

Decision Theory for Performance Evaluation of New Technologies Incorporating Institutional Issues: Application to Traffic Control Implementation

By

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Doctor of Philosophy in Civil Engineering

University of California, Irvine, 2000

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This dissertation develops a new framework for transportation evaluations. Most evaluation techniques fail to adequately assess all factors involved in transportation projects, with qualitative and institutional issues typically receiving less attention than easily quantifiable technical factors. This dissertation uses quantitative decision-theory techniques to develop a flexible approach that allows an analyst to look at all of the myriad issues involved in the evaluation of transportation projects.

The research approach focuses on identifying an *overall worth*, which provides decision-makers with a quantitative measure to compare different system components. The innovative technique developed here integrates the multiple-attribute value function (MAVF) technique with the analytic hierarchy process (AHP). The overall worth of a project may be a combination of its worth under various operational conditions, with subjective relative weights, depending on the decision-makers. A hierarchy of such combinations are possible where the values for individual attributes themselves can be derived from the decision-makers using MAVF schemes. Certain complications arise in the technique, which require the development of a new scaling approach through the use of a *universal scaling proxy*. The research utilizes a hierarchical approach throughout the analysis while examining a total of four weighting schemes.

The methodology is applied to the Anaheim Field Operational Test, a federally funded project, that implemented new traffic control technologies in Anaheim, California's special events area. The research's primary focus is on the city Traffic Engineer's values and preferences over the entire hierarchy. The development of six testing scenarios creates an opportunity to investigate the effects of many evaluation components as well as individual *branches* within the hierarchy.

The evaluation looks at the percentage change in value between the system "before" and "after" implementation across scenarios. While the new system appears to decrease in value for most scenarios, one scenario, the alternate data set, actually shows an overall increase in value. The special event only operations scenario shows improvement over the base case, which indicates the system performs better under these conditions. The evaluation provides valuable insight into the behavior of the system under various conditions and provides guidance for future applications of this evaluation tool.

CHAPTER 1
BACKGROUND AND OBJECTIVES

1.1 Problem Definition

This research develops a new procedure for handling the evaluation of new transportation technologies. Each new technology implemented for transportation systems has many factors that impact its ultimate success or failure. Combining these factors poses a difficulty that few evaluators attempt to address. Successful evaluations must examine these technologies under varying operating conditions and assess the institutional effects. Furthermore, combining technologies creates additional scenarios. Finally, these evaluations typically involve multiple stakeholders interested in the evaluation's results. The ultimate goals of each of these stakeholders should carry some weight when performing the evaluation. Clearly, the evaluation of new technologies involves many competing factors that require analysis. This research creates a flexible procedure that permits detailed analysis of these competing factors.

1.2 Research Motivation

The need for evaluation exists in many areas of the transportation field. Evaluations can look at two different situations. In the first type, pre-implementation, an agency needs to select a course of action from multiple alternatives. This option might include choosing between multiple construction and retrofit options while a second evaluation type, post-implementation, wants to identify the impact of a previously implemented change. In reality, a pre-implementation evaluation is just an exercise in decision-making; therefore, it will be referred to as decision-making throughout this dissertation. Decision-making occurs under other situations as well, but this research wants to specifically examine post-implementation evaluation, which is simply referred to as evaluation. Through evaluation, agencies may identify the need to alter the routes for buses, commercial vehicles or airplanes, change the existing infrastructure, or modify the traffic control system. Typically, such decision-making and evaluation activities address only the technical or performance aspects of these changes. Furthermore, most agencies use a simple cost-benefit analysis to perform both types of analyses and limit the scope in the process. The emphasis on technical aspects and the reliance on cost-benefit analysis may fail to capture all of the impacts involving multiple attributes and decision-makers. Furthermore, cost-benefit analysis may not adequately identify the relationships between attributes and objectives. In rare cases, agencies may choose to use some evaluation techniques that are commonly used in business decision-making to decide on one option. Theoretically, it is also possible to use value functions derived from subjective and preferential information to evaluate a smaller part of a project with clearly identifiable multiple performance attributes though application of such techniques have been even rarer. Creating a comprehensive new framework while incorporating decision theory techniques in a flexible manner is the primary objective of this dissertation research.

No comprehensive approach exists however for estimating and evaluating objective *overall worth* of transportation projects, possibly among the most complicated decision/evaluation problems that any analyst can face. The complexities are a direct result of the multiple agencies, multiple actors, multiple users, multiple funding sources, in both public and private sectors, which are part of any transportation project. This is especially so in the case of the several new technology implementation projects currently underway in the United States and around the world, projects that motivate the research in this dissertation. Finally, the need for detailed evaluations in the transportation field should increase in the future as more agencies implement new Intelligent Transportation Systems (ITS) technologies which use new approaches and are often implemented incrementally by modifying existing technologies. The decision theory based approach to find overall worth for evaluation incorporating subjective values perceived by multiple actors, as developed in this dissertation may solve some of these issues.

Whenever an agency chooses to use a new technology, it needs to determine if that technology meets expectations by identifying all associated impacts, both positive and negative. Often, agencies find it difficult to examine the institutional implications or impacts of new technologies in an objective manner in conjunction with measurable impacts for selected performance criteria or cost. Such institutional aspects would include inter-agency cooperation among multiple public agencies involved as well as public and political response to the projects. Strong evaluations may allow agencies to develop new operating policies and examine existing ones. Additionally, other agencies need to examine the new installations to recognize the factors that may impact the same technology's implementation within their agencies (the issue of transferability). This information can prove invaluable in the decision-making of all agencies that use a specific technology, may want to use a specific technology, or may want to combine multiple technologies together. Another area of focus in the research is the incorporation of non-quantitative variables into a framework flexible enough for scenario analysis with even transferability to other projects being a possibility.

The expansion of ITS technologies creates the need for formal evaluations of these new technologies. The Federal Highway Administration (FHWA) provides vendors and public agencies the opportunity to test new ITS technologies through their Field Operational Test (FOT) Program. While the vendors want to prove their product's value, and the public agencies want to improve their traffic conditions, the FHWA wants an evaluation of the new technology's contribution to the ITS America, a consortium of American businesses that serve to promote the development and application of ITS technologies, National Program Plan. As a result, each FOT requires its own evaluation; therefore, these FOT evaluations and future evaluations of ITS technologies need an effective and efficient approach that allows evaluators to determine the *overall worth* of both an entire installation of ITS technology and each individual technology. In order to establish an ITS technology's net value, the researcher has to determine its impacts on network performance, its relationship with the infrastructure, and its effects on the institutional environment. The research approach described here addresses these areas of concern and presents a methodology that yields such an *overall worth measure* by combining preferential information from the actors involved such as agencies, decision-makers, and the users in an integrated fashion with the multiple objectives, and multiple attributes involved therein.

This research develops the new evaluation schemes in conjunction with two FOTs in Orange County, California, the Anaheim Advanced Traffic Control System FOT and the Irvine Integrated Ramp Metering/Adaptive Signal Control FOT. Although similar, the specific technologies varied in the two FOTs, where the Anaheim FOT focuses on SCOOT (Split, Cycle, and Offset Optimization Technique) arterial traffic control and the Irvine FOT focuses on both OPAC (Optimized Policies for Adaptive Control) arterial control and SWARM (System-Wide Adaptive Ramp Metering) freeway control. Since only SCOOT has been successfully implemented at this time, the application examples in this dissertation focus primarily on this FOT.

1.3 Research Premises

The research begins with an initial premise that evaluating transportation projects requires more than a simple "before" and "after" comparison. There are a multitude of operating conditions in the before and after cases. In other words, transportation systems with implemented new technology may be viewed as a system with a continuous response function towards multiple inputs (demand levels, operating conditions). Thus, a technique developed for the evaluation must be one that can do more than a simple comparison of two states of a transportation system.

This research looks at many facets of post-implementation evaluation. The primary goal of this research focuses on the development of an evaluation approach that provides an overall measure of performance while accounting for all of the system's institutional and technical components. Decision theory techniques provide a theoretical backbone for the new evaluation scheme. Specifically, this research looks at the viability of combining two different methods from decision theory, analytic hierarchy process (AHP) and multi-attribute value functions (MAVF), to simplify the evaluation process. Additionally, it examines a hierarchical approach that allows for the isolation and identification of each specific component. The groupings within the hierarchy must be examined to determine the appropriateness of their specification. This research expects to identify techniques that govern the grouping process. While the hierarchical organization itself is a critical aspect of the evaluation, the relative significance (weights) of various parts of the hierarchy plays a major role as well. This dissertation investigates the use of four different weighting schemes, all based on preferential input from the actors of concern, and attempts to identify one that remains theoretically sound and user-friendly. User-friendliness seemed important because an evaluation technique must be readily applied. As a result, the research expects to make recommendations to improve its ease of applications while ascertaining any potential theoretical deficiencies. While the impact of multiple decision-makers is briefly investigated, no attempt to perform a thorough investigation is made.

It is fair to ask which existing evaluation schemes the new schemes are expected replace. Current approaches that are used in practice in the transportation and many other economic evaluation contexts are largely based on cost-benefit analysis. The difficulty involved in cost-benefits analysis is that there is no easy way to quantify the dollar worth of subjective components, especially when the dollar worth is nonlinear with respect to a given factor, and when multiple actors and their preference structure need to be considered. This dissertation develops a scheme that also finds a project's worth in dollar terms, but the technique is substantially different and much more flexible towards subjective factors and multiple actors than cost-benefit analysis.

While a real-world example of technology implementation is the case study used, a series of hypothetical scenarios are also studied in an attempt to isolate the effects of the new technique as well as the specific contributions of operating conditions, attributes, objectives, and technologies towards the project-worth. When analyzing the performance of specific operating conditions, a separate worth can be calculated, such that an ideal operating plan may be devised that utilizes each technology's strengths. These scenarios provide an invaluable resource for investigating the evaluation technique.

1.4 Research Approach

The starting point for the research is to recognize the fact that evaluation of an implemented project has several steps similar to the evaluation alternatives within a decision-making problem. In essence, this implies that evaluation is a one-alternative (or two-alternative when considering the current system) decision problem by itself. Similar techniques as used in decision theory to compare the worth, value, or relative decision-maker preferences among alternatives are as applicable to evaluation as they are for decision-making.

This research proposes the integration of two methods from decision theory, Analytic Hierarchy Process (AHP) and Multi-attribute value functions (MAVF). The former generally focuses on the multiple criteria or objective decision-making technique while the latter focuses on the values of the attributes involved in the decision problem. AHP requires knowledge of the different alternatives when making a decision. In order to avoid the potential for biasing responses, the evaluation process requires a decision-maker to state his or her preference structure without knowing the evaluation's results (i.e. alternatives). However, AHP can be used to determine a decision-maker's preference or priorities across the various evaluation components. Therefore, AHP is not useful by itself when the worth of the project is to be found; MAVF allows an analyst to identify a value/preference structure across attributes without any knowledge of the alternatives. The research examines different possible methods for combining the two methods to create an integrated process and also examines different value function assessment approaches that may be used in this process.

The above two techniques are rarely, if ever, used together by decision theory researchers in practice, and it is possible that this dissertation is the first to attempt this. The academic community is divided in their conclusions on the usefulness and limitations of each approach, and the users of one technique are often critical of the users of the other, despite the fact that the techniques themselves are rarely applicable to the same problems. This dissertation finds evaluation of large-scale projects as an ideal case for joint application of the schemes. While doing this, the research also brings out the fact that there is tremendous potential for the two techniques to complement each other, though it becomes apparent only in a large-scale application. Simply put, the large number of attributes involved in an implemented transportation project makes the use of MAVF techniques impractical and methodologically unsound, and grouping of MAVF attributes and incorporation of a hierarchy and AHP weighting schemes makes it viable. On the other hand, the methodological underpinnings of appropriately applied MAVF schemes reduce the common criticisms of AHP where the inflexible weighting and scaling schemes have caused theoretical deficiencies, which can be avoided by the use of true preferential value information from the decision makers. These aspects are discussed further in chapter two. It suffices to say that the research here provides a significant bridge between two quantitative techniques in decision theory.

Since the research develops a completely new approach, it is important that its application is carefully studied. The robustness of the new processes is examined by changing the objectives and attributes involved in the valuation process and also the levels of the attributes. These could potentially allow the evaluator to develop values for hypothetical systems of technologies or hypothetical improvements and/or degradations in technology performance. These hypothetical systems demonstrate the percentage improvement possible by improving performance. These improvements remain possible because an evaluation's results do not have to represent a non-dominated solution.

Research on new technologies in transportation involves many institutional issues. To combine these issues with the qualitative results from other portions of the evaluation, the evaluator needs to convert the qualitative institutional results into quantitative values. The techniques developed in this research avoid qualitative assessments of institutional issues by assigning a quantitative, proxy attribute for each institutional issue.

The simple determination of whether the technology should have been implemented based on the test's data may prove difficult because the evaluator must assess the overall worth or value of new ITS technology. Many issues contribute to the evaluator's assessment, which makes any determination based on the comparison of one measure of effectiveness (MOE) inadequate. These include not only performance issues, but institutional and infrastructure issues as well. The final value uses the opinions of the decision-makers interested in the evaluation process, typically the FHWA and the public agencies involved in the FOT. These values and opinions need to be determined through interaction with the decision-makers. Unfortunately, creating a value function that adequately represents these decision makers' preferences presents a further complication because each individual will have his or her own opinions. To accumulate these values, the evaluator needs to design an interview format or survey that allows for the acquisition of the necessary information.

Interview development and implementation represent one of the most critical aspects of an evaluation because, without the proper material to assess and compare the objectives, the evaluation can not reach any reliable conclusions. After creating a hierarchy of objectives and attributes, the evaluator must develop a psychologically sound approach to gather decision-maker preference information. Many techniques currently exist from decision theory research, and this research examines the appropriateness of many of these. Until an analyst becomes an expert at implementing decision-theory techniques, a pilot study should be performed to test the interview's approaches to correct any problems. Any evaluator needs to decide on the appropriate individuals to include as decision-makers, and if a need exists to add organizational levels to the hierarchy.

The analyst must aggregate each of the decision-maker's individual value functions to form a group value function. Frequently, an aggregation method causes more problems than the interviews themselves. Therefore, this research briefly attempts to implement a simple approach, which eliminates individual interviews and determine the group value function directly. The research leads to possibilities such as a forum where the decision-makers discuss their opinions and arrive at a group decision on each question. This approach requires that all of the proper stakeholders participate in such a forum.

Collecting the necessary data can pose some problems for the evaluator; therefore, an appropriate testing procedure has to be carefully designed. If the tests remain poorly designed, the evaluator may fail to collect all of the necessary data or may even collect unreliable or biased data. Ideally, all of the network, test, and traffic characteristics need to remain unchanged between the before and after studies; however, if systematic changes occur between the two tests, then the study needs to be able to account for these. In addition to the investigations that provide quantitative results, the evaluator needs to devise a collection scheme that gathers the necessary qualitative information about the institutional issues. Data collection represents another portion of the evaluation where an error may result in inaccurate results.

1.5 Application of the New Approach

Researchers with the Institute of Transportation Studies at the University of California at Irvine served as members of the evaluation team on two FOTs in Orange County, California. The new evaluation approach is applied in the evaluation of these tests. The FOT in Anaheim, California, focuses on the implementation of the SCOOT algorithm in parallel to the existing Urban Traffic Control System (UTCS). This FOT included a separate evaluation of a Video Traffic Detection System (VTDS) and the implementation of 1.5 Generation Control (GC) UTCS. The Irvine FOT included the integration of multiple technologies. The City of Irvine intended to implement the OPAC algorithm for adaptive control of an arterial corridor that parallels the I-405 freeway. The City of Irvine planned to use the Management Information System for Traffic (MIST) as their traffic management platform for this area. Additionally, Caltrans District 12 wanted to introduce the SWARM algorithms as their new freeway ramp metering algorithms. The Irvine FOT included a separate evaluation of the 2070 Advanced

Traffic Controller (ATC) (on which OPAC was installed.) Unfortunately, the functionality of all of these components was in doubt at the much delayed implementation stage, thus the project concluded without the performance evaluation being conducted. Since the Irvine FOT proved to have no functional products, it could not be subjected to a post-implementation evaluation. Therefore, the Anaheim FOT served as the theater for the application of the evaluation techniques that were developed because it was sufficiently elaborate and involved a variety of technologies and operating conditions.

1.6 Organization

This dissertation begins with a brief examination and review of some of the relevant literature on technical evaluation. Chapter two primarily serves to provide a thorough presentation of the methodology developed in this research. This includes discussion of existing methodologies as well as the methodological extensions developed in this dissertation. Chapter three reviews the data collection effort as well as the initial data preparation. Most of the chapter focuses on the entire process required to successfully complete decision-maker interviews. Chapter four describes a complete application of the approaches developed for this dissertation while Chapter five looks at a limited-scope application that focuses on a few specific value functions as well as on the group decision-maker problem. Chapter six discusses the key institutional issues from the Anaheim FOT. Chapter seven concludes the dissertation with a description of conclusions, contributions, and possible avenues for future research.

CHAPTER 2 RESEARCH METHODOLOGY

This chapter provides a description of the existing decision techniques as well as the methodological extensions necessary for a complete, flexible evaluation scheme. The existing decision-theory techniques include Multi-Attribute Value Functions (MAVF), Analytic Hierarchy Process (AHP), and general group decision-making. MAVF form the core of this evaluation strategy using them to provide a value associated with each specific attribute. They must, however, be adapted so that they meet all of the desired characteristics. AHP as well as a variety of value function weighting approaches are described because these techniques will provide the objective priorities from the upper-levels of the hierarchy. A few aggregation strategies as well as group assessment are examined to address group decision-making concerns. As part of the development of this scheme, this research briefly examines and attempts to solve some of the problems associated with aggregation.

As a note for future research, it is hypothesized that a given group or individual changes their core value structure slowly (from project to project, over time, from technology to technology) if at all; however, the priorities that they assign to different objectives may vary dramatically (from project to project, over time, from technology to technology). Thus, the inherent value functions for the attribute variables, which are oftentimes not consciously known to the individual, are much less variable than the weights and priorities, which are more tangible to decision-makers. A further extension states that the attribute value structure does not vary dramatically from individual to individual when compared to the priority structure across discernible factors. The latter is a stronger assumption. This is a reasonable hypothesis. Under these hypotheses, the new techniques developed here provide the flexibility to create a comprehensive evaluation approach that can be adapted to many different projects by only respecifying the project's priorities and not respecifying the value functions. This makes the difficult task of assessing attribute value functions a one-time event.

2.1 Literature Review

This research focuses on applying decision-theory techniques to the evaluation of transportation systems. Each of these topics has its own separate body of research. In some instances, an existing decision technique is used to make a decision involving a transportation system; however, little, if any, fundamental research has been devoted to cases where transportation system evaluation and decision-theory techniques are integrated. Therefore, this review examines each body of research separately where the following sections examine the literature from both transportation evaluation and decision-theory.

2.1.1 *Transportation System Evaluation*

Evaluation of the transportation system has existed for a long period of time, and these evaluations have addressed many components of this system, including maintenance, operations, safety, design, and planning. Cirillo and Council (1986) examine the knowledge base regarding the effectiveness of safety countermeasures and find that little has changed since 1970. While some evaluation of countermeasures occurs, far greater go unstudied, which restricts the development of reasonable implementation plans. This pattern seems to be repeating itself with

ITS technologies; however, the evaluations in this case affect the transportation system in a holistic manner where overall system performance depends on operations, maintenance, safety, and technical performance. Typically advances in transportation have not been expected to solve all problems at once, but they addressed them incrementally, for example design improvements that improve operational performance, safety devices that improve safety, and pavement improvements that decrease maintenance requirements. Thus, the ITS revolution presents researchers with the unique problem of evaluating technologies that are expected to improve the transportation system at all levels. The first section reviews literature that addresses the evaluation of the transportation system in general while the subsequent section identifies literature devoted to the evaluation of ITS technologies and their implementation.

2.1.1.1 General Evaluation

This section looks at literature that generally addresses the evaluation of transportation systems. The term evaluation tends to be overused, especially with regard to transportation systems because an evaluation needs to be systematic and comprehensive. Many researchers "evaluate" ideas rather than technologies; however, this review focuses on the evaluation techniques used to affect improvements in the transportation system. Although the term evaluation may appear overused, it remains a critical aspect of improving the existing transportation system. Evaluations identify potential concerns and separate decision-making exercises select the proper alternatives. This section treats the evaluation of planning alternatives, which is in reality a decision-making exercise as defined in this dissertation, as evaluation because most researchers merely present the results objectively and make no attempt nor incorporate any tool for identifying the best decision. The topics that are addressed range from the evaluation of planning alternatives to the evaluation of safety improvements.

Safety represents a critical concern for all transportation activities, and thus its importance affects maintenance, operations, planning, and design. According to Streff (1991), evaluations are frequently overlooked when implementing changes to a community's traffic safety program. While the tradition of evaluation seems to be well established it still is frequently overlooked even in such critical areas as safety. Evans (1994) suggests a framework for evaluating transportation safety measures that combines cost-benefit analysis with a limit on the tolerable risks to individuals. In addition to safety, some research looks at system operations. Allen and Di Cesare (1976) examine transit service evaluation by looking at certain performance indicators. While safety and system operations remain important, most of the research is devoted towards the evaluation of transportation systems.

The evaluation of planning alternatives primarily relies on cost-benefit analysis where market costs and benefits are compared to determine the best alternative. Small (1999) advocates the use of cost-benefit analysis for all project evaluations because it can identify the key project consequences by providing quantitative information. Pardee (1969) uses cost-benefit analysis in a comprehensive evaluation of alternatives for the Northeast Transportation Corridor. As opposed to traditional cost-benefit analysis, he introduces the concepts of balancing competing planning goals, such as to make a significant improvement in transportation service while maintaining acceptable investment returns and emphasizing economic development while maintaining service and revenue. A report by IBI (1995) attempts to extend conventional cost-benefit analysis (i.e. based on quantified dollar-based measures) to include other quantifiable but non dollar-based measures and additional measures (often more qualitative in nature), which are not generally captured in conventional cost-benefit analysis. A report by Peat, Marwick, Mitchell & Co (1973) identify the need for an evaluation component that trades off the attainment of competing objectives. This report does not identify a method for accomplishing this, but De Neufville and Keeney (1973) accomplish this task by introducing the idea of using multiattribute decision analysis for evaluating transportation systems. They apply this technique for the planning of an airport facility in Mexico. This may have been the first application of a decision-theory technique for the planning of transportation facilities. While cost-benefit analysis remains the primary technique for evaluating transportation systems, the need for alternative techniques has existed since the mid-1970s. As the transportation industry moves towards the extensive implementation of emerging technologies this need for a new evaluation technique increases.

2.1.1.2 ITS Evaluation

In this section, the literature in the area of new technology implementations and Field Operations Tests (FOTs) in transportation is examined. The working paper by Bolczak (1993) should be considered as among the first to provide some basic guidelines for a FOT evaluation framework; however, this paper fails to deal with the evaluation process itself in any great detail. Known informally as the MITRE guidelines, it did provide initial stimulation for evaluation schemes used in many FOTs recently. Furthermore, Booz, Allen and Hamilton, Inc. (BAH), Washington, D.C. have provided additional evaluation support and some modified techniques as the FOT consultant to the Federal Highways Administration (FHWA). BAH (1998) present these modifications in its case study of the Atlanta NAVIGATOR system. As previously discussed, ITS projects have the potential to improve safety; ITS America and the National Highway Traffic Safety Administration (NHTSA) joined together to sponsor a 1996 workshop that tried to highlight these potential savings. Once again, evaluation concepts and potential benefits were readily identified, but few of the papers from the proceedings actually attempted to evaluate ITS effects on safety.

A few other researchers have recently looked at ITS evaluation; however, much of their research focuses on evaluation at the planning level. For example, Brand (1994) uses a multi-criteria approach for selecting the appropriate operational tests for funding. Additionally, he creates a large list of candidate criteria for evaluators to select from for their specific evaluation. Levine and Underwood (1996) use a modified AHP to determine ITS planning goals. Furthermore, they look at multiple stakeholders as opposed to a single decision-maker. While evaluation for ITS planning purposes may introduce interesting techniques, it fails to address an evaluation's results. Lu et al. (1997) move beyond this initial planning stage and actually select a specific automatic vehicle identification (AVI) technology for implementation in Hillsboro County, Florida. They use the results from a simulation to perform cost-benefit analysis and select the best technology and configuration of manual and AVI lanes. Bishop et al. (1994) use cost-benefit analysis to evaluate the life-cycle of a rural Advanced Traveler Information System (ATIS). Obviously, adjusting planning programs to include ITS technologies represents a major concern as well as selecting the best ITS alternatives for a given problem; however, the actual performance of these technologies still requires investigation.

The results of a previously conducted operational test serve as one of the best planning aides possible. Underwood and Gehring (1994) provide a better look at the techniques available for evaluating specific ITS projects. They discuss different types of evaluation and recommend types of data sources for seven different objective categories. A report by James et al. (1998) for the State of Texas summarizes the reported benefits of deployed ITS technologies and the evaluation techniques used to quantify these benefits. The report discovers that many of the reported ITS benefits are made without reference to pre-existing conditions; therefore, the State of Texas may need to develop its own research program to investigate these reported benefits. Hall, Miller, and Khattak (1996) discuss the steps associated with evaluating the effectiveness of integrated traffic corridors. Their research looks at developing an evaluation plan, selecting data sources, and data collection techniques. They could not fully execute this evaluation plan due to certain institutional difficulties. A report by Peeta et al. (1998) looks at the impacts of ITS technologies on a freeway segment in Indiana. The report focuses on the impacts to mobility, air quality and safety when an Advanced Traffic Management System is implemented. As ITS continues its development, many researchers focus on the potential benefits of ITS; however, comprehensive system evaluations seem to be occurring infrequently.

2.1.2 *General Decision Making and Evaluation*

Operations researchers and business decision analysts have undertaken most of the research in general decision-making and evaluation. Rigorous quantitative decision modeling seeks to insure the selection of the "best" alternative from a set of possible alternatives. These approaches use techniques that resemble those of optimization because the "best" decision maximizes the benefits for a given decision-maker. Ideally, a decision-maker will not be narrowly focused and consider societal benefits when selecting an alternative as opposed to behaving in a selfish manner that only maximizes individual benefits. While little research has examined evaluation as defined in this dissertation (see section 1.2 for clarification), evaluation is really a decision-making process that selects between the new treatment and the "do-nothing" alternative. This section provides a synthesis of some of the research in decision-theory.

An evaluation model needs to be created that modifies existing decision-theory to make it suitable for this new application. The following steps outline traditional procedures for building models (Vemuri, 1974): (i) choosing a collection of goals and defining the corresponding objective functions, (ii) gathering relevant information, (iii) building a model, (iv) validating and operating the model, (v) determining a feasible control policy, (vi) applying the policy to the model, and (vii) reaching the stated goals. Although traditional procedures for building models assist with the formulation of a multi-objective problem, they do not guarantee a single optimal solution. In multi-objective programming, the problem tries to identify a set of non-dominated solutions. Non-dominated solutions represent alternatives where increasing one objective creates a decrease in another objective. Many methods exist for obtaining a portion of these non-dominated solutions. According to Levine and Underwood (1996), these methods proceed according to five basic steps:

1. Identify relevant participants in the decision process. These can be either a single decision-maker or a group of decision-makers.
2. Identify the dimensions, criteria, or goals that will characterize the alternatives.
3. Generate preference-based weighting schemes.

4. Develop measures by which each of the alternative projects is assessed along the relevant dimensions.
5. Rank or rate alternatives based on measured outcomes and groups' preferences, and perform analyses. These frequently include marginal analysis of costs and outcomes between alternatives, sensitivity analysis in which changes in the assumptions are tested for their capacity to alter final outcomes.

Commonly, decision-theory techniques utilize decision-maker input when generating preference-based weighting schemes; however, the type of decision-maker input varies amongst the schemes. Most techniques use these weights to prioritize the criteria (attributes and objectives) to determine the amount of emphasis to place on each when trying to make a final decision. In order to rank alternatives, comparisons are made between the criteria and the criteria combined.

Frequently, decision-makers' values and preferences are found by using surveys that quantify their values and preferences. Conflicts between different decision-makers arise because they value the objectives and attributes in different manners. Since a single optimal solution for the multi-objective case does not exist, the final solution that an analyst recommends should be termed a *satisfactory solution*. Simon (1953) states that, "most human decision making, whether individual or organizational, is concerned with the discovery and selection of satisfactory alternatives; only in exceptional cases it is concerned with the discovery and selection of optimal solutions." This study asks the decision-makers to determine and quantify their priorities prior to their learning of the evaluation's results. This approach insures that the evaluation results remain as unbiased as possible. By combining the evaluation's results with the decision makers' preferences the evaluator attempts to determine a degree of satisfaction associated with the evaluated system. Utility theory describes the selection of a satisfactory solution as the maximization of satisfaction derived from its selection. Thus, the best alternative is the one that maximizes utility for the decision-maker's stated preference structure.

In addition to utility theory, other techniques exist for determining the best decision. The selection of the appropriate technique depends on the specific problem as well as decision-maker and analyst preference. Goal programming, a technique that Charnes and Cooper (1961) develop, requires the decision-maker to specify a target value for each objective function. The preferred solution is the alternative that minimizes the sum of the deviations from the set of target values. Another technique, Surrogate Worth Tradeoff (SWT), that Haimes et al. (1975) develop, requires that the objective functions be differentiable. Using an optimal set of tradeoffs where a tradeoff function describes the preference relation between two objectives identifies the best solution. The multicriterion algorithm ELimination and (Et) Choice Translating Algorithm II that Roy (1974, 1975) develops provide a complete ordering of the nondominated alternatives through the use of outranking relationships. The outranking relationship is based on decision-maker value judgements. Goicoechea et al. (1982) develop the Probabilistic Tradeoff Development Method as a multi-objective stochastic programming solution to the decision-making problem. These represent a small selection of the variety of decision models that exist. While many decision-theory approaches exist, utility theory is the technique that lends itself towards adaptation for evaluation research.

In many approaches, the decision-makers' Multi-Attribute Utility Functions (MAUFs) are assessed and used to solve multi-objective problems. MAUF assessment procedures typically assume preferential independence and utility independence. In addressing the issue of tradeoffs between objective functions, Von Neumann and Morgenstern (1947), identify two properties relevant to the decision maker's utility function $u(\mathbf{z})$, where $u(\mathbf{z}) = u(z_1, z_2, ..., z_p)$ and $\mathbf{z}$ is the vector of p objective functions. These are:

1. $u(\mathbf{z}') > u(\mathbf{z}'')$ if and only if $\mathbf{z}'$ is preferred to $\mathbf{z}''$.
2. When uncertainty exists, the expected value of u should be used to make decisions.

These properties greatly simplify the use of utility theory; however, determining an appropriate MUF still poses some difficulties. Keeney and Sicherman (1976) suggest that ideally, the functional form of the MAUF should:

1. Be general enough to allow application to many real problems,
2. Require a minimal number of decision-maker assessment questions,
3. Require assessments that are reasonable for a decision-maker to consider,
4. Be easy to use when evaluating alternatives and conducting sensitivity analysis.

The MAUF provides a powerful tool for analyzing potential alternatives; however, identifying a simple form that fulfills the properties above can prove difficult. These properties require careful development of the MAUF and questionnaire that determines decision-maker preferences. Broadly speaking, two different techniques, holistic and decomposed, exist for assessing utility functions. Holistic approaches to decision-making require the decision-maker to look at each alternative and indicate his or her preferences between the alternatives. Srinivasan and Shocker (1973) develop LINMAP (LINear Programming techniques for Multidimensional Analysis of Preferences) for assessing the weights as well as identifying the ideal solution and the best alternative for this case. Beinat (1997) identifies another frequent use of holistic models. They capture the importance and relevance of the attributes based on actual decision-maker selections, specifically this can be used in consumer research. The decomposed assessment technique allows a decision-maker to identify his or preferences without knowledge of the specific alternatives. This approach is very attractive for the evaluation case because the actual evaluation results remain unknown to the decision-maker. Utility theory still can not be applied directly to the evaluation case because it incorporates uncertainty into the decision-making process. In the case of an evaluation the final results are known with certainty; therefore, value theory or decision-making without uncertainty seems to be a better fit for this research.

Decision making with certainty better fits this research because the evaluator wants the decision-maker to make trade-offs with certainty. Other than this difference regarding certainty and uncertainty, utility theory and value theory are very similar. Prior contributions in value theory comes from many researchers, including: Debreu(1960), Gorman (1968a, 1968b), Krantz et al. (1971), Leontief (1947a, 1947b), Luce and Tukey (1964), Pruzan and Jackson (1963), and Ting (1971). Since a decision-maker no longer must address the question of uncertainty, the MAVF problem is actually easier to assess than the MAUF problem. Similarly, two broad classes for assessment, decomposed and holistic, exist. MAVF theory is described in more detail in section 2.4.1.

Unfortunately, all of this research involves decision-making between different alternatives, and these techniques can not translate directly to evaluation. This difficulty exists because the results of an evaluation do not have to be non-dominated because a system may simply be operating inefficiently. For example, an agency may have all of the data required to retime its traffic signal system, but it may opt to not pursue this improvement. An agency that can retime its signal system without incurring a cost to system operations is not operating at a non-dominated level. Therefore, evaluation research does not involve the optimization of objective functions mathematically because these mathematical solutions will unlikely correspond to the specific results identified when evaluating an improvement or existing operations. An example of mathematical optimization is the selection of a specific alternative or operations and maintenance plan that finds optimal attribute levels over a set of objective functions. Where an attribute may be loop maintenance and its corresponding objective function is to minimize maintenance costs. Although evaluation can not use mathematical optimization directly, the decision-theory techniques can be adapted for use in evaluation. The next section continues this discussion of evaluation versus decision-making and the remainder of chapter two adapts some decision-theory techniques for use in evaluation.

2.2 Evaluation vs. Decision-Making

There exist many reasons for developing an evaluation scheme that incorporates decision theory techniques. Traditional evaluation approaches for both pre-and post-implementation focus exclusively on an economic assessment of the costs and benefits. The decision-makers can not examine all of the pertinent information and prioritize impacts based on their value structure under these circumstances. Although recent research by Gillen et al.(1999) has begun to address these problems by allowing an analyst to assign weights to different aspects of the project, virtually all current strategies ignore two key aspects. One of the most critical concerns for transportation projects involves the operation of a system post-implementation; rarely, if at all, is a post-implementation evaluation considered as an important tool. A decision-oriented approach allows a manager to examine the post-implementation performance of the system and identify the key aspects that require improvement. Additionally, the manager can identify the degree to which changes might improve the overall system.

Secondly, a decision-theory approach uses decision-maker priorities as opposed to externally determined, market-driven values. These benefits identify many interesting advantages for using decision-theory for evaluation.

While all of these benefits make the use of decision theory appear essential, difficulties still exist that hinder its application to evaluation. The first few concerns are simply associated with decision-theory, but others exist in particular for the evaluation case. A decision-theoretic approach can be quite time-intensive, and require a great deal of effort from the decision-makers, who may often consider investing this effort unnecessary. Decision-theorists can not agree to present a single approach as the "best" that captures all of the needs in an easy to apply technique. Since all decision-theories focus on the selection of alternatives, they assume that a decision-maker fully knows all of the impacts of a given alternative and must simply select the proper one. Unfortunately, in evaluation one does not specifically know what the exact impacts of the new system will be, and therefore, many traditional decision-theory techniques are not completely suitable. All of the techniques that use a holistic as opposed to a decomposed approach must be rejected out of hand because they look at an entire profile without examining each attribute separately. Additionally, most of the decomposed schemes assume that an analyst will know the minimum and maximum levels of every attribute, which is not possible in the evaluation case. Without this knowledge, the decision-theory schemes need to be adjusted to address these concerns as well as the scaling concerns that develop when the previously mentioned techniques can not be applied. Since most decision-theory approaches simply identify an ordinal ranking of alternatives as a solution, decision-makers will not be able to identify the degree of change between two alternatives, specifically, the "before" and "after" case of a post-implementation evaluation. This presents a difficulty that must be overcome to utilize a decision theory technique for evaluation. Additionally, when an evaluation scheme looks at a new system as opposed to the selection of competing alternatives as in decision-theory, a decision-maker hopes to learn something about the new system whereas other agencies are interested in learning something about the new technologies. This knowledge can be used to change operating policies more proficiently, improve future implementations of the new technology, provide for easier expansion, and increase the general understanding of the new system. Decision-theory provides a good starting-point to increase the understanding of the new system because it can analyze individual aspects of the system, but the overall approach needs to be modified to look at evaluation. The rest of this chapter looks at existing decision-theory techniques, and expands on these to adapt the approach to a post-implementation evaluation.

2.3 ITS Evaluation Context - An Example

To explain the methodologies described in this chapter, consider a simplified problem. For this problem, there exist five measures or attributes that the decision-makers believe contribute the overall worth of a transportation system. These are network running time in minutes per mile, network stop time in minutes per mile, capital costs in dollars, operating costs in dollars, and system maintenance in man-days required. For notation:

x_1 - Network running time (minutes per mile)
x_2 - Network stop time (minutes per mile)
x_3 - Capital costs (dollars)
x_4 - Operating costs (dollars)
x_5 - System maintenance (man-days)

Under the most basic approach, each of these attributes can be compared to one another to determine the relative values associated with them. These relative values are made by asking a decision-maker to determine tradeoffs that are preferentially equivalent. As an example of preferential equivalence consider attributes x_1 and x_2 the attributes both start a given value, in this case two minutes per mile for x_1 and one minute per mile for x_2. Two intervals exhibit preferential equivalence when a decision-maker receives equal "value" by traversing either interval. Continuing the example, the decision-maker decides that the following intervals are preferentially equivalent: x_1 (2) → x_1 (1.85) and x_2 (1) → x_2 (.9). Thus, a decrease in running time from 2 to 1.85 minutes per mile is equivalent to decreasing the stop time from 1 to 0.9 minute per mile. This approach is quite time intensive, but it limits most other concerns. Figure 2.1 displays the relationships between two attributes.

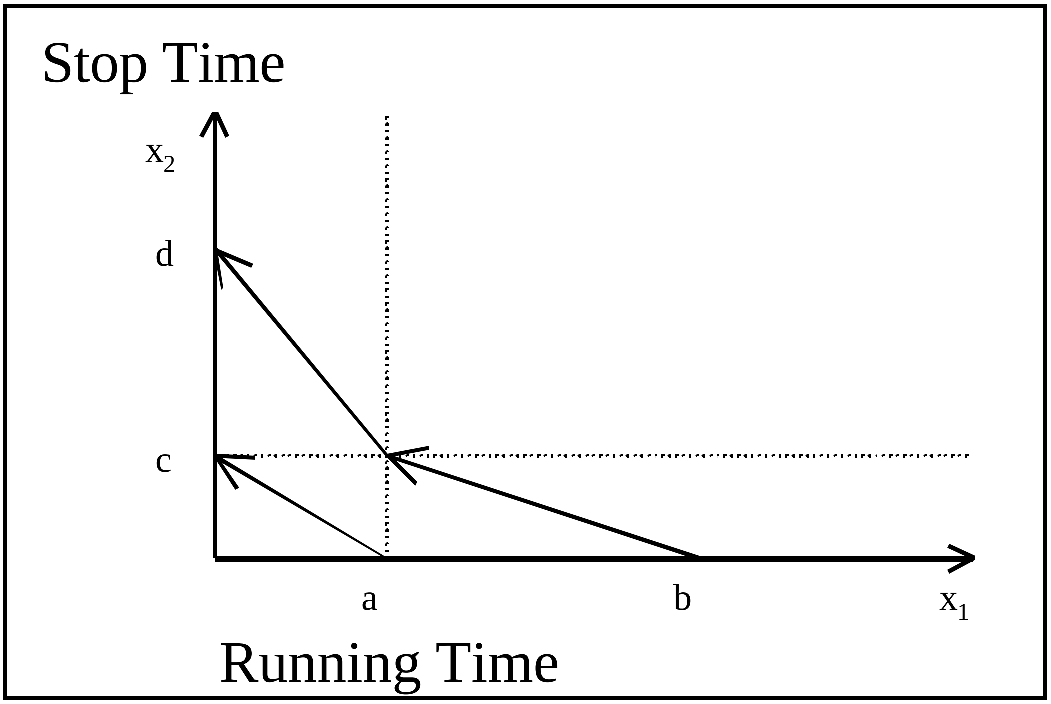

Figure 2.1. Network Running Time Compared to Network Stop Time

The value function associated with this basic approach takes the following form:

$$V = \sum_{i=1}^{5} v_i(x_i) \tag{1}$$

In this formulation, v_i refers to the value function for the ith attribute ($i = 1$ to 5 here), x_i is the level of attribute present in the system and V is the sum of all values for the system.

An easier technique for obtaining the value function of each attribute is to assess it individually. In order to eliminate any difficulties associated with mixing attributes of different scales, the value of each function is based on its range of values. Each value function is assessed individually, but the decision-maker must identify his or her priority weights between the attributes that detail his or her preferences. Figure 2.2 displays two, network running time and network stopping time, of the five value functions for all of the attributes. These value functions are intrinsic to a given decision-maker or group of decision-makers, and can be generated by asking a series of questions pertaining to value and attribute levels. The responses to these questions help enumerate the value functions that identify the value or worth attributable to different attribute levels.

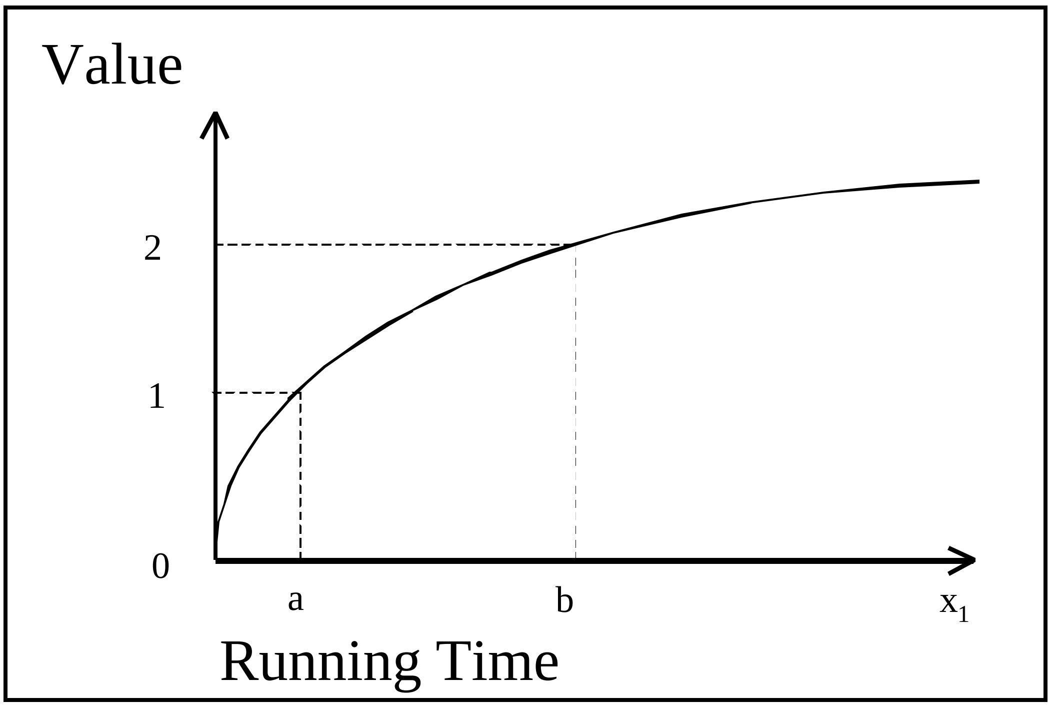

Figure 2.2. Value Function for Network Running Time

In addition to these value functions, an individual or set of decision-makers possesses a priority structure that may emphasize specific attributes at the expense of others. Although the decision-makers have previously established a value for each attribute through the specification of their value functions, they may decide to give the attributes unequal emphasis because of their particular role in this system or application. For example, a city decision-maker may value the beautification of city streets extremely highly (as shown in his or her value function); however, for a given project, the capital costs and construction time may have a much greater importance than aesthetics. The reverse could also be true where aesthetics received priority over both capital costs and construction time. Once again, these weights or priorities should be determined by asking an individual or set of decision-makers a series of objective comparisons where attributes are compared to one another as opposed to value levels. Table 2.1 provides the weights for each of the attributes, W_i, i = 1 to 5. The discussion that addresses the theoretical aspects of the weights points to the nonexistence of additivity when all the attributes functions are added together as in equation 1. This topic is covered in detail later in this chapter.

Table 2.1. Attribute Weights

Attributes	Weight
Network running time (minutes per mile)	.35
Network stop time (minutes per mile)	.35
Capital costs (dollars)	.10
Operating costs (dollars)	.10
System maintenance time (man-days)	.10

The inclusion of the weights with the value functions modifies the overall value of the system to the following formulation:

$$V = \sum_{i=1}^{5} w_i v_i(x_i) \qquad (2)$$

A particular concern develops when the range of the attributes is unknown. Under this circumstance, the previous procedure can not be applied. As a result, all of the value functions must be converted to a common scale. While this concern exists in the example, a thorough discussion of the solution exceeds the scope of this example. Section 2.5.1 provides a thorough description of the universal scaling proxy; a technique used to solve this problem.

Looking at the weights identified in Table 2.1, one notices that some of the attributes seem to have a common factor and can be grouped together. In this example, network stop time and network running time can be grouped together and the remaining three attributes, capital costs, operating costs, and system maintenance, may be grouped together as well. In fact, these groups may be combined into a hierarchy where every *branch* of the hierarchy has a separate set of weights. A branch occurs at the separation of the hierarchy into two or more separate factors, such as institutional issues and technical performance, and describes all of the components that comprise a single factor. When branches join together, a *junction* is formed. Figure 2.3 shows the structure of such a hierarchy and its weights associated with each branch.

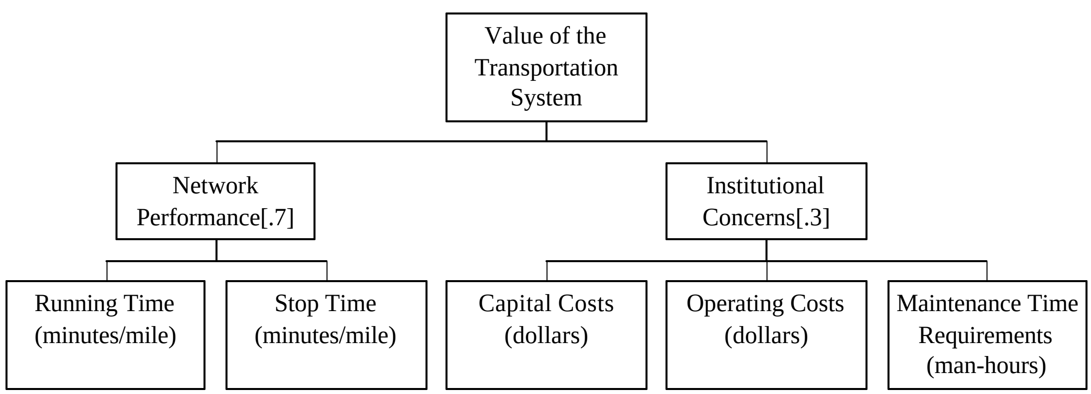

Figure 2.3. Basic Hierarchy

The formulation for this hierarchy is given by the following equation:

$$V = a_1 \sum_{i=1}^{2} w_i v_i(x_i) + a_2 \sum_{i=3}^{5} w_i v_i(x_i) \tag{3}$$

or, in general:

$$V = \sum_{j=1}^{J} a_j \sum_{i=a_j}^{b_j} v_i(x_i) \qquad (4)$$

In these formulations, a_j refers to the weights for each grouping, J refers to the number of groupings or branches, and a_j and b_j give the node locations (taken from a vector N of all nodes) within a given jth branch.

A further extension to the hierarchy is displayed in Figure 2.4. It shows that the priorities associated with different operating conditions can differ while Figure 2.5 shows that the addition of a new junction may change the weights throughout all of its branches; however, one should note that the overall percentage impact of the attributes at the leaf level remain unchanged.

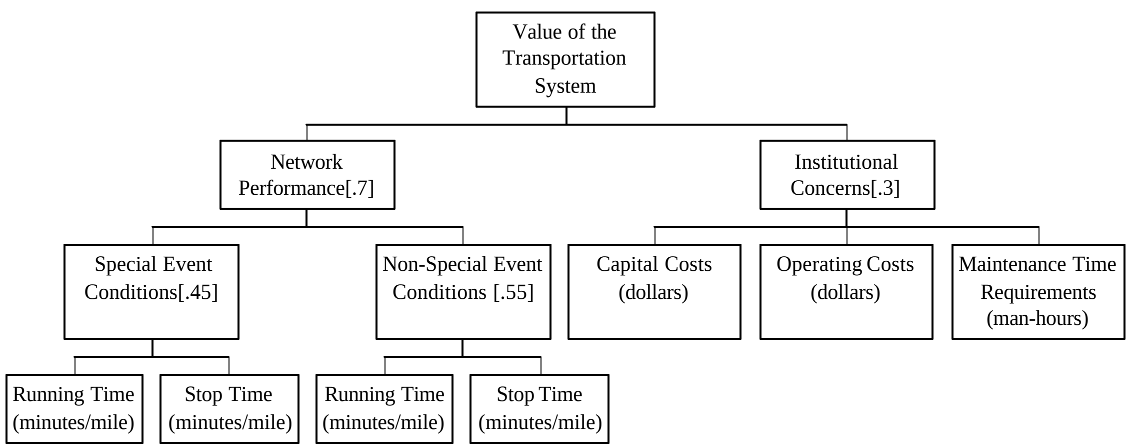

Figure 2.4. Extended Hierarchy Incorporating Operating Conditions

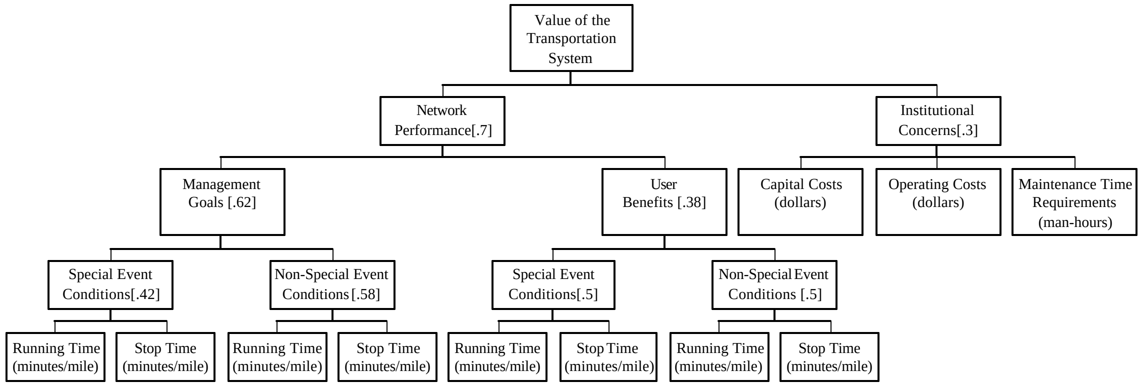

Figure 2.5. Extended Hierarchy Adding a Layer and Changing the Leaf Weights

The value function for the hierarchy in Figure 2.4 can be formulated in the following manner:

$$V = a_1 b_1 \sum_{i=1}^{2} v_i(x_i) + a_1 b_2 \sum_{i=3}^{4} v_i(x_i) + a_2 \sum_{i=5}^{7} v_i(x_i) \tag{5}$$

In equation (5), b_k represents the second layer of the hierarchy, but equation (5) must be generalized further to express the value function for the hierarchy in Figure 2.5:

$$V = \sum_{j=1}^{J} O_j \sum_{i=a_j}^{b_j} v_i(x_i) \qquad where \quad O_j = \prod_{k=1}^{J} a_{jk} \tag{6}$$

In equation (6), O_j represents the objective weighting, which is a product of the layer weights a_{jk} for each branch j and layer k, for each branch j of the hierarchy. As in equation (4), J refers to the number of groupings or branches, and a_j and b_j give the node locations (taken from a vector N of all nodes) within a given jth branch. This example provided a description of the methodologies used and developed in this dissertation. The remainder of this chapter covers these topics in greater detail.

2.4 Multi-Attribute Value Functions

MAVFs enable the researcher to evaluate and combine multiple attributes to arrive at an overall value function. This method develops a value function that provides the worth for every i attribute, $v_i(x)$. The evaluation results serve as the variable, x, which in conjunction with the aforementioned value function provides the specific worth associated with an attribute at its specific level of performance, x. This approach can only use attributes based on a continuous, ratio scale. Many of the institutional attributes are not represented on a continuous, ratio scale; therefore, proxy variables are needed to capture these attributes. The use of proxy variables is a straightforward procedure and Keeney and Raiffa (1976) provide a detailed description of their use.

Value functions can only be used in situations involving no uncertainty; this situation corresponds directly to evaluating a new technology because the values for the attributes are often known with certainty. MAUFs that incorporate uncertainty can potentially be incorporated in the scheme here but this is not attempted in this research. In order to determine a MAVF, the analyst needs to decompose the multi-attribute function into single-attribute functions where every attribute is represented individually. The analyst can develop a simple additive function, the simplest method available, to combine these functions to form the MAVF.

Beinat (1997) presents the axiomatic foundation for value function theory. This reference is used to present many key points in conjunction with Keeney and Raiffa (1976) and French (1986). All of these references rely heavily upon measurement theory presented by

Krantz (1971). Based on axioms from Dyer and Sarin (1979) and French (1986), a measurable value function has two primary conditions:

Existence: a real-valued function v: A→$\Re$ is a representation of $\geq^*$, where $\geq^*$ is a preference relation, if $\forall$ $a,b,c,d, \in$ A, $a>b$,c$>d$:

$$ab \geq^* cd \leftrightarrow v(a) - v(b) \geq v(c) - v(d) \tag{7}$$

Which stated in words is given four objects or attributes (a, b, c, d) such that a is preferred to b and c is preferred to d. The strength of preference for a over b is either greater than or equal to the strength of preference of c over d. Thus, the value of a minus the value of b is equal to or greater than the value of c minus the value of d.

Uniqueness: two value functions, v and u, agree with the same preferences if and only if there exists $\boldsymbol{a} > 0$ and b such that:

$$u(x) = \boldsymbol{a}v(x) + b, \qquad \forall x \in X \tag{8}$$

Due to the uniqueness property, v has an interval scale. Thus, analysts are free to choose the origin and a common scale for each attribute within a value function.

In order to use an additive representation for a value function, the attributes must be *mutually preferentially independent*. To explain this, first consider *preferential independence*, which extends from the so-called *corresponding trade-offs condition* (Keeney and Raiffa, 1976). This condition states that given two attributes, x_1 and x_2, an increase of a in the value of x_2 is worth b units of x_1 regardless of the values for x_1, x_2, a and b. The extension to three or more attributes is straightforward.

> A set of X attributes is partitioned into two sets, X_I and $\underline{X}_I$. X_I is preferentially independent of $\underline{X}_I$ if $\forall\ x_I, x_I' \in X_I$, $(x_I, \underline{a}_I) \geq (x_I', \underline{a}_I)$ for some $\underline{a}_I \in X_I \rightarrow (x_I, \underline{b}_I) \geq (x_I', \underline{b}_I)$ for every $\underline{b}_I \in X_I$. The attributes $x_1,...,x_n$ are mutually preferentially independent if for every subset I of $\{1,...,n\}$ X_I is preferentially independent of its complement $\underline{X}_I$.(Beinat, 1997)

If the value functions for n attributes meet these requirements, then their additive value function takes the form:

$$v(x_1, x_2, ..., x_n) = \sum_{i=1}^{n} v_i(x_i) \qquad (9)$$

The assessment of any of the v_i cannot be made independent of other components, and any single v_i cannot be interpreted by itself (Sarin, 1990; Dyer and Sarin, 1979). This difficulty can be overcome when making a few more assumptions. Dyer and Sarin (1979) use the difference independence property to define their measurable additive value functions. In difference independence, the preference difference between two levels of a given attribute x_i is unaffected by the levels of all other attributes.

Measurable additive value function: If $X_1,...,X_n$ are mutually preferentially independent and X_I is difference independent of $\underline{X}_I$, i=1,...n, then there exist functions v_i: $X_i \rightarrow \Re$, i=1,...n, such that

$\forall\ x, y, k, z \in X$,:

$$xy \geq^* kz \leftrightarrow \sum_{i=1}^{n} v_i(x_i) - \sum_{i=1}^{n} v_i(y_i) \geq \sum_{i=1}^{n} v_i(k_i) - \sum_{i=1}^{n} v_i(z_i) \qquad (10)$$

where $x=(x_1,...,x_n)$, $y=(y_1,...,y_n)$, $k=(k_1,...,k_n)$, $z=(z_1,...,z_n)$ (Beinat, 1997).

Given four alternative sets of attribute levels (x, y, k, z) and n attributes, which are mutually preferentially independent and difference independent. Furthermore, the strength of preference for the x alternative over the y alternative is greater than or equal to the strength of preference for the k alternative over the z alternative. Value functions can be found for all attributes such that the sum of the values of the x alternative minus the sum of the values of the y alternative is equal to or greater than the sum of the values of the k alternative minus the sum of the values of the z alternative.

The measurable additive value functions allow an analyst to assess marginal value functions on single attributes regardless of the levels of the other attributes. Restated, if an attribute has a measurable value function, then the levels of all other attributes have no impact on its value, and this value function can be assessed without any regard for the other attributes that it may be combined with to form the overall additive value function. This is a significant finding because assessing more than two attributes at a time is virtually impossible for decision-makers using existing techniques. Furthermore, this finding allows for the separation of the problem into distinct groups or *leafs* (at the bottom most branching of the hierarchy, referring back to the example in section 2.3), where the leafs may contain a single attribute or collection of attributes. While this raises a topic of concern that needs to be addressed, namely the common scaling of values needed across the leafs, it lays the groundwork for discovering a solution as well; section 2.6.1 provides details on the problem and its solution, the universal scaling proxy.

Goicoechea, Hansen, and Duckstein (1982) outline a number of significant theoretical and practical difficulties associated with MAUF. These include the tedium of calculating the component utility functions and scaling constants, the lack of immediate feedback to the decision-maker of the implications of his preferences, and the absence of an efficient procedure to update the decision-maker's preferences and conduct sensitivity analysis. While not fully resolving all the concerns that arise, the technique developed in this dissertation specifically addresses many of them. The component value functions still must be calculated for each attribute; however, the calculation of the scaling constants has been simplified and reduced through the use of the Analytic Hierarchy Process (AHP) and universal scaling proxy. Furthermore, the universal scaling proxy allows the analyst to provide immediate feedback to the decision-makers. Finally, one needs to investigate the process of updating the preference structure in MAVF applications; however, this difficulty is diminished through the incorporation of the AHP and its hierarchical approach, which enables fairly efficient updating and sensitivity analyses. These must be considered significant improvements to overcome certain well-known difficulties in applying MAVF, which are mostly procedural difficulties rather than theoretical deficiencies.

2.4.1 *Value Function Assessment*

Many techniques exist for obtaining the value functions $v_i(x_i)$ for every attribute x_i and the corresponding weights between these value functions. Typically, an interview of a decision-maker, who could be an actor such as a representative of the agency involved in the project, or a funding agency project manager, or simply a user of the technology from interviewing a decision-maker, is used to accomplish this task. Beinat (1997) outlines several of these techniques. Almost all of which estimate the marginal value function for each attribute individually, then assess the weights for all attributes, and finally combine all of the attributes together into a multiattribute value function. Additionally, the assessor must select a range for each attribute. As mentioned in section 2.2, this requirement makes most of these techniques difficult to apply in the evaluation case, and the final solution becomes less meaningful. Beinat describes six techniques for assessing the marginal value function: direct value rating, curve selection, bisection, difference standard sequence, parameter estimation, and semantic judgment. Semantic judgment is not formally reviewed because it requires knowledge of all of the possible alternative scores for each attribute. Parameter estimation is excluded because it closely resembles the technique that is used in this research, except that only linear and exponential functional forms are permitted. The remaining four techniques are described next for completeness, though none of them are directly applicable to the research in this dissertation. The technique used in this research is described in section 2.4.3.

2.4.1.1 Direct Value Rating

This technique requires the decision-maker to specify the value attached to a score on a given attribute. The scores can be selected either by dividing into equal intervals, like the bisection and difference standard sequence methods (see below for further discussion), by selecting scores that have a clear interpretation for the assessor (Beinat, 1992), or by using the actual scores for each of the alternatives under consideration (Edwards *et al.*, 1988; Pliskin and

Beck, 1979). This technique can be difficult for decision-makers because the decision-maker must set a value with minimal reference points.

2.4.1.2 Curve Selection

In this technique, the analyst selects the value functions functional form and uses direct rating to fit the selected form. This technique is frequently used in conjunction with graphical software packages, which can make this approach very user-friendly; however, this technique does not guarantee that the functional form matches the one selected by the analyst. Finally, any attempts to verify the functional form can be influenced by the previously fit curve. This technique can still be used if employed with care.

2.4.1.3 Bisection or Mid-Value Splitting

This technique originates in Keeney and Raiffa (1976) as a simple technique for assessing a single value function. The decision-maker has to compare intervals and determine the midpoint at which both intervals are preferentially equivalent. This is done by defining the maximum attribute level, x_1, equal to 1 and the minimum attribute level, x_0, equal to 0, and then asking the decision-maker to find the mid-value of this range. The question is phrased in the following manner, "give me a value, $x_{.5}$, such that you would give up the same of amount of 'value' to go from x_0 to $x_{.5}$ and $x_{.5}$ to x_1."

$$v(x_1) - v(x_{.5}) = v(x_{.5}) - v(x_0) \tag{11}$$

The term $x_{.5}$ is known as the midvalue for the x_1 to x_0 interval and its value equals 0.5. Then, the decision-maker must select the midvalue of the two new regions that he or she just created (i.e. $v(x_{.25})$ and $v(x_{.75})$.) This technique is probably the most commonly used because it is fairly easy to apply and the analyst can continue to bisect regions when a curve appears particularly complex. Additionally, it is methodologically appealing due to reduced chance for bias if the questions are framed properly.

2.4.1.4 Difference Standard Technique

Similar to the bisection technique, the difference standard technique subdivides the score range into equal value spaced intervals. In this technique, the analysts must preselect the number of intervals and can not adapt during the process. Additionally, the assessment approach where the decision-maker identifies the predefined value points sequentially is sensitive to random error magnification. Once again this technique is very simple, but it fails to provide some of the flexibility observed in the bisection technique.

After completing the assessment of each of the value functions for every attribute, simple curve fitting must be used to complete the function from the point estimates. While the number of points necessary for a good interpolation varies with the complexity of the function, four points are frequently sufficient. The functional form of a value function can vary, but typically polynomial, exponential or logarithmic fitting should be used for simple curves. More complex forms may require a piecewise formulation. After completing all of the work on assessing the value functions, each attribute needs to receive its particular weight.

2.4.2 *Value Function Weight Determination*

Beinat (1997) covers weighting techniques in great detail. This weighting allows the decision-maker to prioritize the value of certain attributes over others. This research examines these techniques potential use in the upper-levels of the hierarchy as an alternative to AHP priorities. The five techniques that Beinat discusses, include swing weights, rating, pairwise comparison, trade-off, and qualitative translation. This study examines the first three; the rating and pairwise comparison techniques as well as a proposed technique are then applied.

2.4.2.1 Swing Weights

The swing technique (von Winterfeldt and Edwards, 1986) uses the value of swinging from one end of the pre-specified range to the other. To start this approach, all of the attribute scores, where the number of attributes is given by n, must be set at their lowest level. Then, the decision-maker must identify the attribute that provided the highest value increase when it moves to its maximum score. This attribute has the highest weight, and the pattern must be repeated until all of the attributes have been ordered. The numerical assessment typically assigns scores from 0 to 100 in a uniform distribution where the most important attribute receives 100 points, the second most important receives $100(n-1)/n$, the third receives $100(n-2)/n$, etc. This technique can be difficult to apply to qualitative attributes because the scores have to be swung from one extreme to the other. Under certain situations, some analysts have created special scales to address this situation and they have used this technique successfully. The uniform distribution of weights makes this technique fairly ad-hoc because two attributes that are very close to one another in degree of importance would have the same weight differential as two attributes that are very far apart in degree of importance if they were ordinally adjacent. Finally, the assessment of dissimilar attributes can cause problems because a decision-maker may not be able to make the required comparisons.

2.4.2.2 Weight Rating

This technique does not require the decision-maker to explicitly consider the range of scores for each attribute. The decision-maker simply prioritizes each attribute and finds their numerical rating. The ratio approach to numerical rating attaches a unit weight to the least important attribute and the other attributes are compared against this reference attribute (von Winterfeldt and Edwards, 1986). Alternatively, the decision-maker can distribute 100 points amongst all of the attributes (Nijkamp et al., 1990). While these techniques are widely used for their simplicity and intuitive appeal, their validity without reference to the attribute range remains questionable (Beinat, 1997).

2.4.2.3 Pairwise Comparison

The pairwise comparison approach refers to AHP's potential application to estimate weights for value functions. This is a rare situation that attempts to use AHP in conjunction with MAVF; however, the usage differs markedly from AHP's application in this dissertation. Beinat (1997) recommends adapting AHP to estimate ratios linked explicitly to ranges, for example by estimating the ratio of value increase corresponding to the swing of one attribute from its minimum to its maximum compared to another attribute swung from its minimum to maximum.

This approach is different from the scheme developed in this dissertation to combine AHP weights with MAVF because Beinat's scheme uses AHP with swing ranges, as opposed to hierarchically finding weights for grouping of attributes as in this dissertation. While this study applies the aforementioned scheme, it does not appear to be suitable for evaluation; however, it is included as a candidate technique for completeness and comparison to the AHP approach outlined in this dissertation.

2.4.3 *Candidate Techniques for Application*

An existing technique from Keeney and Raiffa (1976), conjoint-scaling, is selected for application for three primary reasons. First, the previously discussed techniques can not be applied to an evaluation problem unless the evaluator already knows the potential range of values for a given attribute prior to the evaluation (such as, what the maximum delay resulting from a new traffic control technique can be). Secondly, the research needs to fix all attributes with a true zero in order to create a ratio scale for the value functions. Lastly, the value functions should preferably be usable for more than one project as opposed to reassessing them every time. Using the lock-step procedure, a decision-maker compares two attributes with one another where increases or decreases in one attribute are traded off with increases or decreases in the other attribute. This procedure intertwines the scales of the two attributes because their values relate to each other; therefore, within a single value function, the quantity of a given attribute has no meaning unless it converted to its corresponding value. Even though one pair of attributes is considered at a time, a joint value function with a common scale can be established by taking the pairs in such a way that each pair has at least one attribute in common with at least one other pair, with no set of pairs being disjoint (unconnected) with its complementary set of pairs. As an example, if x_1, x_2, x_3, x_4, x_5, and x_6 form an additive value function together, comparison pairs can be (x_1, x_2), (x_1, x_3), (x_3, x_4), (x_3, x_5) and (x_4, x_6), but not a set of pairs as in (x_1, x_2), (x_1, x_3), (x_3, x_4), (x_5, x_6) as the last pair of the latter is disjoint from the rest of the variable. Note that only (n-1) comparisons are required for n attributes, to develop a value function, and that there is combinatorial explosion as the number of variables increase. Furthermore, the evaluator establishes the existence of the corresponding tradeoffs condition between two attributes while implementing this procedure. Once a sequence of questions are asked, it is a rather straight-forward procedure to find a few sample points of the value function, the function itself is then found using polynomial, exponential, or logarithmic curve fitting. These techniques are rather standard in MAVF schemes. Section 3.3 presents the assessment procedure in more detail and provides an example of the questioning format.

For the type of transportation evaluation problems addressed here, it is often impossible to find a joint value function across the numerous attributes. The addition of hierarchical weights to the value functions appears necessary because strict preferential independence does not hold. When the same attribute or value function appears in more than one branch, a decision-maker's preference can not be strictly independent of the same attribute under differing conditions. The inclusion of weights represents a technique for overcoming the difficulty associated with the analysis of a large number of attributes because often a single additive value function across all the attributes does not exist. Grouping the attributes and finding weights can be theoretically considered to be effectively equivalent to the development of a weighted additive value function. Thus, grouping the attributes and finding separate value functions for the logical groupings, and then combining the values from those groupings, is the method proposed to derive an overall value. These groupings may be based on factors, objectives, criteria, operational conditions, etc. Combining these grouped values can be achieved with direct input from the decision-maker on priority weights across groups. There is also a related issue that the values across multiple groupings should be based on a common scale. The next two sections describe how the research uses the AHP techniques and generic hierarchical approaches to combine the values, and the scheme developed to achieve a common scale.

2.5 Analytic Hierarchy Process

Although the MAVF technique is used to handle the values attached to subjective *attributes*, such as project delay due to project management or legal concerns, MAVF may fail to handle comparisons between subjective *factors*, such as no-event conditions and special event conditions. Therefore, this dissertation introduces a new approach where the AHP is used to incorporate the comparisons between factors such as objectives and criteria, elicited during the interview process. This yields an alternative method for assessing weights within the hierarchy. In this section AHP is discussed in detail, and the new approach to using it with MAVF is discussed in section 2.6.

Thomas Saaty introduced AHP in the mid-1970s (Saaty, 1977, 1980, 1994). Saaty bases AHP on three principles: decomposition, comparative judgments, and the synthesis of priorities. The decomposition principle requires that the problem needs to be broken down into a hierarchy. This hierarchy begins broad and becomes more specific as subsequent levels are needed. The relationship of the elements on different levels must conform to certain independence and dependence requirements. The principle of comparative judgments makes pairwise comparisons of elements within a level with respect to the next-higher level. These comparisons combine to form matrices. The synthesis of priorities principle constructs a composite set of priorities for the elements at the lowest level of the hierarchy. The hierarchies developed for the Anaheim FOT are shown in Figures 2.6 through 2.19. The hierarchies are self-explanatory and a detailed description appears unnecessary here. The main groupings are into institutional and technical performance attributes. One should notice that the bottom leafs show repetition of the same attributes under various conditions. This case study uses 238 total attributes, however due to the AHP-MAVF technique, the actual number of required value functions is only thirty-one.

Saaty designed AHP as a new measurement framework that captures peoples' values and perceptions. Saaty and Vargas (1982) use matrix theory and behavioral assumptions to form AHP's theoretical framework. If a decision maker compares a set of n objects (A_1,...A_n) in pairs according to their relative weights (w_1,...w_n), then these pairwise comparisons may be represented by a matrix of underlying ratios, or:

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{cccc} A_1 & A_2 & \cdots & A_n \\ \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{array} \qquad (12)$$

This matrix has positive entries everywhere and is a reciprocal matrix. If the matrix is multiplied by the column vector w, where w is (w_1,...w_n), a new vector nw can be created. Given the comparison matrix *A*, the analyst needs to determine the vector w to identify the weights of each object; therefore, he or she needs to solve the system $(A-nI)w = 0$ for w.

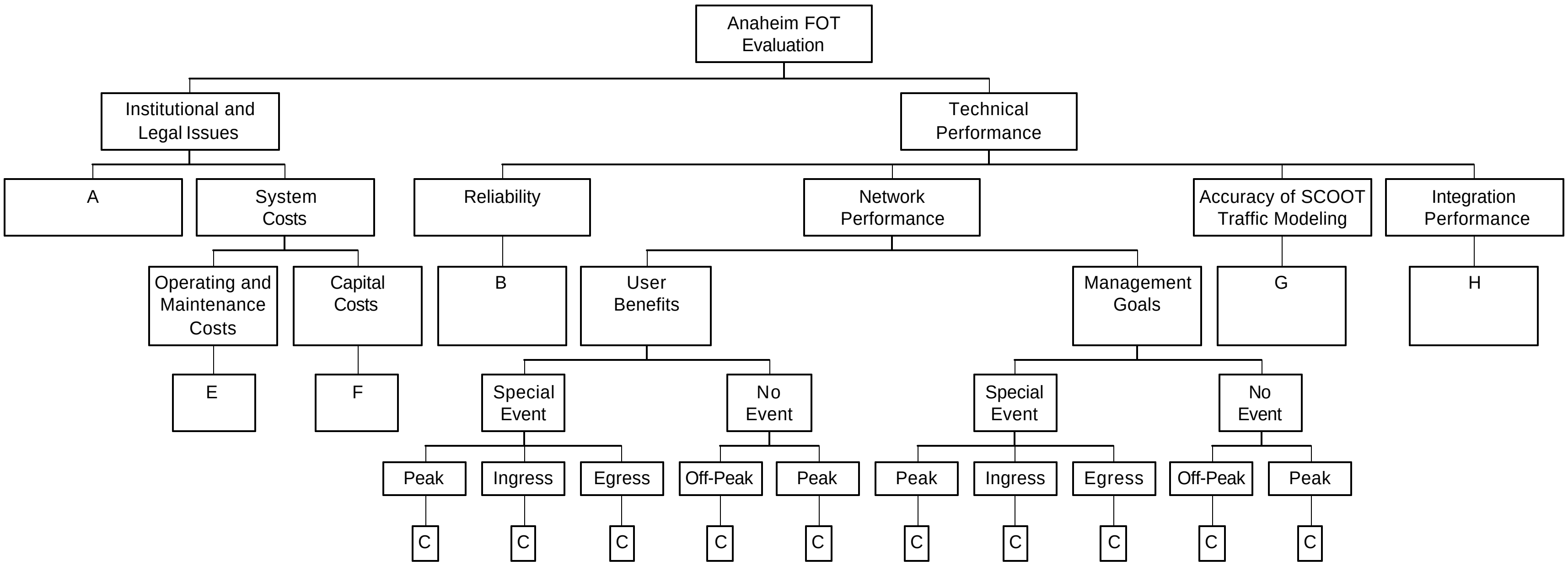

Figure 2.6. Anaheim FOT Hierarchy

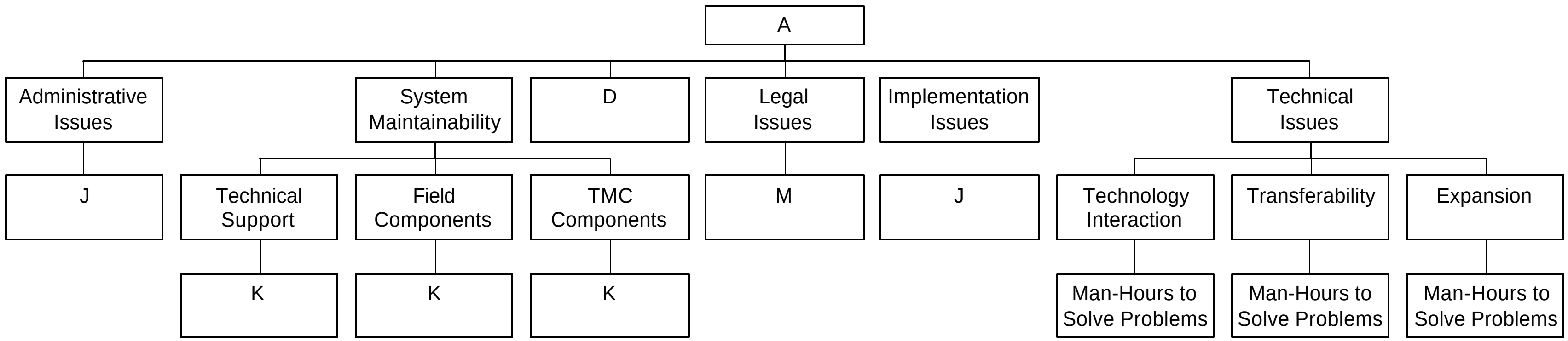

Figure 2.7. Institutional Issues

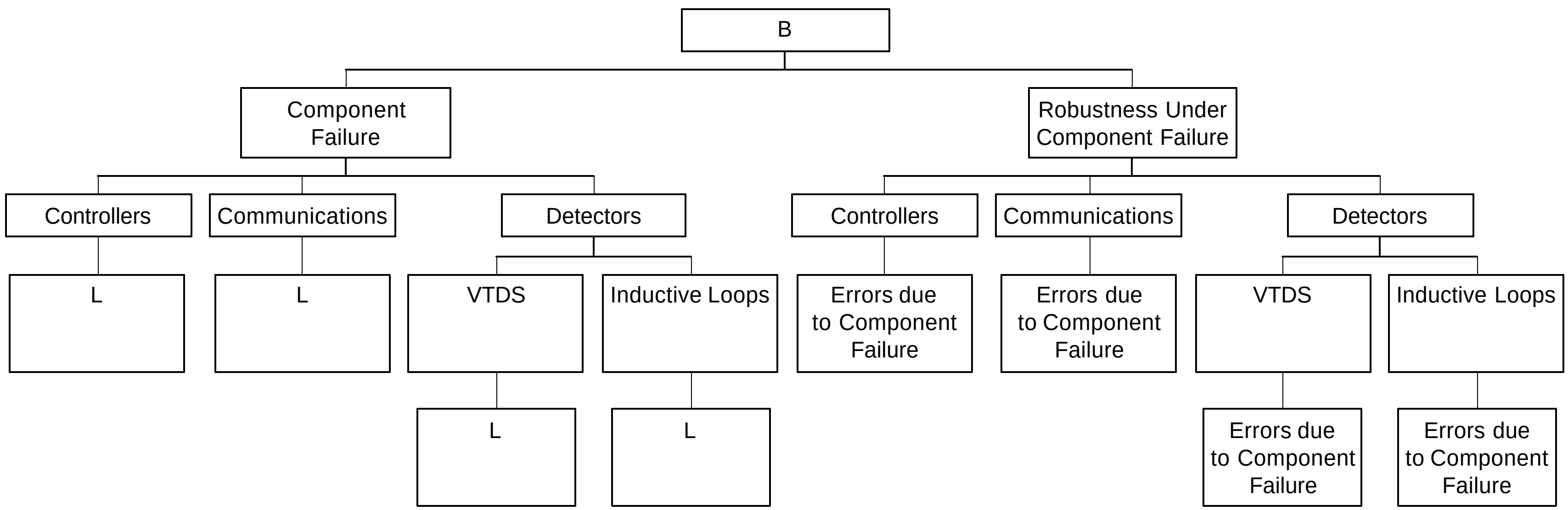

Figure 2.8. Reliability

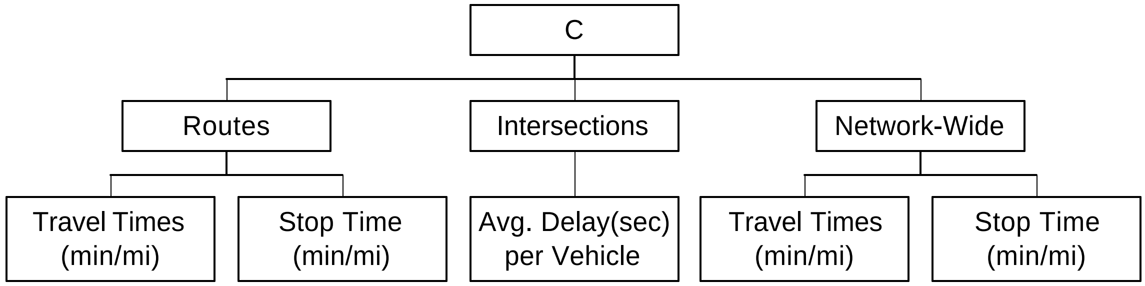

Figure 2.9. Traffic Network Performance

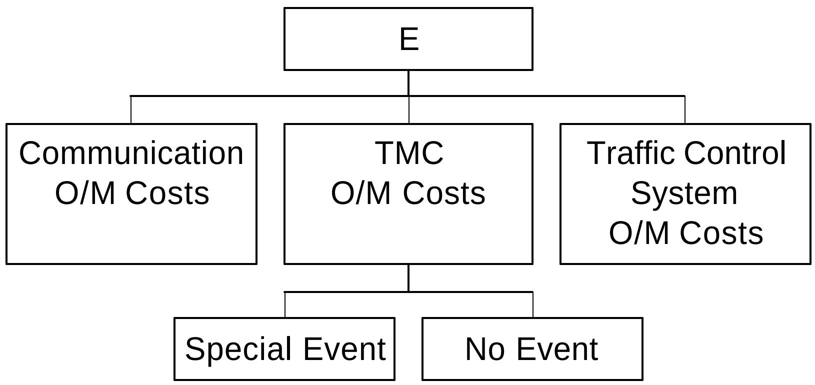

Figure 2.10. Operating and Maintenance Costs

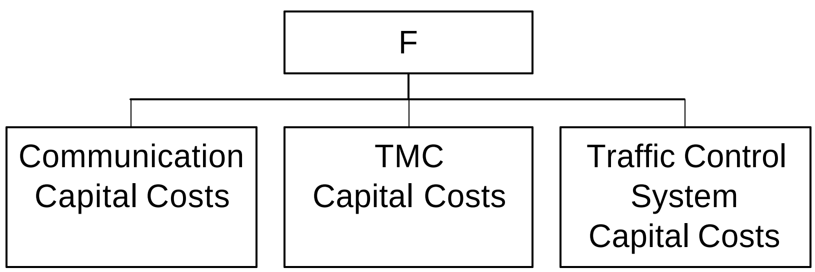

Figure 2.11. Capital Costs

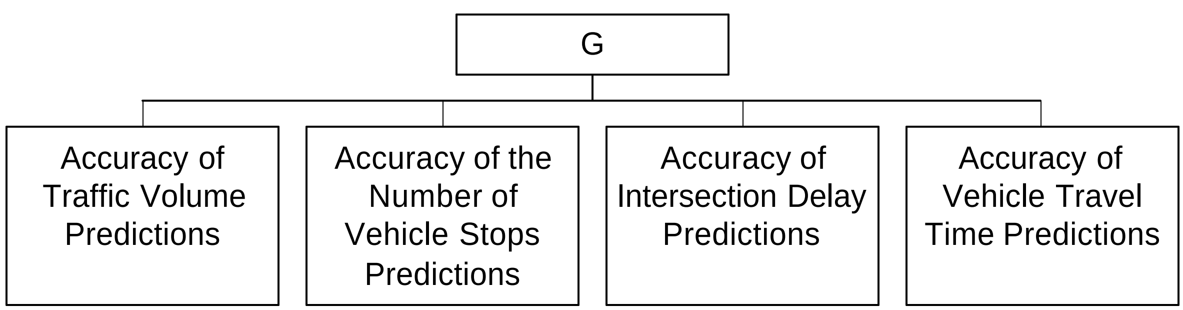

Figure 2.12. Accuracy of SCOOT Traffic Model

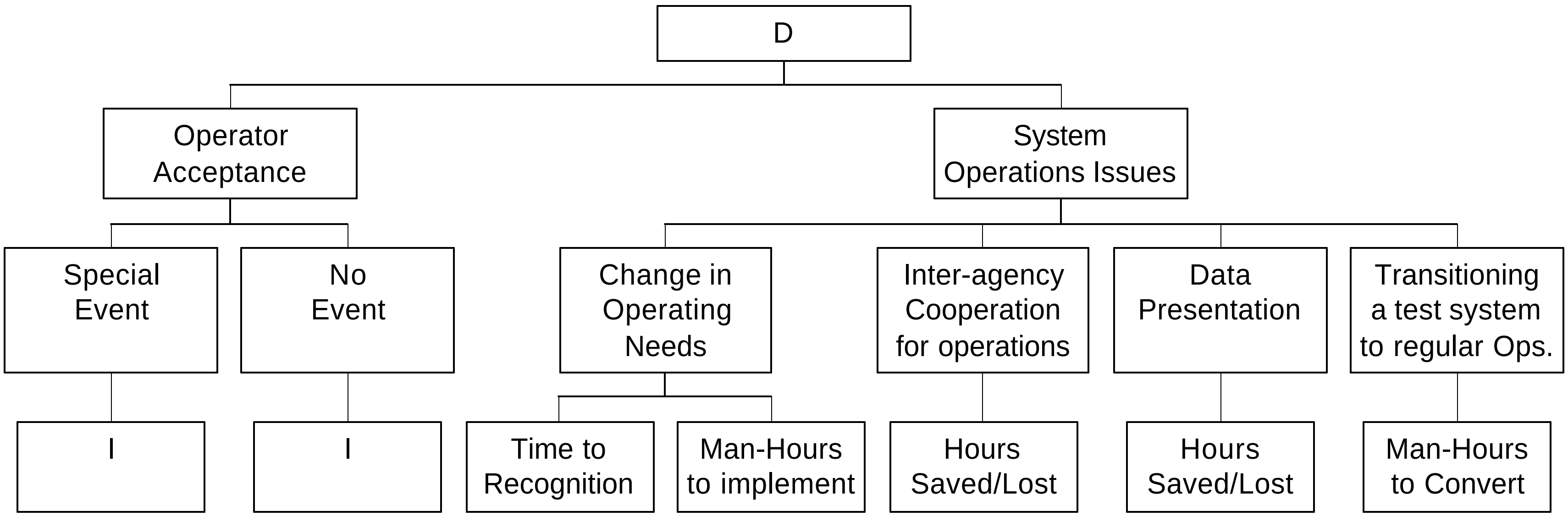

Figure 2.13. Operator Acceptance and System Operations Issues

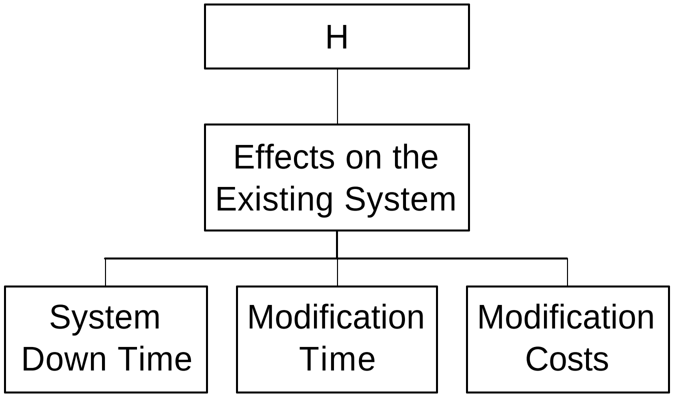

Figure 2.14. Integration Performance

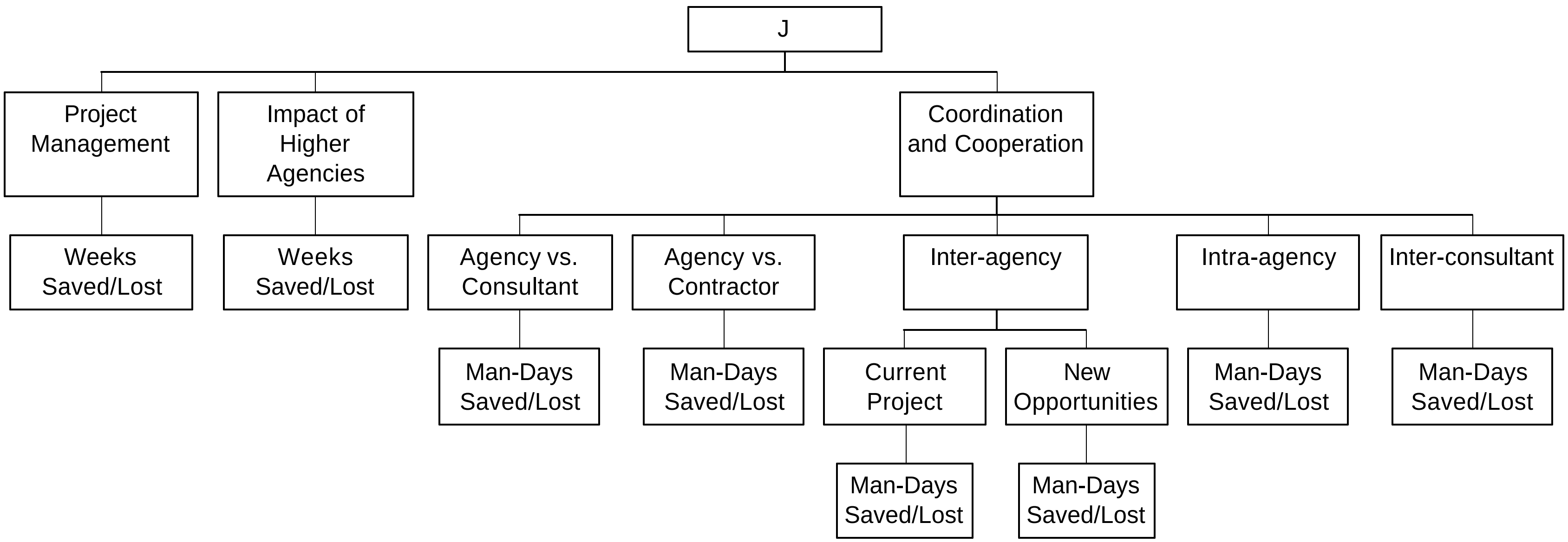

Figure 2.15. Administrative and Implementation Issues

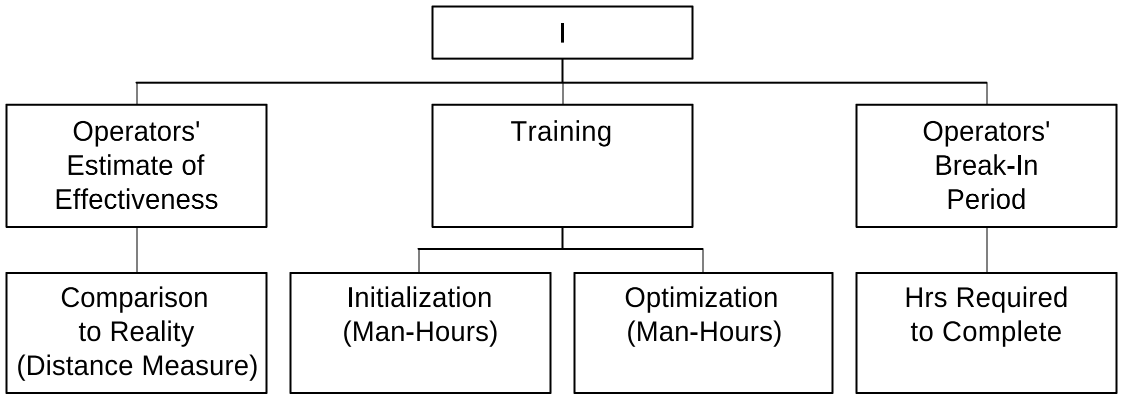

Figure 2.16. Operator Acceptance

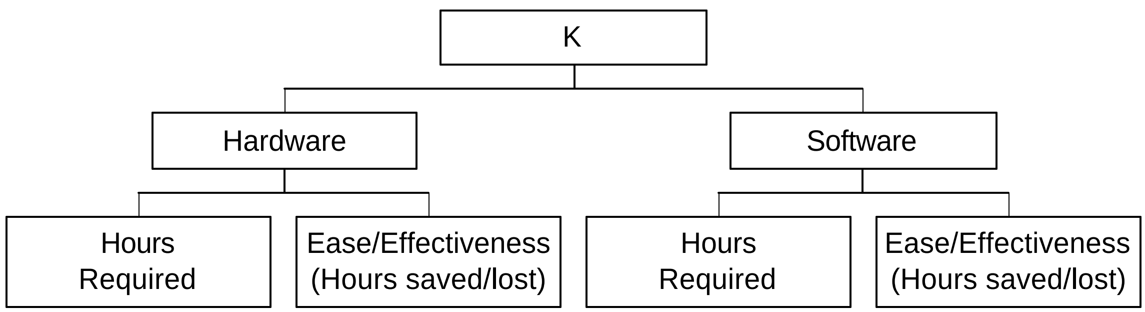

Figure 2.17. System Maintainability

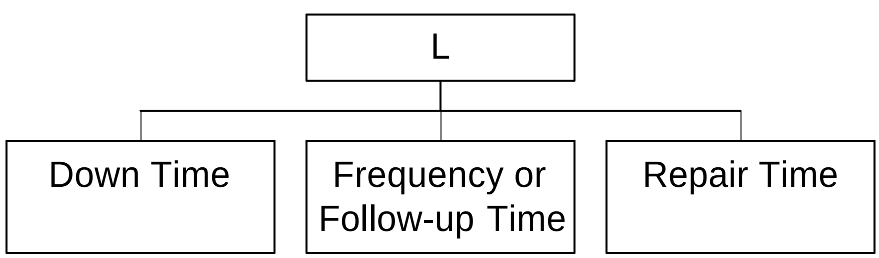

Figure 2.18. Component Failure

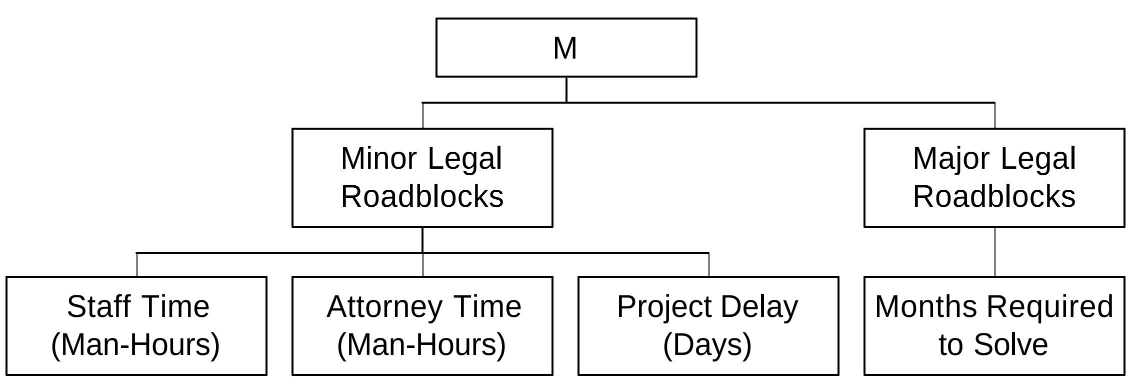

Figure 2.19. Legal Issues

This system has a nonzero solution if, and only if, n is an eigenvalue of A. Since A has unit rank, all of the eigenvalues, λ_i ($i = 1,...n$), of A are zero except one.

$$\sum_{i=1}^{n} l_i = tr(A) \equiv total \quad of \quad diagonal \quad elements = n \tag{13}$$

Therefore, a single λ_i known as λ_{max} is equal to n. If the decision-maker is completely consistent while providing the pairwise weights in the comparison matrix, this solution is given by any column of A (Saaty and Vargas, 1982). However, the AHP technique permits some inconsistency. Thus Saaty proves that in a positive reciprocal matrix, small perturbations in the coefficients imply small perturbations in the eigenvalues. Thus, the eigenvector is insensitive to small changes in judgment and is stable, relative to larger changes (Saaty, 1980). The result from these properties is that $Aw = nw$ becomes $A'w' = l_{max} w'$. In order to obtain a valid solution, l_{max} needs to approach n and w' needs to approach w. The closer these values are to one another the more consistent the matrix becomes. The measure of consistency allows that the ratio estimates in the matrix seem to be closer to a logical ordering than being a random distribution. If the matrix appears to be too inconsistent, then the decision-maker will have to reassign preferences. Thus, the reciprocal matrix A appears to be consistent if, and only if, l_{max} is equal to n. In all other cases of inconsistency, $l_{max} > n$.

Assume each row of the matrix either dominates or is dominated by every other row. Therefore, the rank ordering is preserved when solving the eigenvalue problem.

$$l_{\max} w_i = \sum_{k=1}^{n} a_{ik} w_k \geq \sum_{k=1}^{n} a_{jk} w_k = l_{\max} w_i \tag{14}$$

This relationship holds when consistency exists, but may or may not hold without it (Saaty and Vargas, 1982). In the case when a decision-maker is inconsistent, the aforementioned dominance is violated where some objects in the row are dominated while others are not. The rank ordering of alternatives can be preserved at a certain level of consistency. AHP provides a measure of the decision-maker's judgment, which checks if the elicited preferential information follows the reciprocal requirement. Saaty refers to this measure as the consistency index, C.I., defined as:

$$C.I. = m \equiv \frac{l_{\max} - n}{n-1} = \frac{-\sum_{i=2}^{n} l_i}{n-1} \tag{15}$$

Saaty (1980) approximates the Random Indices (R.I.) for various matrix sizes in Table 2.2 using simulation. In this simulation, matrices were populated with random numbers. The R.I. values in Table 2.2 are the C.I. values for these random matrices; therefore, they represent a worst case possibility for consistency. Given matrix's consistency ratio (C.R.), which makes a comparison of the decision-maker's consistency to this worst case of random numbers, can be found by dividing C.I. by R.I. According to Saaty (1980), C.R. must be ten percent or less to be acceptable. If a decision-maker's responses fail the consistency test, then the analyst must re-question him or her until obtaining consistent responses.

Saaty and Vargas (1982) generalize the measurement of consistency to look at an entire hierarchy. The C.I. from each matrix is multiplied by the priority attached to that particular matrix and the results are summed over the entire hierarchy. This sum can be compared to the sum of the corresponding index obtained from multiplying the R.I. by their priorities. Let n_j, j =

1,2,...*h* be the number of elements in the *j*th level of the hierarchy. Let w_{ij} be the composite weight of the *i*th activity of the *j*th level, and let $\mu_{i,j+1}$ be the C.I. of all elements at the (*j*+1) level compared with respect to the *i*th activity of the *j*th level. The consistency index of a hierarchy is defined by:

$$C_H = \sum_{j=1}^{h} \sum_{i=1}^{n_{ij}} w_{ij} m_{i,j+1} \tag{16}$$

where w_{ij} = 1 for *j* = 1, and n_{ij} is the number of elements of the *j*th level. The random index of the hierarchy, CR_H, can be found by using the R.I. as opposed to the C.I.; the consistency ratio still needs to be within ten percent.

Table 2.2. Random Consistency Indices, R.I.

Size of Matrix	Random Consistency
1	.00
2	.00
3	.58
4	.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Saaty has devised a scale for use with AHP that helps the results from his qualitative judgments make sense. Saaty wants the subject to be aware of all gradations at the same time. After he examines the psychological experiments of Miller (1956), which found that an individual can not simultaneously compare more than seven objects, plus or minus two, Saaty selects the seven plus two, places a unit between each measure and introduces the nine-point scale in Table 2.3. AHP determines the local priorities for each level within a hierarchy by calculating the normalized principal eigenvector.

Table 2.3. AHP Importance Scale (Saaty, 1982)

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Weak importance of one element over another	Experience and judgment slightly favor one element over another
5	Strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation

In this dissertation, AHP provides a simple process for weighting portions of the hierarchy that can not be enumerated by data directly. AHP can not be used independent of other techniques for evaluation unless the only decision of importance is whether to continue use of the new system or to revert to the old system. This approach does not provide very valuable information to any of the parties involved. Additionally, this fails to address many of the benefits of using decision-theory for evaluation. While AHP is more cumbersome, than the standard weighting schemes used with MAVF, it allows the decision-maker to make "easy" qualitative assessments as opposed to quantitative assessments of priorities. Significantly different objectives may be difficult to quantitatively assess. In AHP, decision-makers are permitted to use judgments that are not strictly consistent as long as they maintain a modicum of variation from perfect consistency. Finally, the ability to easily assess consistency makes this technique even more appealing.

AHP represents one of the more popular forms of multicriteria decision-making. Some experts have expressed concerns about some features of AHP in the past, especially rank-reversal when new alternatives are introduced; however, the benefits that it provides to this research outweigh the negatives. As a quick example of rank-reversal, a decision-maker prefers to purchase a red bus over a blue bus and the blue bus over a yellow bus. When a new bus, green, becomes available, the decision-maker's preferences indicate the red bus over the yellow bus over the green bus over the blue bus. Rank reversal can occur in the evaluation case when changes are made to the overall hierarchy, but the hierarchy should remain stable for the evaluation and not be subject to rank-reversal concerns. Additionally, many experts have criticized the ad-hoc nature of the nine-point scale. This feature remains of greater concern for the evaluation case. The nine-point scale artificially creates a situation where one objective is preferred at least twice as much as another and typically three times or more. This is not a major concern when the matrix contains at least four objectives, but when there are fewer than four this can create significantly divergent priorities. This severity of this problem can be further reduced if the decision-maker standardizes the scale to represent the actual magnitude of his or her preferences. In the decision-making situation, the scale does not pose such a major problem because the result is simply an ordinal ranking of alternatives.

2.6 Integration of MAVF and AHP

In order to capture the effects of different components and different conditions, an integration of AHP and MAVF is devised that simplifies the overall valuation process through the use of a hierarchy and various weighting schemes. A hierarchical approach is selected because decision-makers may have preferences for one technology over another or stress one operating condition over another. MAVF uses scaling constants; however, these constants deal only with the interaction between attributes. The integration of AHP and MAVF allows the analyst to handle the interaction between attributes, objectives, technologies, and operating conditions. If the analyst wants to capture these effects using MAVF a separate value function must be found for each technology and operating condition, even when they have identical attributes. The proposed approach avoids this problem and simplifies the evaluator's tasks. This innovative process is described, and a testing procedure is proposed in the following sections. The discussion begins with a specific problem in finding MAVFs that needs to be addressed first before presenting the details on how AHP and MAVF are integrated.

2.6.1 *Universal scaling proxy for MAVF*

A significant scaling problem exists when combining multiple value functions. The techniques for generating an additive value function, the lock-step approach and mid-value splitting, identify a common scale for each attribute. While the common scale for mid-value splitting may be applicable to many attributes, the common scale for the lock-step approach is appropriate only for a given pair or group of attributes. An evaluation must combine multiple separate value functions at the bottom *leafs* of the AHP hierarchical tree structure with the

AHP-generated weights along the tree to derive a final value for the problem. Here, a leaf refers to a set of attributes with a separate joint value function at the bottom level of the hierarchy. Figures 2.6 through 2.19 show the hierarchy used in application to the Anaheim FOT. Note that a separate additive value function is found by combining the individual value functions of the set of attributes at each such leaf. For the *overall value* found over the whole tree to be reasonable, however, the value functions across these leafs should have a common scale. In order to create a standardized scale, the dissertation uses a *universal scaling proxy* (USP). A proxy attribute, the universal scaling proxy, is selected which has a linear relationship with the value structure created for each leaf (using pairwise comparisons and the lock-step approach described earlier). This proxy needs to possess an unusual characteristic where a decision-maker can select it to represent his or her intrinsic values. Within our society, money may be the only proxy that meets these criteria; therefore, for each leaf, the value function must be related to the *universal scaling proxy.* The USP will form a linear relationship with each leaf's value scale; therefore, one value point will equal a quantity *n* of the USP while two value points will equal 2*n* of the USP. After completing the lock-step procedure for two attributes, the analyst must use the universal scaling proxy to determine the value of each value point in this comparison. Furthermore, this technique provides an opportunity to provide another check for the assumptions required by the MAVF technique and to give the decision-maker some immediate feedback on the meaning of his or her responses. This is important because the lack of immediate feedback is one of the primary concerns regarding the use of multiattribute value functions.

To explain the scaling procedure, consider an attribute, travel time savings. Assume that we elicit an original value function from the decision-maker that shows one unit of value for five minutes of travel time savings. Assume that we then find the decision-maker to be indifferent between five minutes of travel time savings and two dollars. Then the transformation of the value function will be to multiply each value point by two. If a joint additive value function exists across a set of attributes, one of which is travel time savings, then each of the attributes can be transformed into its equivalent value of the scaling proxy. Thus the analyst accomplishes the transform using a proxy transform, p_i (which is equal to two in the example). Stating this more rigorously, based on the construction of an additive value function, the similarity transformation is identical for each attribute; therefore, the analyst only needs to find one *key* attribute (such as the travel time delay in the example) and its corresponding, proxy transform, p_{key}. After selecting a key attribute to use in the creation of the additive value function and determining that it can be assessed in terms of the USP, the analyst needs to identify the value for p_{key}. The analyst determines the value p_{key} by asking the decision-maker to determine an indifference relationship where he or she is indifferent between the two values, p_{key} and a.

$$p_{key} \sim a \qquad\qquad such \;\; that \qquad a = v_{key}^{-1}(1) \tag{17}$$

Where v_{key} is the value function for the key attribute, and v^{-1}_{key} (1) is the level of the key attribute where its value is equal to one. Using p_{key}, one can transform the original value function into a new value function, $v'_{key}(x_{key})$.

$$v'_{key}(x_{key}) = p_{key} * v_{key}(x_{key}) \tag{18}$$

Where v'_{key} is the value of the key attribute transformed into the USP. For example, a leaf exists with two attributes, running time (v_1) and stop time (v_2) where both are measured in minutes per mile. Their value functions are $v_1(x_1) = 5x_1$ and $v_2(x_2) = 8x_2$ where the value v_1 = 1 is equivalent to the value v_2 = 1. Stop time is selected as the key attribute; therefore, a value, p_{key}, for the proxy must be found such that the decision-maker is indifferent between it and .125 minutes per mile of stop time (this value is determined by setting v_2 = 1 and solving for x_2.) In this case, p_{key} is found to be \$100,000, thus, $v'_2(x_2) = 800{,}000x_2$ and $v'_1(x_1) = 500{,}000x_1$. After finding p_{key} and using equation 18, the analyst can transform the additive value function, $v(x_i)$, for a given leaf to its respective level of the USP. The generalized equation for this process appears below.

$$v'(x_1, x_2, \ldots, x_n) = p_{key} \sum_{i=1}^{n} v_i(x_i) \tag{19}$$

Where $v'(x_i)$ represents the transformed value function for a given leaf. The question arises whether such a common scaling proxy would always exist across all the additive value functions. In most cases, a dollar value comparison appears possible with at least one of the attributes in each attribute set, especially in the case of transportation evaluation problems (it is important to note that there is *no* requirement that a dollar-value comparison be possible with all attributes). This remains important because the dollar costing of some attributes, such as value of life, may prove difficult, and this technique will not have to specify them directly with a dollar amount. Below, a procedure outlines the integration of the re-scaled value functions into the hierarchical structure using AHP.

2.6.2 *Integration*

Once the MAVFs are found based on a universal scaling proxy and the AHP weights for the upper hierarchies are found, the MAVF and AHP schemes must be combined to determine the final function that represents the decision-makers' preferences. The technique uses MAVF to handle all of the attributes of the system at hierarchy's leaf level while AHP addresses the higher *branches*. A branch occurs at the separation of the hierarchy into two or more separate factors, such as institutional issues and technical performance and describes all of the components that comprise a single factor. When branches join together, a *junction* is formed. The hierarchical approach here allows the analyst to account for the decision-makers' preference structure without creating brand new value functions for every possible combination. Furthermore, all of the attributes may not be comparable to one another in pairwise comparisons; however, the universal scaling proxy allows the analyst to combine multiple distinct value functions. The value functions represent the principal role in evaluation because they establish a scale for comparing different types of data from the evaluation. The value functions retain their validity while receiving a weighting structure from AHP because the common scale created by the USP makes their integration possible.

The process begins with determination of the value function for each attribute and the application of the USP to every leaf. As an example, take the simple two-branch hierarchy shown in Figure 2.20. The value functions of the four attributes, running time (v_1), stop time (v_2), maintenance time (v_3), and operator time (v_4), are as follows: $v_1(x_1) = 5x_1$, $v_2(x_2) = 8x_2$,

$v_3\ (x_3) = .7x_3$, $v_4\ (x_4) = .4x_4$ (v_1 and v_2 are measured in minutes per mile and v_3 and v_4 are measured in hours). As part of specifying the value functions, the value $v_1 = 1$ is found to be equivalent to the value $v_2 = 1$ and that the value $v_3 = 1$ is found to be equivalent to the value $v_4 = 1$. The key attributes for each leaf are designated with an asterisk in the hierarchy and the corresponding p_{key} values are $p_2 = \$100,000$ and $p_3 = \$30$. Therefore, the transformed value functions take the following forms: $v_1\ (x_1) = 500,000x_1$, $v_2\ (x_2) = 800,000x_2$, $v_3\ (x_3) = 21x_3$, $v_4\ (x_4) = 12\ x_4$.

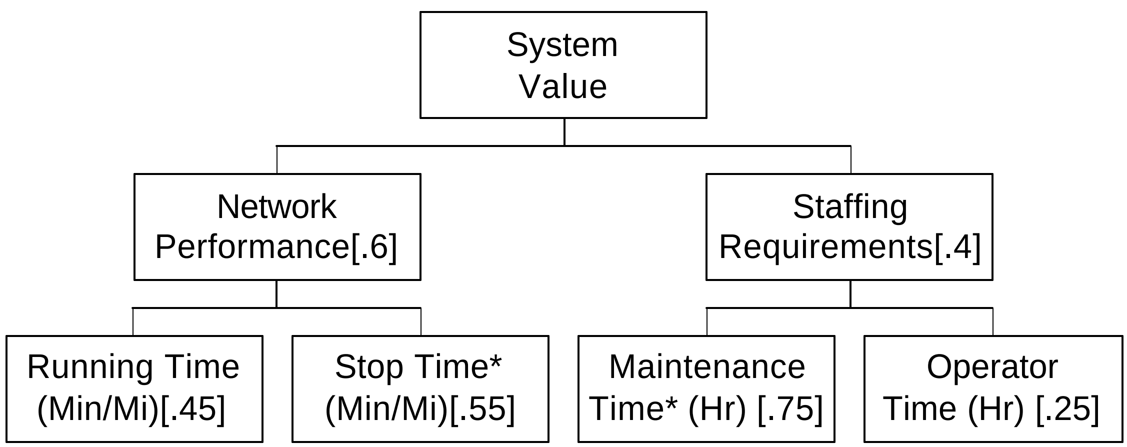

Figure 2.20. Example Two-Branch Hierarchy

After transforming each of the additive value functions at the leaf level, the analyst needs to perform the AHP analysis on the entire hierarchy. As a result of this analysis, the local weights, $\ell_{\alpha\beta n}$, at each junction within the tree can be calculated; these are shown on the hierarchy in brackets. This notation identifies a unique local weight by specifying its address, *a* gives the location of this node on the *n*th hierarchy level, where the hierarchy has *j* levels, and *b* gives the address of its predecessor node in the (n-1)th level. Through the use of AHP or similar hierarchical weighting strategy, the analyst determines the priorities for every objective. To provide a weighting structure for the attributes, the local weights must be combined to create the attribute priorities or weights, w_i. These attribute global weights, which have their formulation given in equation 20, must be multiplied with each leaf's value function. Given k objective priorities or weights (w_1, w_2, w_3,..., w_k) and the transformed value functions, v', for the leafs below each objective, the overall value function, v_{total}, is given in equation 21.

$$w_i = \prod_{n=2}^{j} \ell_{abn} \bullet \ell_{b*(n-1)} \qquad \textit{where * denotes any hierarchical address} \qquad (20)$$

$$v_{total} = \sum_{i=1}^{k} w_i (v_i') \qquad (21)$$

Where a and b are determined by the ith attribute's location in the hierarchy. Continuing the example, the global weight for w_1 is found by multiplying its local weight, 0.45, with the local weight for network performance, 0.6, weights for the other attributes, w_2, w_3, and w_4, are found in a similar manner. These weights are given as follows: w_1 = 0.27, w_2 = 0.33, w_3 = 0.3, and w_4 = 0.1. The v_{total} for the example is given in equation 22:

$$v_{total} = 135{,}000x_1 + 264{,}000x_2 + 6.3x_3 + 1.2x_4 \qquad (22)$$

2.7 Group Decision Theory

In the event that a study has multiple decision-makers, the researcher needs to settle on a suitable group decision-making technique to arrive at suitable preference information. All group decision-making techniques still require interaction between the decision-makers and the evaluator; however, in order to identify a consensus value function, the different decision-makers must interact. This interaction may occur through mathematical manipulation after identifying each individual's value function, or the group members may gather together to settle on a group value function.

Two ways to handle group decision-making techniques appear useful. First, final values are generated by a typical aggregation technique that combines each decision-maker's individual value function to form the group value function. In the second scheme, the final values are generated by a group forum technique for quantifying the group's preferences directly. The solution structure developed as part of this research can accommodate a hybridization of various group decision-making techniques. After settling on a common value structure, the weights for a given problem can be generated a variety of ways. The next section reviews a variety of group value function techniques.

2.7.1 *Value Function Assessment*

This section discusses some standard techniques from group MAVF that can be used to find group value functions. Approaches for assessment include both aggregating individual decision- maker value functions and directly assessing the group's value function.

2.7.1.1 Standard Approaches

Typically, the determination of the success or the failure of new technologies rests with multiple individuals. Additionally, each of these individuals might value specific attributes and objectives differently. Therefore, group value functions and aggregation techniques require examination. Using aggregation rules called *social welfare functions*, Arrow (1951) tried to determine a group value function that satisfies a set of "reasonable" individuals. This work, which is briefly discussed in the following paragraph, serves as a reference point for most subsequent collective choice research. Many group decision-making methods are built upon utility theory where utility-aggregate methods require identification of each group member's utility function. Past research (Kirkwood, 1972, 1974; Harsanyi, 1955, 1975; Keeney, 1976) proposes two preference aggregation models: an additive model and a multiplicative model. These models use scaling constants (parameters) to determine the weight of each individual utility function. The parameters are measured by requiring the group members to make explicit interpersonal preference comparisons. The final values of each parameter need to reflect the group's consensus. Bodily (1979) proposes a delegation process to determine a mutually satisfactory set of scaling constants. Brock (1980) uses a different approach to preference aggregation; in this approach, the parameter values equal the relative weight of the interests of the parties affected by the decision. This approach eliminates the need for interpersonal utility comparisons and computing weights. Krzysztofowicz (1979) critiques utility aggregation models and introduces an alternative approach. This model directly elicits the group utility function and does not require identification of individual utility functions. These approaches and others merit further consideration when considering group decision making for evaluation.

The key problem with all group decision-making ventures centers on Arrow's impossibility theorem, which is that no *social welfare function* (SWF) exhibits all of the following properties where a SWF is a collective choice rule that requires all group preferences to be orderings as well:

Property 1 – Complete Domain – The SWF includes every possible preference profile.

Property 2 – Independence of Irrelevant Alternatives – If the original set of alternatives is reduced in size and the preference relations for the remaining alternatives are held invariant, then the group ordering of the alternatives in the reduced set should be the same as it was in the original set.

Property 3 – Individual's sovereignty – For every two alternatives, a_1 and a_2, there is some preference profile such that the group prefers a_1 to a_2.

Property 4 – Nondictatorship – There is no individual *i* such that if individual *i* prefers a_j to a_k ($\forall a_j, a_k \in A$), then the group also prefers a_j to a_k.

Property 5 – Positive Association of Group and Individual Orderings – Assume that for a particular preference profile the group prefers a_1 to a_2. If this preference profile is modified such that (1) individual paired comparisons involving alternatives other than a_1 are not changed, and (2) individual paired comparisons involving a_1 remain unchanged or change in favor of a_1, then the group ordering still implies a_1 is preferred to a_2.

The most common approach to conquering this problem is to allow interpersonal comparisons, although many analysts (Thrall, Coombs, and Davis, 1954; Kirkwood, 1972, 1974; Harsanyi, 1955, 1975; Keeney, 1976; and Churchman and Ackoff, 1954) frequently generate value functions for every individual in a group. If the analyst chooses to generate each of these value functions, then time requirements increase by a magnitude equivalent to the number of group members (because generating each value function requires approximately the same amount of time.) Then, the analyst must combine these value functions to create the group value function, and this represents a highly controversial task. Experts are unable to agree on a single approach for combination because one of the key difficulties in combining different value functions is that every individual's personal value structure may differ greatly from one another. A USP is used in this research to mitigate these problems, but as this research observes it can not overcome all of the difficulties. Two different individuals may not view a dollar with the same intrinsic value. A multi-billionaire may not care about saving 100 dollars because this has little value to him whereas a blue collar worker may believe that a 100 dollar savings is extremely valuable. Without having the USP to compare between decision-makers, the problem becomes even more difficult because a common frame of reference for values does not exist. Unfortunately, previous research fails to indicate a straight-forward approach for remedying this problem; however, according to Beinat (1997), the body of research in value function aggregation seems to fall into two different camps, distance minimization and weighting schemes. Weighting schemes seem to be the more prevalent of the two approaches, but both merit investigations.

Four common weighting schemes exist, as well as a few somewhat less standard techniques. In all of these strategies, the people that make up the group contributing to the decision must be knowledgeable in the areas under investigation. In the simplest aggregation approach, the analyst simply weights each member's opinion identically. This technique, however, allows a value function that fails to agree with any of the members when a few decision-makers have significantly different value functions from the rest of the group. This research uses this technique to combine a sample of system users' value functions, and observes this disparity in individual value functions. Another criticism of the previously mentioned technique is that it fails to capture any differences in the expertise amongst the group's members. Alternatively, the group can set its own weights for its members. According to Keeney and Kirkwood (1975), is can be accomplished by using (at least) two different strategies. In the first, one individual, a *benevolent dictator*, can set each individual's weight; in the second, the members can agree to a satisfactory arrangement. In addition to sometimes selecting an inappropriate group value function like the equal weighting technique, this technique presents further difficulties. Most people rarely distribute power in a completely appropriate manner because they find it difficult to quantify the differences in importance between each member. Therefore, the members frequently ascribe equal weights to each of their peers.

Another less common approach effectively solves the two previously mentioned problems with identifying a group value function that does not agree with any of the participants and the unfair distribution of power. Its drawback is that it makes the overall process extremely difficult for decision-makers. (Especially, decision-makers that remain unfamiliar with value functions). Bodily's technique (1979) involves an iterative delegation process where one decision maker provides weights for the rest of the decision makers' value functions to construct his or her own value function. After the first decision-maker builds his or her value function, a new decision-maker constructs a value function using the same process. This iterative process continues until the value functions converge. Obviously, this approach requires a tremendous amount of effort.

The distance minimization schemes of Yu (1973), Cook and Seiford (1978) and Cook and Kress (1985) find the consensus solution of the group by minimizing a distance function among the individual utilities. These techniques reduce the group choice to an optimization problem. By relying on optimization, this approach eliminates the interpersonal difficulties of the weighting schemes, but it exacerbates the problems of having a value function that fails to meet any of the members' requirements. Additionally, the fact that these techniques focus on a solution makes them difficult to apply them to the evaluation problem.

2.7.1.2 Group Utility Model

Kryzysztofowicz's (1979) Group Utility Model allows the evaluator to develop the group value functions without any knowledge of the group members' individual value functions or explicit interpersonal comparisons of utility. Kryzysztofowicz assumes that the group-utility function is decomposable on the basis of attributes. Additionally, he assumes that the following definitions apply:

1. The pair (G,d) defines the *Group Decision Maker* (GDM) where G is the set of members constituting the group and d is the decision rule used by the group to arrive at collective decisions. For example, d could be debate and majority voting.

2. *Individual Value Judgment* is an individual's nondeceptive expression of preference at a specific time.

3. *Group Value Judgment* is the group expression of preference resulting from application of the decision rule, d. The group response does not need to agree with the response of any individual member of the group.

4. *Decision Setting*. The group is composed of experts who are able to arrive at a decision for any problem in a reasonable length of time. The experts may come from various disciplines, may possess heterogeneous beliefs, and may base their judgments on differing sets of information.

Furthermore, each group member and G behaves according to multiattribute utility axioms. Kryzysztofowicz proposes that using these assumptions, the group utility function, $W(\boldsymbol{x})$ is assessable. He recommends dividing the group into subgroups, G_i, that handle each attribute individually; however, the subgroups are not necessarily disjoint. He defines g_i as G_i's utility function on an attribute, x_i. Finally, he assumes that G_i's utility function on x_i is G's marginal utility function because the subgroup serves as the group's representatives.

This dissertation only examines the equal weighting technique as well as Kryzysztofowicz's Group Utility Model. The research examines these techniques in the context of generating a user value function. In the end neither scheme seemed to fare very well.

2.7.2 *Weight Assessment*

All approaches to group decision-making focus on combining the value functions of multiple individuals. The structure of the proposed technique allows for the selection of different group decision-making schemes for value function assessment as opposed to the hierarchical weights. The weighting techniques that section 2.4.2 discusses apply easily when determining the group hierarchical weights. Therefore, two rating techniques are used for identifying these priorities. Kryzysztofowicz's Group Utility Model is used to gather group priorities as part of this research. The research observes little difference between individual preference weights and a grouping of two individuals

2.8 Overall Valuation Analysis

Following the integration of the overall hierarchical structure with the value functions, the levels or quantities of each attribute are determined. In the case of an evaluation, the attribute levels vary with every different alternative scenario. This section discusses some of the key concerns as well as the assessment techniques that prove to be useful when performing an evaluation of new technologies.

As part of the evaluation, not only must the evaluator collect data for every attribute, but also data must be collected under all of the necessary conditions. Each scenario has its own overall worth that is independent of all other scenarios. For comparison's sake, all evaluations need a before study of current conditions. The results from this study form a baseline and the "do-nothing" alternative. The results from this study are applied to the appropriate value functions to determine the current benefits or value of the system. Then, the results from the other tested scenarios are applied to the appropriate value functions to determine the benefits for each alternate scenario. By comparing these values to the baseline benefits, changes in benefits from the baseline to the appropriate scenario are ascertained. These results provide a starting point for further analysis.

Generally speaking, following the completion of the evaluation, its results and value functions can use sensitivity analysis and other techniques to assess critical areas and possible solutions. For example, comparisons between the before and after benefits during specific traffic conditions will assist decision-makers in the formation of operating policy. Furthermore, hypothetical systems with small changes in the evaluation's data which assist to identify the benefits that an agency can expect if this goal is reached. Additionally, another agency can look at the results of the evaluation determine their own weighting structure and identify the critical areas of concern where they would want to improve the process. For example, if another agency wants to install SCOOT in their jurisdiction and they believe they can reduce TMC capital costs by $50,000, what overall benefit could they expect? If the decision-making panel wants to generate an entire suite of alternate evaluation results or operating policy alternatives, the evaluation team can calculate the benefits associated with each alternative.

Finally, the evaluator can use multiple hierarchy branches to hypothesize the values associated with recurring events. In the example of a new traffic control system, its effects on the performance of the network will continue to occur throughout its operating life, but its level of performance and its value may change over time. Each branch of the hierarchy can look at the performance of the system over a single year, but its overall worth needs to consider all of the years combined. Unfortunately, all of the attribute levels for future years must be forecast to use this approach. All of the implementation effects can be examined in a totally different branch of the hierarchy.

The overall worth analysis provides a powerful analysis tool that allows for basic comparisons between many varied alternatives. Basic comparisons are expanded to more complex involved comparisons in the next chapter. Unfortunately, all of the results that this section discusses thus far carry with them one significant factor; they rely on the preference structure of a pre-determined decision-making panel. Therefore, some results may not transfer to other agencies because the other agencies may not espouse the same value structure. If an agency simply varies in its priorities, these weights can be generated fairly easily. On the other hand, operating policies for the participating agencies should be easy to determine and extremely reliable. The overall worth analysis provides a method for examining and comparing alternatives.

CHAPTER 3
DATA COLLECTION

This chapter provides details on the procedures for collecting the data necessary for the application of the methodology that chapter two describes. This research presents the procedures used for collecting data, and the actual experiences associated with collecting the required data. The procedures developed for data collection include the formation of the hierarchy and conducting decision-maker interviews. A particular case, where the new methodology is applied to a specific case, is described in greater detail while a second trial application is considered and eliminated. The experiences associated with this application are presented, and recommendations for improvements in the data collection procedures are made.

3.1 Evaluation Framework

This research combines the methodology from chapter two into a framework that consists of three primary components: decision maker interview and aggregation, data collection and analysis, and overall valuation. Each of the three components relies on the others for the completion of a successful evaluation. Chapter two discussed the first and third components while the second component varies for each different measure. This chapter refers to a listing of stakeholders and their levels of involvement as well as a listing of objectives and measures of effectiveness. As part of the overall evaluation, the evaluator must decide which stakeholders he or she wants to include in the evaluation process. Different projects may use different stakeholders as the evaluator decides on what he or she wants to emphasize or what is feasible.

According to Papageorgiou (1991), the stakeholders that can be affected by a new control system can be categorized according to the following levels of involvement:

- individual level (directly affected)
  - private users (non-auto)
  - car drivers
  - entrepreneurs (paratransit, etc.)
  - emergency services
  - other transportation modes (public transit, etc.)
- public level (indirectly affected)
  - users of the network outside of the new control system.
  - local residents
  - local businesses
- institutional level (public domain)
  - road transport authorities
  - government and local administrations
  - international institutions
- industry level
  - vehicle manufacturers
  - traffic control equipment industry

The evaluator also must select the proper objectives and measures of effectiveness for any evaluation. The aforementioned objectives represent the objectives that chapter two discusses while measures of effectiveness provide the specific characteristics of an attribute that requires assessment. The identification of the appropriate measures is critical because they need to be readily understood by the decision-maker. Measures where either data describing the measure or decision-maker information is difficult to obtain are unsuitable for the methodologies that this dissertation describes and uses. Papageorgiou continues his discussion and provides a typical set of objectives and measures of effectiveness for evaluating a new control system:

- increase traffic safety

    - accident rate by severity and road type
    - fatalities and injuries per period of time
    - damage to vehicles, infrastructure and buildings
- improve transport efficiency
    - travel time savings for private users
    - travel time savings for commercial transportation
    - travel time savings for public transportation
- reduce energy consumption
    - fuel consumption per kilometer
    - fuel consumption by motor vehicle
- improve environment
    - vehicle exhaust emission rate per component (CO, NO_x, particulates, etc.)
    - vehicle noise emission levels per environment type
    - urban qualities
    - visual barriers
- improve driver comfort
    - travel information density per road type
    - stress frequencies per traffic situation and road type
- reduce costs
    - monetary costs of investment and operation for infrastructure
    - monetary costs for operation of traffic control systems
    - monetary costs for on-board equipment

Before the evaluator can begin work on any of the specific components, the project's objectives must be investigated. These objectives indicate some of the important issues for the project or proposal developer, usually one of the primary decision-makers. If the analyst remains unsure about any of these critical issues, there may be a need to talk to the primary decision-maker to clarify the situation before proceeding. After the evaluator thoroughly investigates the project's background or proposal, he or she can begin to formulate the specific goals and objectives required for the evaluation.

The evaluation plan needs to begin with the formulation of the evaluation goals and objectives. Certain measures or attributes combine to form an objective. As an example, the evaluator decides that an objective should be maximizing network performance. Then, the evaluator chooses the attributes, travel time and stop time, to measure this objective. Unfortunately, the importance of each of these attributes may differ between individuals. The evaluator can choose to select an arbitrary value for weighting these attributes based on his or her experience; however, this arbitrary assessment of each attribute's importance may fail to capture an agency's needs. Therefore, the analyst uses the methodology from chapter two to determine decision- maker preferences regarding the entire set of goals, objectives, and attributes. The rest of this chapter discusses some evaluation case studies, outlines a decision-maker interview, and covers the actual data collection for one of these case studies.

3.2 Evaluation Case Studies

While at the University of California, Irvine (UCI), the author participated in the evaluation of two Field Operational Tests (FOT)s in Orange County, California. The Anaheim Advanced Traffic Control System FOT focused on the implementation of SCOOT (Split, Cycle, and Offset Optimization Technique) arterial traffic control algorithm on top of the existing Urban Traffic Control System (UTCS). This FOT included a separate evaluation of a Video Traffic Detection System (VTDS) and an upgrade of UTCS to 1.5 Generation Control (GC) UTCS. The Irvine Integrated Ramp Metering/Adaptive Signal Control FOT included the integration of multiple technologies. The City of Irvine planned to implement the OPAC algorithm to control an arterial corridor in South Irvine that parallels a freeway. The City of Irvine wanted to use the Management Information System for Traffic (MIST) as their traffic management platform for this area. Additionally, Caltrans District 12 anticipated introducing the SWARM algorithms as their new ramp metering algorithms. This FOT included a separate evaluation of the 2070-Advanced Traffic Controller (ATC) where OPAC (Optimized Policies for Adaptive Control) will be installed. These FOTs provide the researcher with many technologies to investigate.

3.2.1 *Anaheim*

UC-Irvine in conjunction with the University of Southern California (USC) and California Polytechnic University - San Luis Obispo (CalPoly SLO) conducted a systematic evaluation of the performance and effectiveness of a FOT from fall 1994 through spring 1998 in the City of Anaheim, California. A consortium consisting of the California Department of Transportation (Caltrans), the City of Anaheim, and Odetics, Inc., a private sector provider of advanced technology systems, conducted the FOT with the City of Anaheim serving as the lead agency. The Federal Highway Administration (FHWA) provided cost-share funding for the FOT through the Intelligent Vehicle Highway System (IVHS) Field Operational Test Program. The FOT involves an integrated Advanced Transportation Management System (ATMS) which extends the capabilities of the existing arterial traffic management systems in the City of Anaheim. The evaluation entailed both a technical performance assessment and a comprehensive institutional analysis.

The arterial traffic control systems planned for implementation, 1.5GC and SCOOT, respectively, represent a partial automation of the existing UTCS control and the separate installation of an adaptive traffic control system as an independent control option. Since 1.5GC maintains the existing control system and algorithms, the key evaluation issue involves an assessment of the man-in-the-loop operational format more so than a direct assessment of technical feasibility. Similarly, SCOOT has been installed and evaluated in numerous locations throughout the world, thus, the key evaluation issues involve the limited implementation of SCOOT as an option of Anaheim Traffic Management Center operations, the development of operational policies for SCOOT operation, and the resultant operational effectiveness for defined scenarios (particularly for special events). While VTDS was implemented as part of this FOT, CalPoly SLO conducted its evaluation completely independent of all other technologies.

As with all tests, sometimes technologies fail to perform properly when tested. In this FOT, 1.5 GC never met the expectations of the city and had to be eliminated from the test because the City of Anaheim never used it to adjust its timing plans (please see chapter six for a thorough discussion on the institutional factors surrounding the 1.5 GC technology). Therefore, this case study focuses on a single technology, SCOOT; however, this study examines SCOOT under a variety of operating conditions. This study looks at SCOOT's performance during normal conditions (i.e. everyday operations with peak hour directional flows). SCOOT, however, also operates during special event conditions (i.e. before and after Anaheim Stadium events, especially baseball, and before and after Arrowhead Pond events, especially, concerts and ice hockey games). Distinct decision-makers may view SCOOT's effectiveness under each condition differently. For example, one decision maker may value SCOOT's performance during special events twice as much as SCOOT's efficiency during normal conditions while another values SCOOT's effectiveness during normal conditions three times as much as special event conditions. As a result, the decision-maker interview includes some assessments of these priorities because SCOOT needs to operate efficiently under more than one condition.

After thorough discussion with the City of Anaheim's Principal Traffic Engineer, John Thai, the author assembles a hierarchy for the Anaheim FOT evaluation, see Section 2.5 for the complete hierarchy. Table 3.1 lists all of the attributes, identifies the members of each leaf, provides a starting point for the interview process for the key attribute and identifies the value function question approach. The starting point is the arbitrary level of attribute that is equivalent to a value of one. Section 3.3 outlines three different questioning approaches: cost, benefit, and USP. When dealing with two or more attributes that represent costs to the system, the cost approach is used. If two attributes both represent benefits to the system, then the benefit approach is used. In the case where one attribute is a cost and the other a benefit, a hybridized approach can be applied. Finally, when a leaf has a single attribute, the USP technique is used so that the attribute's value function can be directly assessed with reference to the USP. The Anaheim evaluation is divided into two broad sections with Institutional and Legal Issues covering one category and Technical Performance representing the other. Table 3.2 provides the groupings of all of the objectives by identifying their predecessor as well as

Table 3.1. Anaheim FOT Attributes

Objective	Measure/Attribute	Starting Value	Question Type
Change in Operating Needs	Man-Hours to Implement	10	Cost
	Time to Recognition		

Inter-agency Cooperation for Operations*	Operating Staff Hours Saved or Lost	100	USP
System Data Presentation	Operating Staff Hours Saved or Lost	100	USP
Transitioning a test system to regular operations	Man-Hours to convert	100	USP
Legal Roadblocks- Minor	Staff Time (Man-Hours)	4	Cost
	Project Delay (Days)		
	Attorney Time (Man-Hours)		
Legal Roadblocks- Major	Project Delay (Months)	3	USP
Robustness under Component Failure*	Errors due to Component Failure (# of errors)	10	USP
Network Performance - Floating Car*	Stop Time (minutes/mile)	0.1→0.2	USP
	Travel Time (minutes/mile)	1→1.25	USP
Network Performance - Intersection Delay*	Average Delay per Vehicle (seconds)	5→20	USP
Training	Initialization (Man-Hours)	30	Benefits
	Optimization (Man-Hours)		
Operators' Estimate of Effectiveness	Comparison to Reality (Distance Measure)	N/A	USP
Operators' Break-In Period	Length of Break-In (months)	2	USP
All Operating, Maintenance and Capital Costs*	All Operating, Maintenance and Capital Costs	1,000	USP
Technology Interaction	Man-Hours to solve	10	USP
Expansion	Man-hours to solve	100	USP
Transferability	Man-Hours to solve	10	USP
Integration Performance: effects on the exist. system	Modification Costs	$5,000	Costs
	Modification Time		
	System Down-Time		

* - Recurring attributes

Table 3.1(cont'd) Anaheim FOT Attributes

Objective	Measure/Attribute	Starting Value	Question Type
Accuracy of SCOOT Traffic Model	Accuracy of: Vehicle Stops Predictions	N/A	Benefits
	Traffic Volume Predictions		
	Delay Predictions		
	Travel Time Predictions		
Project Management	Months saved/lost	2	USP
Impact of higher agencies	Months saved/lost	2	USP
Coordination and Cooperation	Man-days saved/lost	30	USP
Maintainability - Hardware*	Hours required	2	Costs
	Ease/Effectiveness (hours saved/lost)		
Maintainability - Software*	Hours required	2	Costs
	Ease/Effectiveness (hours saved/lost)		
Component Failure*	Downtime(hours)	2	Costs
	Frequency or Follow-up time(hours)		
	Repair Time(hours)		

* - Recurring attributes

the group that needs to be compared. The research includes interviews with three FOT participants: John Thai, City of Anaheim Principal Traffic Engineer, Richard Macaluso, Caltrans Office of New Technology, and Frank Chechini, FHWA California District ITS/Information Technology Engineer/Team Leader. Mr. Macaluso served as the contract manager (federal funds passed through Caltrans to the City of Anaheim). The interviews occurred during three different settings: Mr. Thai individually over a series of weeks, Mr. Macaluso individually over two intensive days, and Mr. Macaluso and Mr. Cechini together in one sitting.

Table 3.2. Anaheim FOT Objective Groupings

Predecessor Node	Objectives
Overall Evaluation	Institutional and legal issues, and Technical performance
Institutional and legal issues	Administrative issues, System operations issues, System maintainability, Technical issues, Legal issues, Implementation issues, Operator acceptance, and System costs
Technical performance	Reliability, Network performance, Accuracy of SCOOT traffic modeling, and Integration performance(effects on the existing system)
Administrative issues	Project management, Impact of higher agencies, and Coordination and cooperation
System operations issues	Change in operating needs, inter-agency cooperation for operations, data presentation, and transitioning a test system to regular operations
System maintainability	Technical support, Field components, and TMC components
Operator acceptance	Special event, and No-Event
System costs	Operating and maintenance costs, and Capital costs
Network performance	User benefits, and Management goals
Technical issues	Technology interaction, Transferability, and Expansion
Implementation issues	Project management, Impact of higher agencies, and Coordination and cooperation
User benefits - Special event	Ingress, and Egress
User benefits - No-Event	Off-peak, and Peak
Management goals - Special event	Ingress, and Egress
Management goals - No-Event	Off-peak, and Peak
Reliability	Component failure, and Robustness under component failure
Component failure	Controllers, Communications, and Detectors
Component failure - Detectors	VTDS, and Inductive loops
Operator acceptance- Special Event	Operators' estimate of effectiveness, Training, and Operators' break-in period
Operator acceptance- No-Event	Operators' estimate of effectiveness, Training, and Operators' break-in period

Table 3.2. (cont'd) Anaheim FOT Objective Groupings

Predecessor Node	Objectives
Component failure - Detectors	VTDS, and Inductive loops
Operator acceptance- Special Event	Operators' estimate of effectiveness, Training, and Operators' break-in period
Operator acceptance- No-Event	Operators' estimate of effectiveness, Training, and Operators' break-in period
Operating and maintenance (O/M) costs	Communication O/M costs, TMC O/M costs, and Traffic Control System O/M costs
TMC O/M costs	Special events, and No-Event
Network Performance	Routes, Intersections, and Network-wide
Routes	Route1, Route 2, Route, 3, and Route 4
Intersections	Ball/State College, Katella/State College, Cerritos/State College, Cerritos/Sunkist, Sunkist/Ball, and Katella/Howell
Capital Costs	Communication capital costs, TMC capital costs, and Traffic control system capital costs
Coordination and Cooperation	Agency vs. consultant, Agency vs. contractor, Inter-agency, Intra-agency, and Inter-consultant
Inter-agency	Current project and new opportunities
Robustness Under Component Failure	Errors due to Controller Failure, Errors due to Communications Failure, and Errors due to Detector Failure
Errors due to Detector Failure	VTDS and inductive loops
Legal Issues	Major and Minor
Technical support - System maintainability	Hardware and Software
Field components - System maintainability	Hardware and Software
TMC components - System maintainability	Hardware and Software

TMC - Traffic Management Center

Since Mr. Macaluso and Mr. Cechini served as administrators on the project and their residence in Sacramento limited the time available to interview them, their interviews focused on determining weights for the hierarchy. While the interviews focused on finding the hierarchical weights, time permitted the determination of a few of their value functions. While this effort was not comprehensive, it allowed some comparisons between the different points of view as well as facilitating comments on the entire process as opposed to just the weight determination procedures. Mr. Macaluso's individual interview examined all four value-weighting schemes as well as some value functions. The joint interview with Mr. Cechini and Mr. Macaluso looked at two of the weighting schemes, ratio weighting and 100-point. The joint interview proceeded fairly smoothly, and the decision-makers developed their own techniques for settling on a final decision. At times, Mr. Macaluso made the initial weight estimate while for others Mr. Cechini handled this role. Typically, the other participant then either agreed to this value or offered a quick rebuttal to express his preferences. The process required approximately the same amount of time as the individual procedure. In addition to the initial interviews with Mr. Cechini and Mr. Macaluso, there were also follow-up interviews and questionnaires.

The interviews with John Thai covered every aspect of the FOT and maintaining a traffic control system in the City of Anaheim. Prior to beginning the formal interviews, a tentative specific hierarchy and set of attributes was in place, developed in consultation with John Thai. However, throughout the process the hierarchy continued to be modified. Although the interview process began with a set of pre-selected starting values for identifying the decision-makers' value functions, these starting points had to be modified so that the tradeoffs had significant meaning for the decision-makers. Some of the attributes had to be skipped because the measures associated with them were too difficult to assess, specifically operators' estimate of effectiveness. The interviews with John Thai were limited to two to three hours per session; this seemed to be very appropriate because both Mr. Thai and the interviewer had difficulty remaining focused beyond this duration. Oftentimes, a value function would require extensive and repetitive examination because Mr. Thai had difficulty reaching consistency. Determining a multitude of value functions in succession can be quite tedious as observed in the interview with Mr. Macaluso as well as Mr. Thai; therefore, a procedure that interspersed weight selection with value function determination seemed much more satisfactory. Finally, the research has provided a detailed description of the insights and experiences gained during the course of this research regarding the interview process in Section 3.3.2. After each interview session, one of two questionnaires, single decision-maker and group decision-making, was distributed to the participant to get his feedback on the interview process and different techniques under investigation. These questionnaires, which are provided in Appendices A and B, form the basis of many of the comparisons between the various techniques.

3.2.2 *Irvine*

UCI in conjunction with USC and CalPoly SLO orchestrated the evaluation of the performance and effectiveness of an Integrated Ramp Metering/Adaptive Signal Control Field Operational Test (FOT) from fall 1994 through the end of 1998 in the City of Irvine, California. A consortium, consisting of the Caltrans, the City of Irvine, the National Engineering Technology Corporation (NET), a private sector provider of advanced technology systems, and PB-Farradyne, Inc., a private sector provider of advanced technology systems, conducted the FOT with the City of Irvine serving as the lead agency. The FHWA provided cost-share funding for the FOT through the Intelligent Vehicle Highway System (IVHS) Field Operational Test Program. The FOT involves integrated operations between Caltrans District 12 in Orange County, California, and the City of Irvine. The evaluation should have entailed both a technical performance assessment and a comprehensive institutional analysis, but it became only an institutional analysis.

As opposed to the Anaheim FOT, the Irvine FOT requires a large amount of software development to prepare the necessary technologies for deployment. The arterial traffic control system planned for implementation, OPAC, and its management system MIST represent an entirely new system for the City of Irvine. While on the freeway side, SWARM control evolves apart from the arterial system. After both independent systems function properly, the FOT plans to integrate the two individual systems.

This project's evaluation included multiple technologies. Since this project focused on the integration of these technologies, the evaluation needed to determine the efficiency of the interaction. The evaluation wanted to examine different combinations of new technologies under both recurrent and non-recurrent congestion. Additionally, the evaluation wanted to identify corridor-wide effects under different diversion strategies. The technologies involved in this evaluation included: OPAC compared to time-of-day traffic signal operations, SWARMS compared to time-of-day ramp metering, MIST compared to no MIST, District 12 ATMS compared to the old ATMS, and an Arterial Response Plan (ARP) compared to no ARP. Under ideal funding conditions, the researcher develops a test suite that combines the before and after case for each technology to create every possible combination. Unfortunately, ideal funding rarely exists; in this situation, the researcher attempts to isolate the effects of the different technologies by looking at them individually. Additionally, the entire system needs to be examined as an integrated system. In addition to the tests that compare alternatives, the evaluator needs to investigate the institutional issues associated with the project.

Unfortunately, the Irvine FOT failed to reach a satisfactory conclusion. At the end of the project, only the type 2070 detectors seemed to be ready for testing. All of the other technologies were at best in the beta testing stage. As a result, the entire technical portion of the test had to be eliminated. While the technique developed here is completely capable of assessing institutional issues by themselves, the conflicting points of view in this test made reaching a consensus on the appropriate levels of each attribute impossible.

3.3 Decision-Maker Interview

Creating the decision-maker interview allows the evaluator to begin to plot the evaluation's course. The evaluator needs to begin by carefully examining and investigating the project's goals and objectives. After this initial investigation, the evaluator must begin to determine the specific objectives and attributes that he or she wants to use for the evaluation. The analyst needs to provide the objectives and attributes with an overall structure by forming them into a hierarchy. These objectives and attributes form the evaluation's backbone; they need to address all of the aspects that impact the "successful" implementation of new technologies. While many of the objectives and attributes remain constant from one technology to another, each technology will require its own objectives and attributes. The technology's overall evaluation depends on the weights that the evaluator places on each attribute and objective. The evaluator must design a decision-maker interview to solicit their values regarding the affects and importance of each of the attributes and objectives. After identifying all of the objectives and their attributes, the analyst decides on the appropriate structure for the survey and begins its construction.

3.3.1 *Sample Questions*

This section briefly discusses a generalized interview format. This research uses numerous techniques in order to obtain a user-friendly technique.

3.3.1.1 Value Function Assessment

Only one approach is used for determining the value functions for each attribute, but multiple schemes are used for determining the weights for each attribute, based on MAVF and AHP theory. By combining the value functions and weights, the analyst determines the decision-makers' entire preference structure. The first question set uses the traditional conjoint scaling approach for MAVF preferences. First, the analyst needs to describe the two variables for comparison; "One of the axes will be - Travel-time in minutes per mile and the other stop time in minutes per mile." The reader should note that these attributes are costs as opposed to benefits and travel time is an extraordinary attribute where a wide range of quantities has approximately the same value. The analyst then proceeds with an entire battery of questions and statements. For example,

1. Given that the travel time on a certain route is 0 minutes/mile a stop time of 0 minutes/mile,

1a. (This question is peculiar to this attribute.) Since urban travel frequently occurs at low speeds, what range of travel times is functionally equivalent in value to 0 minutes/mile? *Response: 1.0 minute/mile.*

1b. Now, given the travel time on a certain route is 1.0 minute/mile with a stop time of 0 minutes/mile,

2. Now, consider that stop time on this route increases to 0.2 minutes/mile and travel time remains at 1.0 minute/mile. If stop time decreases from 0.2 minutes/mile to 0 min/mi, what increase in travel time would offset this gain? *Response: 1.1 minutes/mile.*

3. Now, consider travel time on the route is 1.1 minutes/mile and the stop time is 0.2 minutes/mile. If stop time decreases from 0.2 to 0.0 minutes/mile what new travel time would offset this gain? *Response: 1.37 minutes/mile.* If travel time decreased from 1.1 to 1.0 minutes/mile what level of stop time would offset this gain? *Response: 0.34 minutes/mile.*

4. Now, consider travel time on the route is still 1.1 minutes/mile, but the stop time is now 0.34 minutes/mile. If travel time decreased from 1.1 to 1.0 minutes/mile, what level of stop time would offset this gain? *Response: 0.43 minutes/mile.*

5. Now, consider travel time on the route is 1.37 minutes/mile and the stop time is 0.2 minutes/mile. If stop time decreases from 0.2 to 0.0 minutes/mile what new travel time would offset this gain? ? *Response: 1.49 minutes/mile.*

6. Etc.

7. Simple USP question: In dollars, what is the cost of stop time delay of 0.2 minutes/mile? *Response: $200,000.*

The reader should note that the value function that the previous approach creates is actually a negative value function. The more typical approach from decision-theory normally uses benefits and is similar in appearance, but uses increases. This example looks at two benefit attributes, accuracy of traffic volume predictions and accuracy of traffic volume predictions.

1. Given that the accuracy of the traffic volume and number of vehicle stops predictions are equal to zero,
2. Now, consider that the accuracy of the number of vehicle stops increases to 30 percent while traffic volume prediction accuracy remains at 0.0 percent. If the accuracy of the number of vehicle stops decreased from 30 to 0.0 percent, what increase in traffic volume prediction accuracy would be required to offset this loss? *Response: 35 percent.*
3. Now, consider that the accuracy of the number of vehicle stops is at 30 percent while traffic volume prediction accuracy is at 35 percent. If the accuracy of the number of vehicle stops decreased from 30 to 0.0 percent, what increase in traffic volume prediction accuracy would be required to offset this loss? *Response: 73 percent.* If traffic volume prediction accuracy decreased from 35 to 0.0 percent, what increase in the accuracy of the number of vehicle stops would be required to offset this loss? *Response: 65 percent.*
4. Now, the accuracy of the number of vehicle stops is still 30 percent, but traffic volume prediction accuracy is now 73 percent. If the accuracy of the number of vehicle stops decreased from 30 to 0.0, what increase in traffic volume prediction accuracy would be required to offset this loss? *Response: 79 percent*
5. Now, traffic volume prediction accuracy is still at 35 percent, but now the accuracy of the number of vehicle stops is at 65 percent. If you could decrease stop time from 35 to 0.0 percent what increase in the accuracy of the number of vehicle stops would be required to offset this loss? *76 percent*
6. Etc.
7. Simple USP question: In dollars, how much would you pay for the accuracy of the number of vehicle stops to equal 30 percent? *Response: $25,000*

When a leaf has a single attribute, the attribute must be directly compared to the USP. This series of questions addresses this approach. This example looks at the number of weeks that the project gained or lost through effective or ineffective project management

1. Given that number of project weeks required and money are equal to zero.
2. Now, consider that the number of project weeks required increases to 4 while the money required remains at 0. If you could decrease the number of project weeks from 4 to 0, how much would you be willing to pay? *Response: $3,000.*

3. Now, consider that the number of project weeks is at 4 while the money required is at $3,000. If you could decrease the number of project weeks from 4 to 0, how much would you be willing to pay? *Response: $5,500.* If you could decrease the amount of money required from $3,000 to 0, what delay would you be willing to accept? *Response: 6 weeks.*
4. Now, the number of project weeks is still at 4 but the money required is now at $5,500. If you could decrease the number of project weeks from 4 to 0, how much would you be willing to pay? *Response: $7,600.*
5. Now, the money required is still at $3,000, but the number of project weeks is now 6. If you could decrease the amount of money required from $3,000 to 0, what delay would you be willing to accept? *Response: 7 weeks.*
6. Etc.

3.3.1.2 Weighting the Hierarchy

The research examines four different weighting techniques, two of the rating variety and two involving AHP. In the first rating approach, the decision-maker first rank orders a given group of objectives and the analyst assigns a unit value to the least important attribute. Given a set of objectives that includes reliability, network performance, accuracy of SCOOT traffic modeling, and integration performance. A sample set of questions follows:

1. Rank-order the four objectives from least important to most important. *Response: accuracy of SCOOT traffic modeling, integration performance, reliability, and network performance.*
2. Now, assume that accuracy of SCOOT traffic modeling is of unit value. Compared to this value, how much more important is integration performance? *Response: 1.8.*
3. Etc.

Using the 100-point approach and the same set of objectives, the questions look entirely different.

1. Given a set of objectives that includes reliability, network performance, accuracy of SCOOT traffic modeling, and integration performance. Please distribute 100 points amongst these objectives with larger values denoting greater importance. You must use all 100 points. *Response: accuracy of SCOOT traffic modeling gets 10, integration performance gets 20, reliability gets 30, and network performance gets 40.*

The AHP approaches involve asking a great deal more questions of the decision-maker. Using the same set of objectives, the following sets of questions apply for standard AHP (see Table 2.3 for the provided scale).

1. Using the provided scale, how important is accuracy of SCOOT traffic modeling when compared to reliability with respect to technical performance? *Response: 1/4.*
2. Using the provided scale, how important is accuracy of SCOOT traffic modeling when compared to network performance with respect to technical performance? *Response: 1/7.*
3. Using the provided scale, how important is accuracy of SCOOT traffic modeling when compared to integration performance with respect to technical performance? *Response: 1/2.*
4. Using the provided scale, how important is reliability when compared to network performance with respect to technical performance? *Response: 2/3.*
5. Using the provided scale, how important is reliability when compared to integration performance with respect to technical performance? *Response: 4.*
6. Using the provided scale, how important is network performance when compared to integration performance with respect to technical performance? *Response: 5.*

The AHP approaches involve asking a great deal more questions of the decision-maker. Using the same set of objectives, the following sets of questions apply for pairwise AHP (see Table 2.3 for the provided scale).

1. Using the provided scale and the variability that you expect within these objectives, how important is moving the accuracy of SCOOT traffic modeling from its lowest to highest value when compared to moving the reliability from its lowest to highest value? *Response: 1/4.*
2. Using the provided scale and the variability that you expect within these objectives, how important is moving the accuracy of SCOOT traffic modeling from its lowest to highest value when compared to moving the network performance from its lowest to highest value? *Response: 1/6.*
3. Using the provided scale and the variability that you expect within these objectives, how important is moving the accuracy of SCOOT traffic modeling from its lowest to highest value when compared to moving the integration performance from its lowest to highest value? *Response: 1.*
4. Using the provided scale and the variability that you expect within these objectives, how important is moving the reliability from its lowest to highest value when compared to moving the network performance from its lowest to highest value? *Response: 1.*
5. Using the provided scale and the variability that you expect within these objectives, how important is reliability from its lowest to highest value when compared to moving the integration performance from its lowest to highest value? *Response: 5.*
6. Using the provided scale and the variability that you expect within these objectives, how important is moving the network performance from its lowest to highest value when compared to moving the integration performance from its lowest to highest value? *Response: 6.*

All of the weighting questions can be easily structured directly from the hierarchy.

3.3.2 *Procedural Comments and Experiences*

The overall procedure for successful completion of the decision-maker interview is quite complex and requires extensive interaction between the decision-maker and the analyst. A good rapport is required because the process needs to remain vital and interesting as well adaptable. Decision-makers need to recognize the importance of their responses and continue to search for their inner preferences throughout the interview; a good interviewer makes this easier for the decision-maker. Although an interview may only begin after careful thought and preparation by the analyst he or she must adapt to whatever circumstances arise during the interview process. These circumstances include confusion, improper construction of the hierarchy, insignificant initial values, and overall difficulty with the material.

Before constructing the actual decision-maker interview, the analyst must meet with the decision-maker to identify and organize all of the key attributes associated with the evaluation. The decision-maker and the analyst must select measures or metrics for each of these attributes. The evaluator can expedite and simplify this process by making an initial attempt to identify all of the previously mentioned requirements. This research found that this process required several iterations and meetings before a final hierarchy could be enumerated. Even after this endeavor, the hierarchy and attributes required additional modification during the actual decision-maker interviews.

Ideally, decision-maker interviews should take place early in the project to identify initial concerns and expectations. If need be, the results of this initial interview can be verified with a short follow-up interview at the end of the project, but this is not necessary. When scheduling interviews, the interviewer needs to be cognizant of the time requirements for the decision-makers. Obviously, the number of attributes has a huge effect on the length of the interview. This research found that enumerating a single value function required between fifteen minutes and an hour and a half with most needing about forty-five minutes. Determining the weights went much quicker; the time required to completely enumerate the entire hierarchy varied from thirty to sixty minutes. This research found that several shorter interviews seem to work well because the participants can remain focused on the process. Additionally, the decision-makers seemed to respond favorably to intermixing weighting questions between value function determination. This allowed them to answer some "easier" questions before returning to the "mentally-taxing" value function-related questions.

The decision-makers found the value functions more difficult for many reasons. Firstly, they did not always feel comfortable making *tradeoffs* between attributes. Secondly, oftentimes they struggled with the contextual setting of the tradeoffs. For example, they wanted to spend money to improve a process mid-stream whereas the evaluation must look at the entire length of the project when assigning values to a given attribute. Finally, they failed to comprehend the meaning of the questions and maintain consistency. The interviewer can reduce these difficulties by clarifying and providing examples of potential decision-making situations where tradeoffs could occur. Additionally, the interviewer must use the decision-maker's responses as a cue to identify when they fail to respond appropriately. Continuing the previously mentioned example, the decision maker responded, "I would spend x amount of money to stop this problem from continuing." An unconcerned interviewer might miss this cue and simply listen to the monetary response. This research found that decision-makers found it difficult to maintain consistency. Often, the interviewer might question them to try to ascertain the reasons for this inconsistency. This requires careful listening and the ability to locate the components that require adjustment. After careful inspection, these inconsistencies could be identified and corrected in all cases.

Although a simple computer program might appear to be more user-friendly, the previously identified ambiguities highlight the need for a personal interview. This research highlights a few additional factors that do not necessarily require personal interaction. Some of the decision-makers found visual aids helpful during the value function determination process. Throughout the entire interview, the decision-makers required definitions of specific objectives and attributes. When they were not in agreement or unsatisfied with the location of these components, the hierarchy had to be adjusted to meet their opinions. (For this dissertation, these changes were only made in accordance with the City Traffic Engineer's concerns). Although the interviewer selected an initial value for every attribute, at times these initial values were too insignificant to have any meaning for the decision-maker and they had to be adjusted.

During the group forum, the interviewer observed group dynamics in action as the two decision-makers shared the responsibilities for arriving at the final weights. The participants tended to share all responsibilities with each making the initial weight estimate while the other participant either agreed to this value or offered a quick rebuttal to express his preferences. Once again a good rapport amongst the decision-makers seemed critical. Personal disagreements could have created serious confrontations that might be difficult to resolve. Obviously, the evaluator needs to keep this in mind when he or she selects the group forum participants.

A laptop computer proved invaluable throughout the interview process because it enabled the interviewer to enter the responses directly into an Excel spreadsheet. Using this procedure reduced data reduction time after the interviews as well as provided an opportunity for the interviewer to provide feedback during the interview. Finally, any inconsistencies in the

AHP responses were readily identified and corrected. The interview process became easier as the process continued. Although the decision-makers continued to experience difficulties, the interviewer was able to readily adapt to the changing situations.

3.4 Additional Data Collection

While the decision-maker interviews represent the critical component of this research, the actual evaluation requires additional data sources. These data sources help provide levels for each of the attributes "before" and "after" implementation. The results collected during the actual field study can be used directly while the institutional portion of the evaluation help set the levels of many of the other attributes. The evaluators establish the appropriate levels of performance for many of the institutional attributes. While the evaluators amass a great deal of data related to the FOT, some attributes still have to be set through direct consultation with the City of Anaheim. This study set those levels following the completion of the decision-maker interviews. Some of the attributes represent recurring concerns, including inter-agency cooperation for operations, network performance, operating and maintenance costs, maintainability, reliability, and component failure. These attributes need to have performance levels estimated for them over the next ten years, and an appropriate discounting rate needs to be applied to this forecasted data. The next two sections go over the field data collection effort and the institutional data collection effort.

3.4.1 *Anaheim FOT Field Data*

The baseline or "before" case for the field data was Anaheim's UTCS fixed-time system. The Anaheim system also included enhanced off-line optimization tools consistent with a 1.5GC system; however, these 1.5 GC tools were not used in real-time due to computing constraints. Further, the City of Anaheim chose to not use 1.5 GC to update any of their timing plans prior to the evaluation. The City of Anaheim updated their timing plans during the FETSIM project approximately seven years before the SCOOT evaluation was conducted. Since the conclusion of the FETSIM project, the City has made some small adjustments to individual intersections based on citizen complaints and engineering judgment.

The evaluation team requested that the City of Anaheim would notify them of any changes in the baseline conditions before data collection efforts began, and that all timing plans to remain unchanged during the entire data collection period. The City of Anaheim appears to have complied with these requests.

The study was conducted over ten days on the dates shown in Table 3.3. These include five before SCOOT dates, and five after SCOOT dates. The field evaluation featured two different components, an intersection delay study and a travel time study.

Table 3.3. Data Collection Dates for the SCOOT Field Study

Tuesday **No-Event**	**Wednesday**[a] **Anaheim Pond Event**
Before (SCOOT) Study	
October 14, 1997 15:30 – 18:30, PM Peak	October 15, 1997 17:00 – 18:30, PM Peak

18:30 – 22:30, Evening Off-Peak	18:30 – 20:00, Ingress 20:00 – 22:00, Evening Off-Peak 22:00 – 23:00, Egress
October 21, 1997 15:30 – 18:30, PM Peak 18:30 – 22:30, Evening Off-Peal	October 22, 1997 17:00 – 18:30, PM Peak 18:30 – 20:00, Ingress 20:00 – 22:00, Evening Off-Peak 22:00 – 23:00, Egress
October 28, 1997 15:30 – 18:30, PM Peak 18:30 – 22:30, Evening Off-Peak	
After (SCOOT) Study	
November 4, 1997 15:30 – 18:30, PM Peak 18:30 – 22:30, Evening Off-Peak	
November 11, 1997 15:30 – 18:30, PM Peak 18:30 – 22:30, Evening Off-Peak	November 12, 1997 17:00 – 18:30, PM Peak 18:30 – 20:00, Ingress 20:00 – 22:00, Evening Off-Peak 22:00 – 23:00, Egress
November 18, 1997 15:30 – 18:30, PM Peak 18:30 – 22:30	November 19, 1997 17:00 – 18:30, PM Peak 18:30 – 20:00, Ingress 20:00 – 22:00, Evening Off-Peak 22:00 – 23:00, Egress

Notes: a. No PM distinction for intersection data on these dates – assumed to be part of ingress

The evaluation examined afternoon and evening activities in the Anaheim special event corridor. This time period was selected so that the evaluation could collect data related to standard special events at the Arrowhead Pond. The special event scenario remained extremely important to the City of Anaheim. The evaluation focused on three time periods for the special event scenario: p.m. peak, special event ingress, and special event egress. The no-event scenario collected data for the Off-peak and Peak periods.

3.4.1.1 Intersection Delay Study

The evaluation team selected six intersections in the SCOOT network and 1 or more intersections from 3 of the 4 SCOOT subareas appearing in Figure 3.1. The intersections included 2 arterial-to-arterial intersections, Katella/St. College and St. College/Ball, three collector-to-arterial intersections, Katella/Howell, Ball/Sunkist, and St. College/Cerritos, and one collector-to-collector intersection, Cerritos/Sunkist. The evaluation team held two data collection sessions at each intersection every night during the study period. For the non-event scenario, one session occurred during the PM peak and one occurred during the evening off-peak while the special event scenario focused its efforts on specific critical intersections during ingress and egress.

The objective of this portion of the test was measurement of queue lengths, total vehicle delay, and flows on intersection approaches. The evaluation team used hand-held electronic counters to monitor all vehicles stopped on intersection approaches, and to complete volume counts of all vehicles passing through the intersection on each approach. The delay study data collection included of two components, a team consisting of two people doing volume counts and a team consisting of four people doing intersection delay counts.

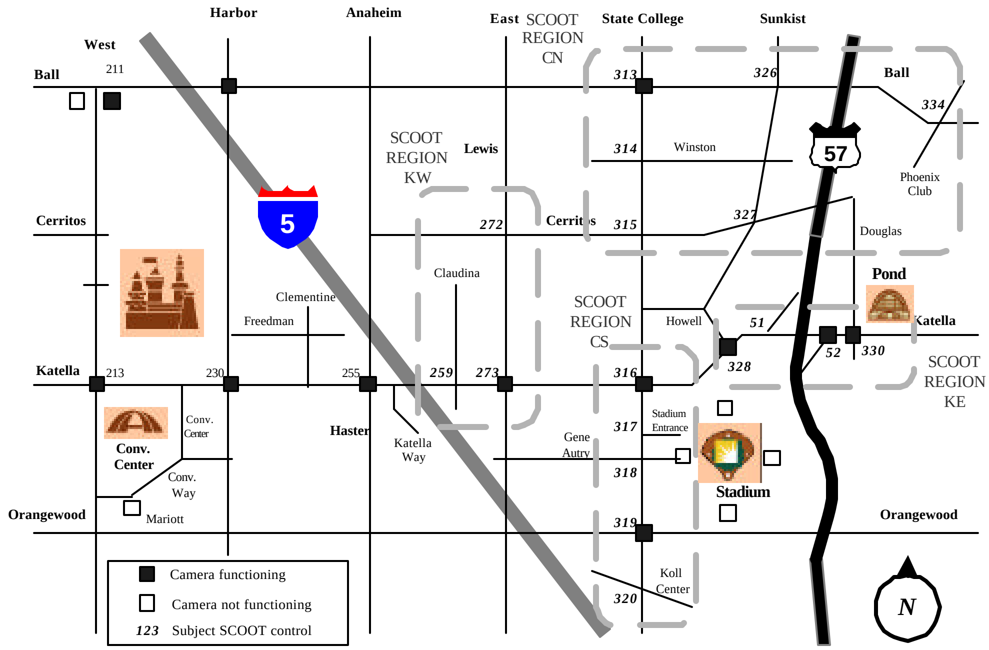

Figure 3.1. Anaheim FOT Network with SCOOT Regions

At each intersection, two members of the delay study team were responsible for counting the volume for each study interval, usually fifty minutes. The first person was positioned at the Northwest corner, and the second at the Southeast corner. The Northwest counter was responsible for all movements on the Eastbound and Southbound approaches. The Southeast counter was responsible for all movements on the Westbound and Northbound approaches. Volume counts were done using electronic JAMAR count boards. The JAMAR counters stored data in one-minute intervals. The evaluation team downloaded the boards (almost) daily.

In addition to the two volume counters, each intersection team included four delay counters. A delay counter stood at each approach counting vehicle delays. The delay counters recorded a numerical snapshot of the queue on the approach every fifteen seconds. Delay counters performed their counts during ten-minute study periods followed by two-minute breaks, recording their data on standard count sheets. The evaluation team compiled this data and entered it into Excel spreadsheets.

3.4.1.2 Travel Time Studies

A travel time study determined the time required to traverse a specific route. A typical travel time study used a test vehicle driven over a street section in a series of test runs. In this study, the test vehicle typically "floated" with traffic, driving at the speed of the average traffic flow. The study provided data such as a measure of vehicle hours and miles traveled through subareas of the network, including queue delays, stop delays, turn delays, and moving times.

The evaluation team used a floating car study that maximized the data collected relative to available collection resources. Floating car study teams consisted of a driver and an observer/navigator/recorder. The observer started his or her stopwatch at the beginning of each run, and recorded the arrival time at various control points along the route. Additionally, the observer used the stopwatch split function to record the length of individual stopped-time delays. The time, location, and the cause of these delays were recorded. The basic unit of observation in the floating car studies is time between control points. Each route includes multiple control points. This increases the number of available observations from which to draw variance estimates. Comparing conditions before and after deployment of SCOOT provides, at a minimum, an opportunity to identify changes in average travel times.

The drivers used their own cars. Only drivers with legal insurance coverage participated in the study. They signed a standard waiver to absolve the University of California at Irvine, the University of Southern California and the evaluation team from liability in the event of accident. Cars were deployed to assure coverage of key intersections where traffic conditions are representative and video resources were available. Test cars were used during ingress to and egress from events, and during nonevent conditions. The study included four different teams that covered four routes in the test area. These routes can be found in Appendix C.

3.4.2 *FOT Institutional Components*

Data required for the evaluation of institutional issues are substantively qualitative and thus may often be somewhat subjective. To minimize bias in the interpretation of the data, it is important to gather data from alternative sources to see if some consensus, if not still subjective conclusions, can be drawn. The first source of data came via direct observation of project participants, primarily at formal project meetings but also informally over the duration of the project. Formal meetings were documented in meeting minutes that were independently recorded and shared by the Project Manager and by members of the evaluation team. Finally, all key project participants were interviewed to gain their opinions on the progress of the FOT and on the relative role of institutional issues.

As part of the institutional evaluation, the evaluation team interviewed key project participants. The interview process began in January 1997, with final interviews and follow-ups occurring in June 1998. The decision was made to interview key individuals from all the agencies and firms that participated in the project, with the exception of participants from Odetics, since this firm was involved in only the VTDS component of the FOT and had minimal interactions with many other participants (an assessment of institutional aspects of this component of the FOT can be found in the Task C Final Report (MacCarley, 1998). For the Anaheim FOT, the individuals who were interviewed included participants from the City of Anaheim, JHK/Transcore, Siemens, Eagle Signal, Caltrans headquarters, and the FHWA. For the Irvine FOT, the individuals who were interviewed included participants from the City of Irvine, City of Los Angeles Department of Transportation, NET, PB-Farradyne, Caltrans District 12, Caltrans headquarters, and the FHWA. Additionally, the evaluators interviewed selected FHWA administrators in Washington to obtain a national view of the project. Under some circumstances, the evaluators conducted follow-up interviews to clarify certain concerns.

The interviews were structured on a series of questions common to each defined groups of participants (some questions were common between groups). These three groups were (1) high level administrative participants, (2) project management (key agency and firm participants), and (3) engineers and technicians. A single member of the evaluation team interviewed each person in these groups separately. During these interviews, an open format was utilized to encourage greater depth and breadth of discussion. Initial interviews averaged 1.5 to 2 hours. Copies of the questions are provided in Appendix D, however, please note that the respondent did not see the questions prior to or during the interview.

Brief summaries of background and project roles are provided for each interviewee in the next two sections while section 6.3 provides summaries of the interviews organized by general topics as defined by the predetermined questions. Several specific issues generated more intense, interrelated discussion; these issues are summarized as cross-cutting issues in section 6.3. Findings associated with the interviews are synthesized with other qualitative data in the chapter six summary of the overall findings for the institutional evaluation by project objective.

3.4.2.1 Anaheim FOT Participants

A brief description is provided of the roles played by key FOT participants who were interviewed.

1. Mike Freitas, Chief, Fleet and Rural Systems Branch, FHWA, manages the Booz-Allen & Hamilton contract for the FOT program. To provide evaluation assistance for the FOT evaluators, he instigated this contract in June 1994. He participated in some of the technical reviews of FOT proposals.

2. Alberto Santiago was Chief, Traffic Systems Branch, FHWA, but left for a position with National Highway Institute during the project. His involvement in the FOT program began in 1991 after the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) passed, and he participated in the evaluation of several FOT proposals. As a recognized ITS expert, he provided technical assistance to the national FOT program. His interest in the Anaheim FOT was driven by his expertise in traffic control, particularly in adaptive control. He expressed personal interest in this project, its interfaces, and the questions it hoped to answer.

3. Frank Cechini, ITS/Information Technology Engineer, FHWA, served as the FHWA project manager for the Anaheim FOT. As project manager, his role was to insure the completion of the FOT according to the stated goals and objectives and, most importantly, to insure the completion of an unbiased evaluation.

4. Richard Macaluso, Caltrans Office of New Technology, served as the contract manager (federal funds passed through Caltrans to the City of Anaheim). He also handled all of the technical reviews for Caltrans. His involvement with the FOT commenced in March 1994 when he assumed responsibilities to establish the initial contracts, handle invoicing issues, and manage budgets.

5. Jim Paral was Principal Traffic Engineer for the City of Anaheim from 1992 through November 1996 when he left the City for another opportunity. He was involved in virtually all stages of the evolution of the FOT. Originally hired in 1989 to manage the TMC, Paral worked under Don Dey, then Principal Traffic Engineer, and assumed that position when Dey himself left the City for another opportunity.

6. John Lower, Traffic and Transportation Manager for the City of Anaheim, initially served as the principal-in-charge for the FOT project, with Jim Paral reporting to him. Upon Mr. Paral's departure from the City in November 1996, Mr. Lower was named Project Manager by Gary Johnson, Anaheim's Director of Public Works. While he served as principal-in-charge, Mr. Lower spent most of his time on other City projects (including the I-5 widening and Disneyland expansion). As project manager, he was responsible for completing contractual extensions with Caltrans and contractual arrangements with Siemens.

7. John Thai, Principal Traffic Engineer for the City of Anaheim, joined the city in July 1997, filling the position vacated by Jim Paral in November 1996. He assumed responsibility for technical oversight for SCOOT implementation and operations.

8. Malcolm Slaughter, attorney for the City of Anaheim, advised the City on legal matters and on the Siemens contract, in particular. He represented the City in contractual matters, but was not concerned with technical issues and negotiations regarding SCOOT.

9. Chris Dahl, Associate Traffic Engineer for the City of Anaheim, handled equipment operations for the Anaheim FOT. He was in charge of traffic systems maintenance for the City, having worked for six years in this capacity.

10. Hoan Nguyen, a Systems Engineer for the City of Anaheim, was responsible for TMC maintenance and signal timing translation. The City has employed him since 1987 when the City established the TMC. He has a degree in electrical engineering.

11. Yo Baba, an Associate Traffic Engineer for the City of Anaheim, oversaw operations of the TMC during the FOT and assisted with administration and installation.

12. Mike Krueger served as Project Manager for JHK/Transcore, the contracted system manager for the City's traffic control system. He was responsible for the integration of SCOOT and UTCS and for the implementation of 1.5 Generation Control (1.5GC). From 1992 through February 1993, Alan Clelland had served in this capacity, and in October 1995, Glenn Havinoviski succeeded Krueger as project manager.

13. Glenn Havinoviski, JHK/Transcore, served as the overall system designer for the Anaheim FOT, responsible for system architecture and functional requirements. He worked on the project from July 1995 to February 1996 and was also responsible for identifying deficiencies and requirements for 1.5GC. After Glenn left, Teresa Squires assumed his technical role and Krueger re-assumed the Project Manager role.

14. Teresa Squires, JHK/Transcore, was the On-Call Support Manager for the City of Anaheim TMC, filling this position since 1992. For the FOT, she concentrated on testing 1.5 GC and integrating SCOOT into the existing system.

15. Tim Allan, Siemens, served as the Project Engineer for SCOOT implementation. His involvement began in November 1995 in the development of the Siemens proposal in response to the City's RFP. His formal duties included SCOOT equipment tendering, procurement, and installation, and SCOOT implementation, validation, and training.

16. Mark Hudgins served as the Project Manager for Eagle, Siemen's US-based affiliate. In the original 1992 FOT proposal, Odetics selected Mark as part of the VTDS team, but he was not involved in this capacity. In January 1997, Mark assumed responsibility for contract management for Eagle, working with Siemens on the SCOOT installation.

3.4.2.2 Irvine FOT Participants

1. Mike Freitas, Chief, Fleet and Rural Systems Branch, FHWA, manages the Booz-Allen & Hamilton contract for the FOT program. To provide evaluation assistance for the FOT evaluators, he instigated this contract in June 1994. He participated in some of the technical reviews of FOT proposals.

2. Alberto Santiago was Chief, Traffic Systems Branch, FHWA, but left for a position with National Highway Institute during the project. His involvement in the FOT program began in 1991 after ISTEA passed, and he participated in the evaluation of several FOT proposals. As a recognized ITS expert, he provided technical assistance to the national FOT program. His interest in the Anaheim FOT was driven by his expertise in traffic control, particularly in adaptive control. He expressed personal interest in this project, its interfaces, and the questions it hoped to answer.

3. Frank Cechini, ITS/Information Technology Engineer, FHWA, served as the FHWA project manager for the Anaheim FOT. As project manager, his role was to insure the completion of the FOT according to the stated goals and objectives and, most importantly, to insure the completion of an unbiased evaluation.

4. Richard Macaluso, Associate Transportation Engineer, Caltrans Office of New Technology, served as the PATH contract manager on this project as well as the contract manager for the City of Irvine. During the summer of 1994, Mr. Macaluso joined the project when he assumed responsibilities to establish the initial contracts, handle invoicing issues, and manage budgets. Prior to his involvement, Craig Denison represented Caltrans HQ's interests during the proposal development. He also handled all of the technical reviews for Caltrans following the resolution of all 2070 issues. Finally, Mr. Macaluso helped the City of Los Angeles, Caltrans and the City of Irvine agree on a memorandum of understanding, Caltrans paid $30,000 for the firmware.

5. John Thai, Principal Systems Engineer, City of Irvine, replaced Rob Hughes late in 1993 and began work on the second proposal update. Throughout the project, Mr. Thai served as the project manager and reviewed all, technical documents, coordinated activities with Caltrans New Technology and FHWA, coordinated consultant activities, managed budgets, worked with purchasing to issue RFPs, and protected the City's interests. He left the City of Irvine in July 1997, but he continued to serve as the project manager from July 1997 to June 1999 as a consultant.

6. Chau Nguyen, Senior Transportation Engineer, City of Irvine, assisted the consultants with all phases of implementation and provided support throughout the project. In March 1997, he replaced John Thai as the on-site supervisor regarding technical issues.

7. Barry Greenstein, Senior Civil Engineer, City of Irvine, accepted the role of City Transportation Engineer (provisional) when the City of Irvine lost a significant portion of their staff. In July 1997, Barry replaced John Thai in all administrative roles and acted as the administrative lead for the City of Irvine. In this role, he authorized payments to the consultants, and coordinated all efforts between PB-Farradyne and ITRAC.

8. Ed Khosravi, ITS Development Branch Chief, Caltrans District 12, began this project with a broader role for the District as Traffic Systems Development Branch Chief. He oversaw Caltrans involvement and met any needs arising from the FOT; he was in charge of all Caltrans FOT interests. He was involved in the original proposal development in 1992.

9. Tadeo Lau (Associate Transportation Electrical Engineer) served as the district coordinator or project engineer. He took this position in early 1997 and served the District 12 representative and primary point of contact for all other partners. Tadeo handled many roles within the District including, coordinating efforts between the City of Irvine and Caltrans to develop a MOU, worked with James A. regarding technical concerns, worked with NET regarding delivery of SWARM and some portions of ATMS, and worked with NET during SWARM software development. Tadeo replaced his predecessor because he had expertise with maintenance and 2070 controllers.

10. James Arceneaux, Associate Transportation Engineer, Caltrans District 12, was responsible for troubleshooting the data and database within the ATMS system and SWARM.

11. Phil Tarnoff filled an advisory role for PB-Farradyne during the Irvine FOT. He served as a trouble-shooter on the proposal, contracting problems, detector locations, and City of Irvine management. Phil recalled that the first mention of an integrated corridor project began in early 1990.

12. Teri Argabright, Vice President, Western Regional Manager, PB-Farradyne, was a Senior Supervising Engineer with PB-Farradyne at the beginning of the project. After the proposal process, Teri replaced Cheryl McConnell as the project manager for PB-Farradyne's work. She handled the scope, schedule, budget, and resources for Farradyne.

13. Arti Gupta, Lead Systems Engineer, PB-Farradyne, served as the deputy project manager and technical lead for the Irvine FOT. She did not have a background in transportation, instead he background was in statistics and operations research. Arti recalled joining the project in June of 1995. She looked after day to day operations and personnel resource management. Chris Tivoli and Arti wrote the requirements documents that covered system design (MIST/OPAC). As part of the system design effort, Arti determined the proper modules and functionality requirements for the system. Finally, she served as the liason between the City of Irvine and the software personnel.

14. Chris Tivoli, PB-Farradyne, served as the lead Software Engineer for ARP and MIST/OPAC in Irvine. Chris entered the project in June 1995 and replaced Mark Sinkavitch, currently with Trosted Systems in Gathersburg, MD. Chris defined requirements for PB-Farradyne, handled resource control and management, and directed six to eight programmers.

15. Mark McDermott, Senior Software Engineer, PB-Farradyne, authored the device driver software and served as the systems integrator for the Irvine FOT. Furthermore, he worked on both the hardware and software for the RS232 communications. Mark worked on the project for about one and a half years and no one filled his role prior to his participation in the project. Additionally, Mark only joined PB-Farradyne two years ago. When Mark started very little prior work existed for him to use as a foundation. Up to eight other people participated in bits and pieces of the overall system.

16. Chris Andrews, Senior Technical Specialist, PB-Farradyne, created an updated version of the OPAC algorithm by designing some minor changes. She verified the infrastructure, assured the quality control for OPAC's implementation, and lab tested the algorithm's interaction with TSCP. In 1987, Chris joined the company and worked on the enhancements to OPAC that extended it beyond two-phase operations. The FHWA provided the OPAC code to PB-Farradyne. As part of this project, she ran OPAC training, designed the OPAC parts of the acceptance test plan, and created the OPAC portions of the user/operations manual.

17. Jim Kerr, NET, served as project manager on the Irvine FOT. He handled all management issues before Carla joined the project. He was unable to participate in the interview process.

18. Jeneane Prince, NET, Joined NET after the project started. Her participation was limited in this project, and she was unable to participate in the interview process.

19. Carla Simone, Senior Transportation Systems Engineer, NET, served as the Deputy Project Manager for the Irvine FOT. She was on personal leave prior to joining the project in September 1995. She and Greg split most of the responsibilities after she joined the project; Greg handled the technical issues. She handled internal cost controls including status reports and adherence to schedule. Carla developed the transportation-related applications, such as response plans, coordinated the project with PB/Farradyne, and acted as the client partner liaison.

20. Greg Mosely, Chief Engineer, NET, served as the senior systems engineer for NET's work on the Irvine FOT. He filled in for Carla after she left the project on maternity leave. Greg joined the project a few months after its inception; he oversaw system development and design. Additionally, he insured that the requirements developed by Jim Kerr and Carla Simone were attained.

21. Sean Skehan, Transportation Engineer, City of Los Angeles Department of Transportation, served as a software developer for the Model 2070 controller. The City of Los Angeles was under contract to the City of Irvine to develop a software package for the Model 2070 controller. Sean wrote the local traffic signal control software used on Irvine's Model 2070 controllers.

22. George Chen, Transportation Engineering Associate, City of Los Angeles Department of Transportation, set up the communications between TSCP and OPAC algorithm. He made changes to TSCP to facilitate these communications and made additional changes to TSCP for the City of Irvine.

3.5 Data Reduction and Handling

Proper handling of the data associated with an evaluation can make the entire process run smoothly. Unfortunately, rarely can reduction occur without any mistakes. The decision-maker interviews, which are described in the next section, had few problems; however, the field study data posed many difficulties. Many of the mistakes that occurred are attributable to human error and thus could have been avoided.

3.5.1 *Decision-Maker Interviews*

Data reduction proceeded relatively easily for this data because all of the raw data was entered directly into a predesigned spreadsheet. While this predesigned spreadsheet had some initial flaws, these were easily corrected. The local and global weights were generated at every level of the hierarchy. Additionally, this research simply used polynomial curve fitting to generate the value functions. The data was formatted such that the value pertaining to each individual attribute as well as the value within each branch and level of the hierarchy could be readily obtained.

3.5.2 *Anaheim FOT Field Data*

The evaluation made extensive use of Excel spreadsheets to condense and organize the data for both the intersection delay study and the travel time study. The evaluation team encountered several SCOOT related problems during the after SCOOT study. The magnitude of the data was immense and created many difficulties trying to combine it into a useable database; however, all of these concerns were finally addressed. Unfortunately, other problems arose that affected the overall quality of the collected data. The next three sections outline many of these problems.

3.5.2.1 Problems Not Related to the Performance of SCOOT

On November 12, a special event day, an accident occurred on California Interstate 5 between State College and Katella. As a result of this accident, the entire network became saturated with traffic diverted from I-5. In addition, several small accidents occurred at other locations in the network during this time period. The traffic traveling southbound on State College became jammed from signal operations in the City of Santa Ana, and the jam extended back into the SCOOT network to locations North of Orangewood.

Rain problems occurred only once. Rain fell in the City of Anaheim on November 19. As a result, the evaluation team suspended data collection efforts from 8:00 PM until 10:00 PM. Data collection resumed in time to gather data on event egress, but the team had to eliminate four off-peak special event intersections from the study.

In general, the floating car teams seemed to have little difficulty after solving the problems associated with not being able to read a stopwatch at night. The teams used small flashlights or the map lights in their cars to provide the illumination needed to create records. During the after SCOOT study, one lane was blocked on one floating car route between Koll Center and Orangewood due to utility work. One of the floating car teams received two tickets from the Anaheim police for running red lights. After the second ticket, the driver was released from the study.

3.5.2.2 Problems Related to the Performance of SCOOT

Overall, problems reduced the available intersection data by about 50%, and completely eliminated some intersections from the non-event portion of the investigation. For the first three days of data collection after SCOOT operation began, SCOOT control was set to terminate at 7:30 PM. Why SCOOT was configured to cease control at this time is unclear. Since this was unexpected, unannounced, and not identified until after data collection had begun, this reduced the amount of off-peak data collected by the evaluation team.

Even more problematic, some SCOOT signals tended to accumulate communication faults throughout the after SCOOT period. Six intersections accumulated so many faults that SCOOT switched these signals to free operation, isolating them from SCOOT control. This occurred without announcement. Unlike the previous problem, this outcome was not a matter of a system setting defined as part of Siemens' SCOOT configuration. The accumulation of communication faults was unanticipated by all parties. As described in Section 1.3.4, this shift from SCOOT control to free operation was eventually identified by the USC graduate research assistant's comparison of the start-of-green times and queue clearance times reported by SCOOT's Node Fine Tuning Display to real time video images recorded in the Anaheim TMC. When the graduate research assistant identified inconsistent results, he referred to a list of SCOOT event driven messages, and found that these intersections were accumulating system fault messages. Once this discovery was made, the faults could be cleared, and with constant attention from a TMC operator, the signals could be maintained under SCOOT control.

Unfortunately, neither the evaluation team nor City of Anaheim personnel could determine when these changes occurred for the period prior to the discovery of system fault messages. As a result, the evaluation team decided to eliminate the use of all data from these six intersections prior to attempts to clear accumulated communication faults.

Finally, the SCOOT logs recorded additional periods during which SCOOT went off-line and signals scheduled for SCOOT control reverted to free operation. All of these problems could have been remedied if the City of Anaheim had acquired more experience with the SCOOT system before the evaluation began.

3.5.2.3 Resulting Constraints on Intersection Delay Study Data Reduction and Analysis

As noted in Section 3.4.1, the field study took place over a period of ten days. Each day, two intersection teams covered a total of twelve intersections, usually at fifty- minute intervals. Given the number of days and intersections, the data reduction process needed to post process and combine the data's volume and delay components was very time intensive.

Usually, after each day of data collection, a member of the evaluation team downloaded the intersection volume counts from the electronic JAMAR counters to PCs using the Petra software program. The Petra count files were then exported into an Excel spreadsheet. The spreadsheet consisted of movement counts for all approaches, as well as approach totals. All counts were recorded in one-minute intervals.

The delay count sheet data were also imported into formatted spreadsheets. These spreadsheets were electronic copies of the sheets the team members used for recording the delay counts. Each sheet had a series of the pages that recorded delays in fifteen-second intervals for ten-minute periods.

After inputting this data, the volume counts were added to the delay count spreadsheets. Since the field study used one-minute intervals for both the delay and volume counts, these data matched together easily. Matching volume counts with delay counts makes it possible to complete delay analysis, including the calculation of delay per vehicle, total stopped vehicles, percentage changes, and other quantities.

However, combining the volume counts and the delay counts to calculate delay per vehicle requires coordination between the volume counts and delay counts. The two teams needed to start and stop their counts at the same time. Unfortunately, this field coordination step was incomplete. As the data reduction/analysis took place, this lack of coordination became a significant hindrance. Problems included the following.

Start/Stop Discrepancies:

The two volume counters at the Northwest and Southeast intersection corners sometimes failed to communicate when starting and stopping counts. As a result, some sections of data (up to ten minutes per period at some intersections) were of no use because the intersection analysis required simultaneous data for all approaches. In addition to the lack of coordination between the volume counters, volume counters sometimes failed to communicate with delay counters, and delay counters sometimes failed to communicate with each other. This resulted in some additional data loss because intersection delay analysis requires both volume counts and corresponding delay data.

Time Discrepancies:

Some field team members failed to make sure that all field clocks, including JAMAR clocks and delay counter clocks, were synchronized. Consequently, if field team members did not communicate start and stop times, the evaluation team was sometimes unable to use the times recorded from unsynchronized clocks. This led to a further data loss.

<u>Extensive Breaks:</u>

As the analysis process continued, some of the field personnel became fatigued. Some of the delay counters took more than the instructed two-minute break between counts. The reduced the number of delay counts that could be matched with volume data, which was continuously recorded. When combined with start/stop discrepancies, these long breaks greatly reduced the useful data set.

These were all relatively simple errors that could have been avoided with better coordination between field team members. Fortunately, the evaluation team had pursued an over-sampling strategy, substituting addition data recorders for field supervisors, and the remaining data was sufficient to perform an adequate analysis. In addition to the field errors listed above, the evaluation team needed to establish a better data storage protocol in the earliest phases of the field study. Data was not always downloaded from JAMAR boards the same evening it was collected. The evaluation team also needed to more closely review the data as it was being collected. By doing so, some of the field errors could have been identified and problems resolved before errors propagated further. For future reference, the field evaluation teams should include a full-time data entry member at work from the beginning of the field study.

CHAPTER 4
ANAHEIM FOT EVALUATION RESULTS - THE CITY TRAFFIC ENGINEER'S POINT-OF-VIEW

4.1 Problem Presentation

The core of the Anaheim Field Operation Test (FOT) traffic control element is the real time integration of the SCOOT (Split Cycle Offset Optimization Technique) system into the Anaheim Transportation Management Center (TMC) and traffic control system. This integration makes possible adaptive optimization of traffic flow across subareas within the Anaheim network. The evaluation assesses SCOOT's implementation with an emphasis on its technical performance and institutional issues.

The City of Anaheim has a population of 300,000 and 150,000 jobs within a land area of nearly 50 square miles. Four major event centers and 15,000 hotel/motel rooms are located within 3 square mile area of the City. These event centers and maximum attendance potential are listed Table 4.1.

Table 4.1. Event Centers in Anaheim, California

Event Center	Maximum Potential Attendance
Anaheim Convention Center	55,000
Disneyland	80,000
Arrowhead Pond of Anaheim	20,000
Edison International Field of Anaheim	45,000

Total	200,000

An urban area such as Anaheim has many signalized intersections connected by short network links. Delay at intersections is a significant problem. Speeds or travel times in these urban areas are dominated by stop delay at intersections rather than significant variations in the time required traversing between nodes. Further, Anaheim's arterial street system is often impacted in unpredictable ways by ongoing expansion of the City's Convention Center, construction of a new Disney theme park and hotels, and the widening of Interstate 5 by the California Department of Transportation. In view of the economic significance of the Anaheim Resort event center area, the SCOOT deployment has the potential to provide substantial benefits. Figure 3.1 presents the Anaheim Resort area and the SCOOT regions that this evaluation examines.

The FOT evaluation addresses two other technologies, Odetics' VTDS (Video Traffic Detection System) and Transcore's 1.5 GC (Generation Control). See section 6.2 for a more detailed description of all three technologies. This dissertation focuses its efforts on the overall traffic system; however, the importance of SCOOT to the City of Anaheim and the performance of the other technologies may have influenced the decision-makers' responses to the extent that they may have neglected the other technologies when assessing the priorities. This is of little concern because this evaluation technique focused on the workings of the entire system as opposed to the specific components.

This results discussed in this section involve a full application of the previously discussed techniques with the exception of group issues. All of the weights and value functions within the

Anaheim FOT evaluation hierarchy were determined directly by John Thai, City Traffic Engineer for the City of Anaheim. The only exceptions to this case are discussed in the next paragraph. The full application is used with John Thai because he has a vested interest in the health and performance of the City's traffic system. Furthermore, he has extensive knowledge of the specific concerns for the City. Finally, his proximity to the author allowed extensive consultation and discussion of all of the key issues.

The only example of group decision-making that is applied in this chapter looks at determining the user benefits for the network performance. Since a complete investigation of the user benefits is beyond the scope of this dissertation, the three value functions under concern are determined using a simple aggregation scheme. With the disparate value functions observed from five randomly selected users of the network, the aggregation technique fails to closely mirror any of the actual respondents. A group forum taken from a sample of the system users may provide a better set of results; however, an attempt that was made to collect these value functions in a group setting failed to define any value functions at all. This occurs because the forum participants' values diverge significantly, and most find stop time to be an embedded cost. These participants are simply unwilling to spend money to improve their stop time, running time, or intersection delay. Even if the participants can reach a compromise on value function determination, trying to maintain consistency can present a sizeable hurdle.

4.2 Value Functions

The value functions associated with two leafs of the Anaheim FOT evaluation hierarchy are eliminated from the evaluation because of the difficulties that are associated with assessing the value functions and determining the actual levels of the attributes. The eliminated value functions include the accuracy of the SCOOT traffic model and the operators' estimate of effectiveness. While the evaluation is still acceptable without the inclusion of these leafs, it does limit its scope slightly. The specific importance of the excluded attributes can be assessed through a combination of the overall weights and an estimate of the potential values associated with the eliminated attributes.

All of the value functions are determined using polynomial curve-fitting, and a majority of the value functions are determined with a zero intercept. This approach poses a few concerns because sometimes the curves resulting from polynomial curve-fitting have unusual shapes that lack meaning over certain ranges. Specifically, the portion of the curve from the origin to the initial data point may have little meaning. Under these circumstances, the value function is assumed to be linear from the origin to the initial data point. A similar circumstance arises for some of the linear value functions that do not pass through the origin. Once again, a piecewise formulation for the value function is used. Another region of concern exists beyond the last known point. Extrapolations into this region pose a concern; however, all of the dominant value functions seem to return reasonable value for attribute levels in this region.

As the literature stated, the actual questioning of the decision-maker to find his value functions proves tedious and difficult. For some of the attributes, the decision-maker struggled to maintain consistency. When this occurs, the analyst attempted to guide the decision-maker towards a level of consistency. The difficulties with respect to consistency, along with the repetitive nature of the value functions frustrated the decision-maker. Additionally, there were justifiable complaints about the detail of the work and the time required to complete the entire process. He seemed to find making direct comparisons to money easier than making tradeoffs between attributes. In fact, he found comparing two of the attributes, stop time and running time, within one of the network performance leafs impossible. These attributes were compared directly to money.

Figures 4.1 through 4.31 display all of John Thai's value functions that this dissertation assessed. Most of the attributes have their own value function; however, some of the similar attributes can be grouped into a single value function. For example, all of the coordination and cooperation that is found in the project is represented using a single value function; however, the specific type of coordination and cooperation can be evaluated by including a weighting structure. With each graphical representation of the value functions, the figure displays the attribute's actual value function. For all of these, the *y* in the formulation of the value function represents its value, *v*.

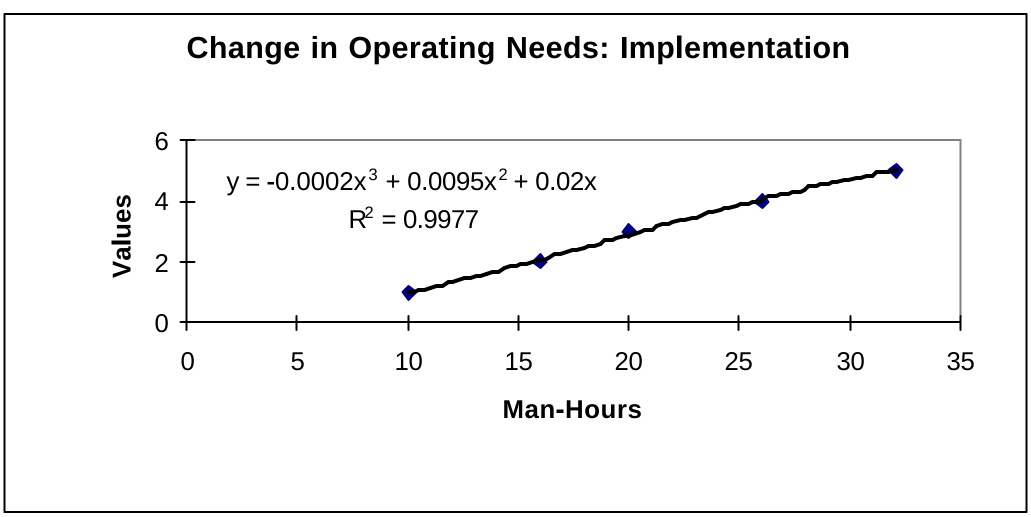

Figure 4.1. Change in Operating Needs: Implementation (Mr. Thai)

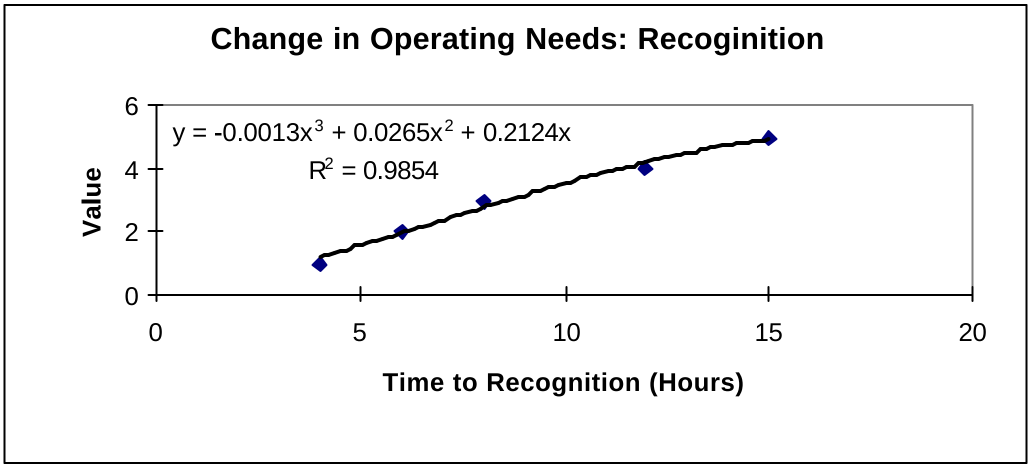

Figure 4.2. Change in Operating Needs: Recognition (Mr. Thai)

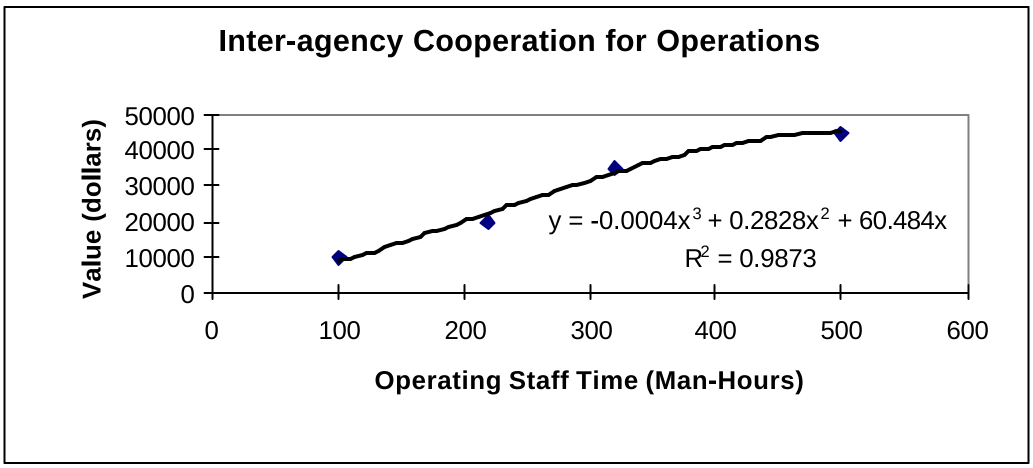

Figure 4.3. Inter-agency Cooperation for Operations (Mr. Thai)

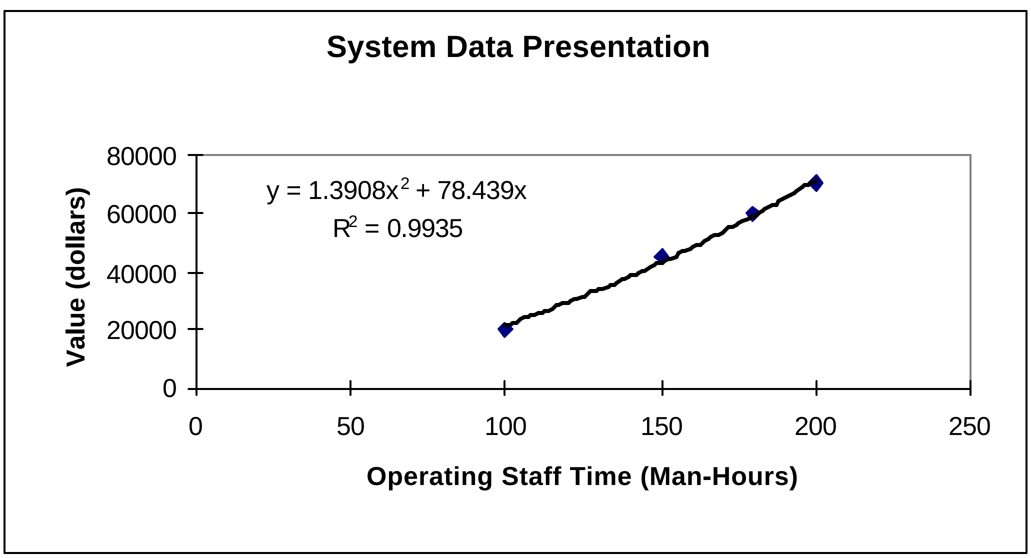

Figure 4.4. System Data Presentation (Mr. Thai)

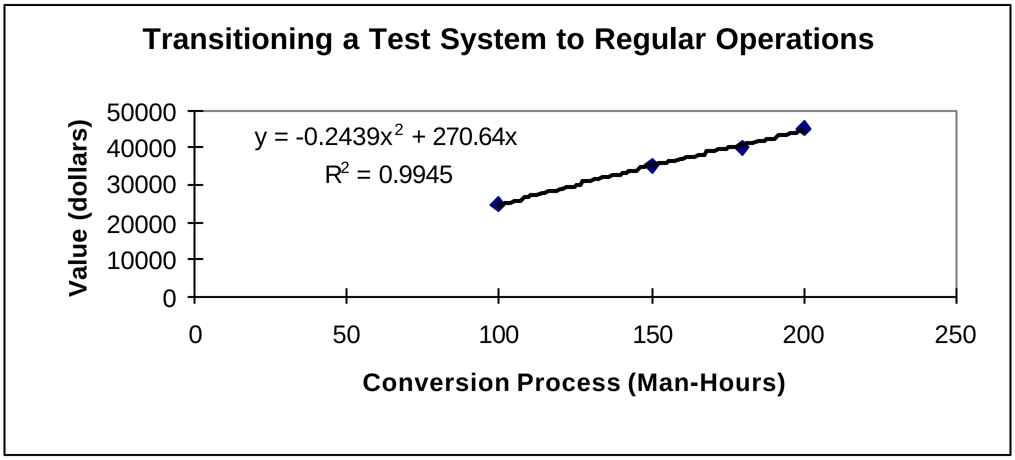

Figure 4.5. Transitioning a Test System to Regular Operations (Mr. Thai)

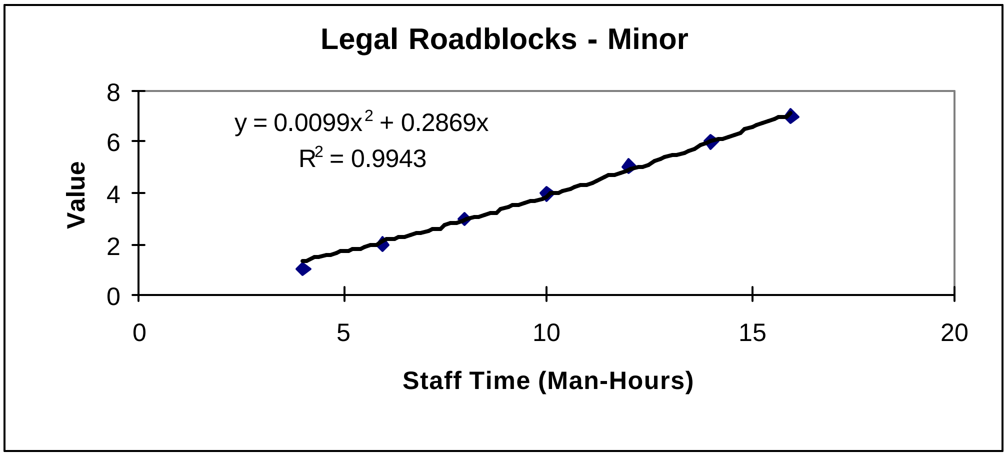

Figure 4.6. Legal Roadblocks - Minor, Staff Time (Mr. Thai)

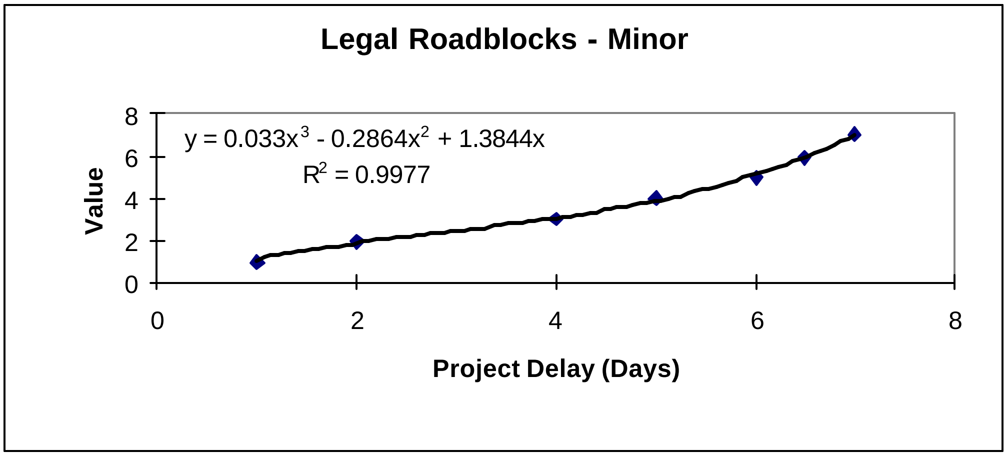

Figure 4.7. Legal Roadblocks - Minor, Project Delay (Mr. Thai)

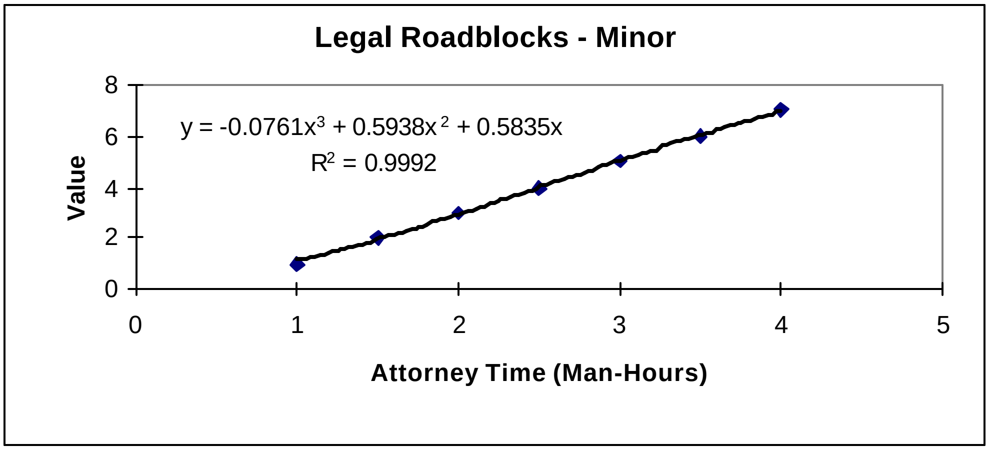

Figure 4.8. Legal Roadblocks - Minor, Attorney Time (Mr. Thai)

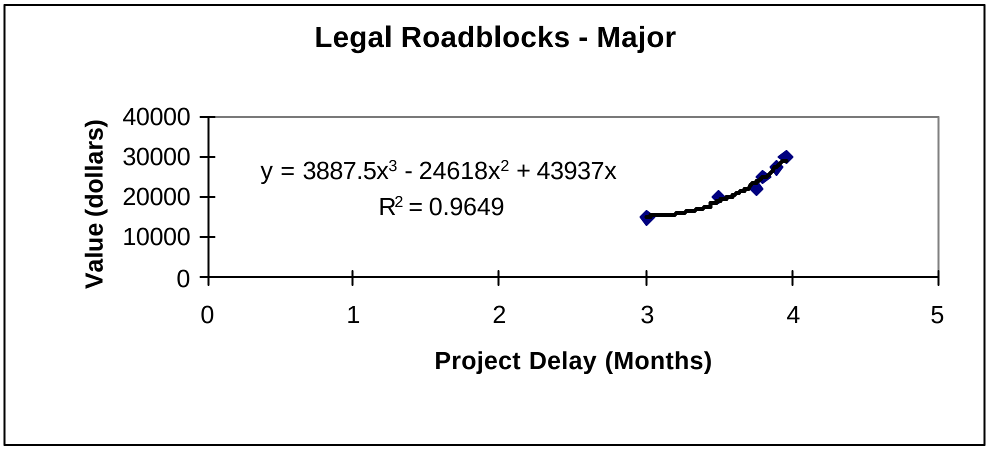

Figure 4.9. Legal Roadblocks - Major, Project Delay (Mr. Thai)

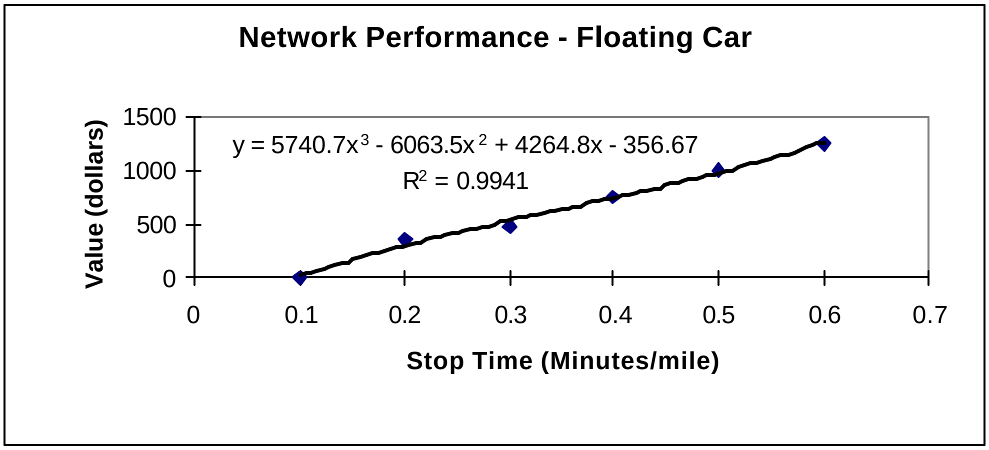

Figure 4.10. Network Performance - Floating Car, Stop Time (Mr. Thai)

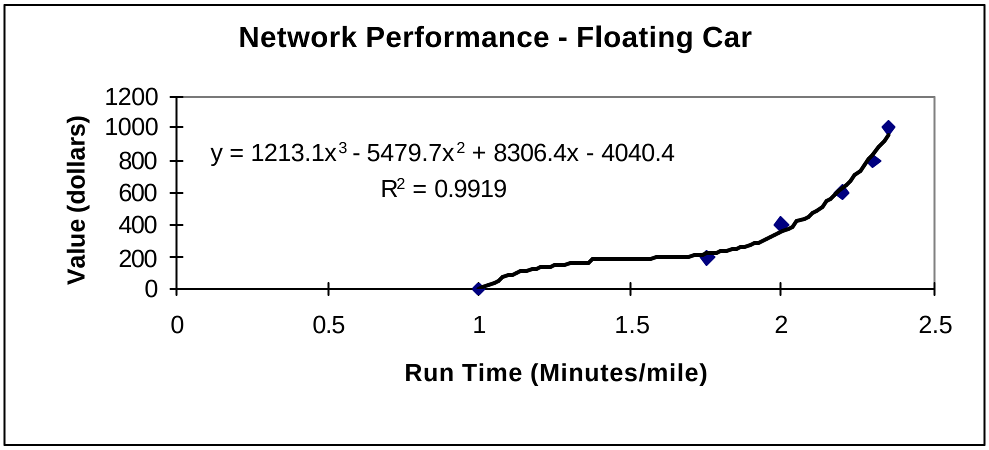

Figure 4.11. Network Performance - Floating Car, Run Time (Mr. Thai)

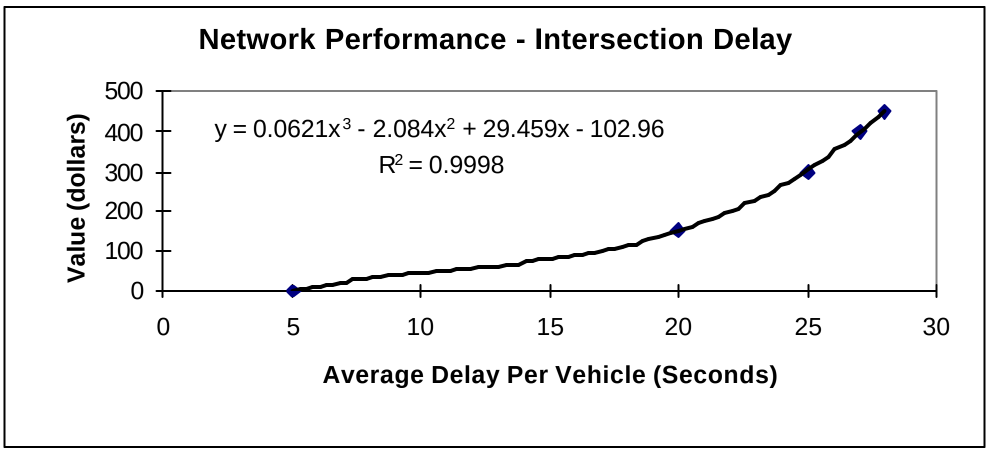

Figure 4.12. Network Performance - Intersection Delay (Mr. Thai)

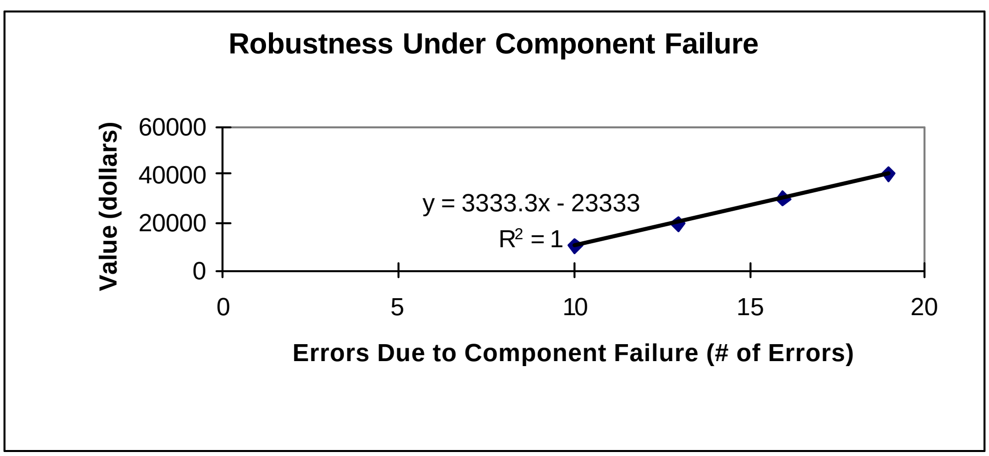

Figure 4.13. Robustness Under Component Failure (Mr. Thai)

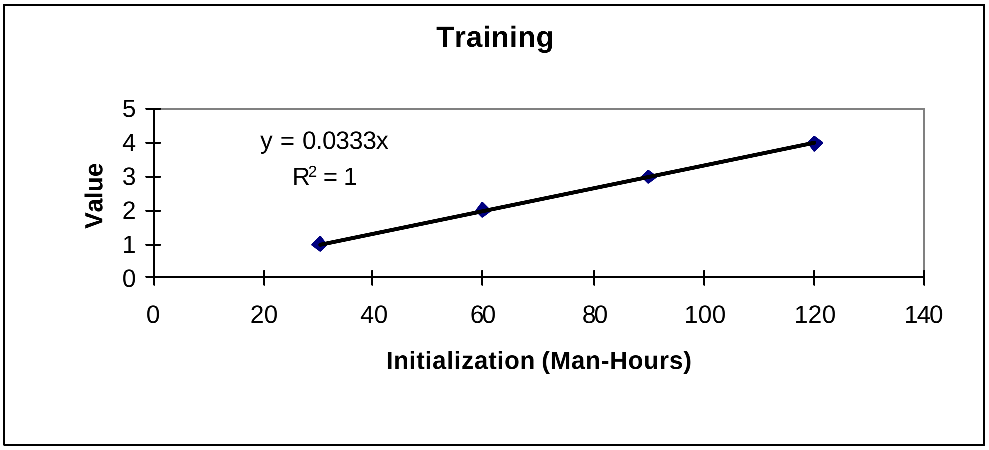

Figure 4.14. Training - Initialization (Mr. Thai)

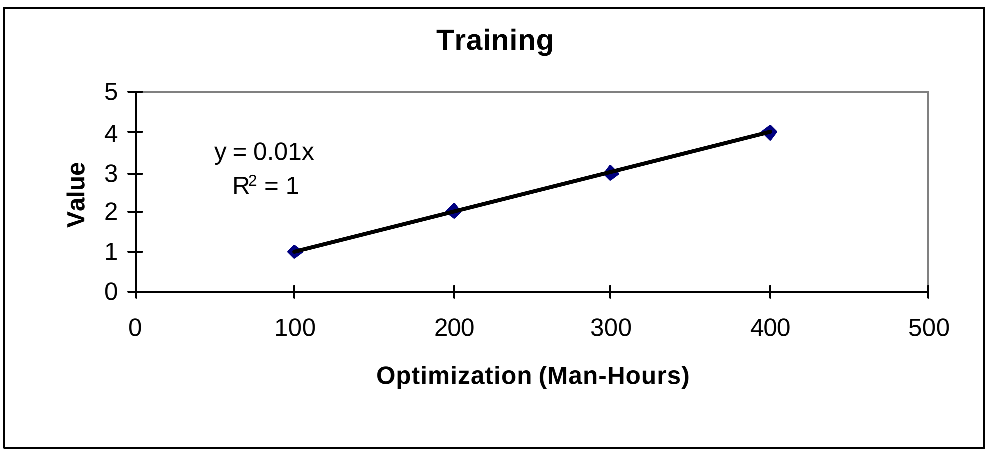

Figure 4.15. Training - Optimization (Mr. Thai)

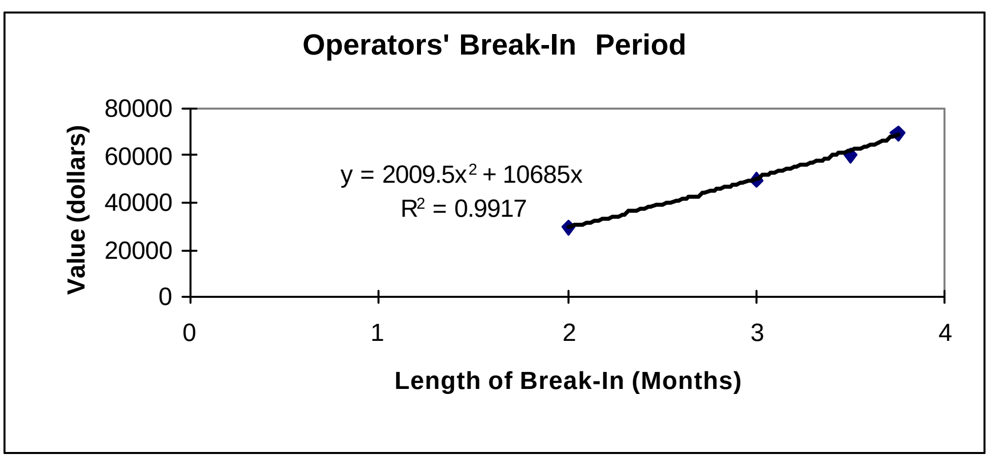

Figure 4.16. Operators' Break-In Period (Mr. Thai)

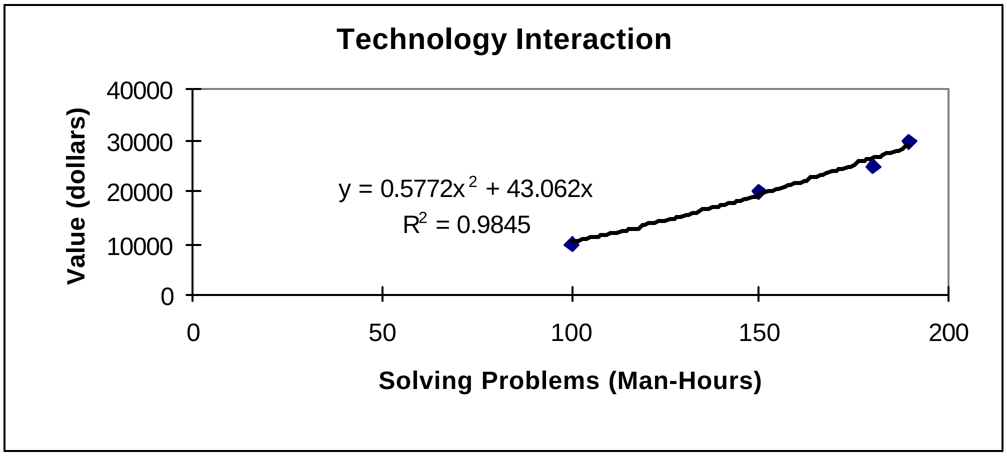

Figure 4.17. Technology Interaction (Mr. Thai)

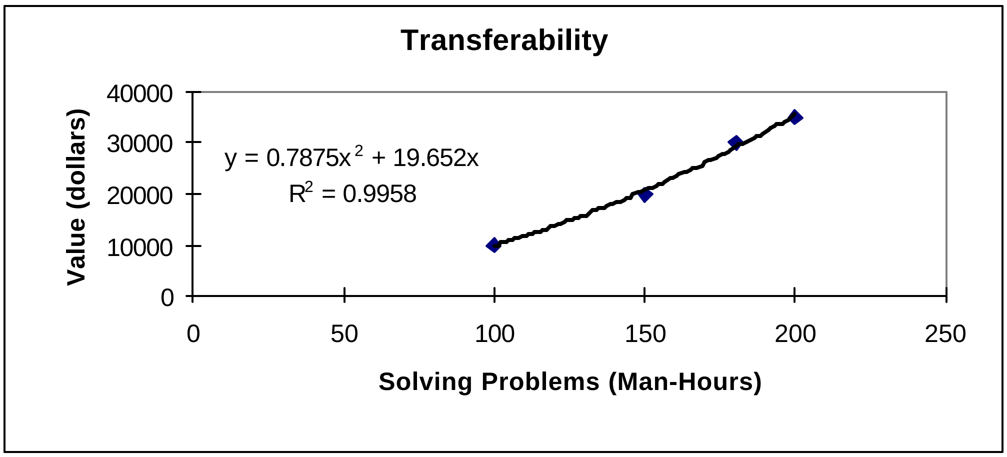

Figure 4.18. Transferability (Mr. Thai)

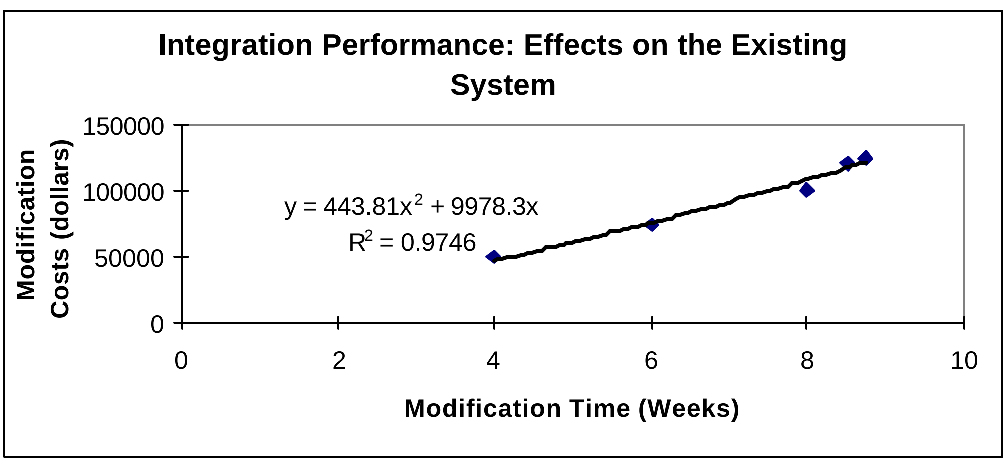

Figure 4.19. Integration Performance: Effects on the Existing System-Modification (Mr. Thai)

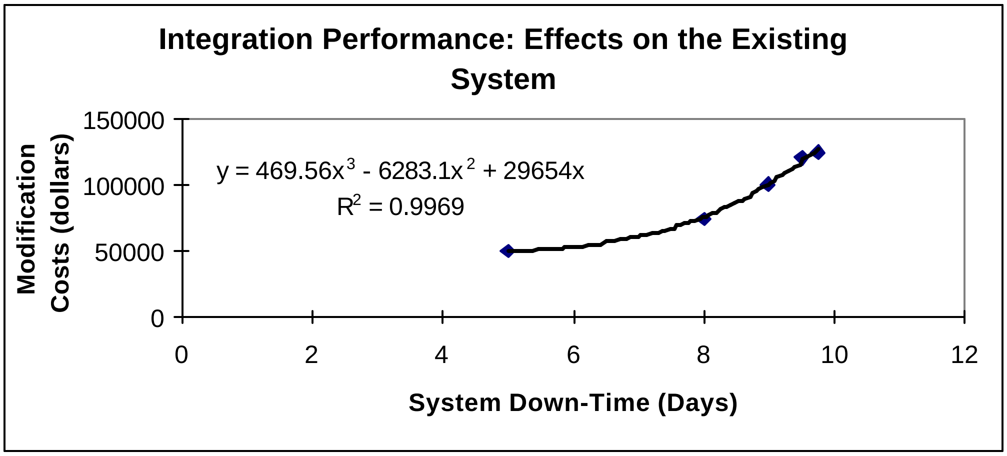

Figure 4.20. Integration Performance: Effects on the Existing System-System Down-Time (Mr. Thai)

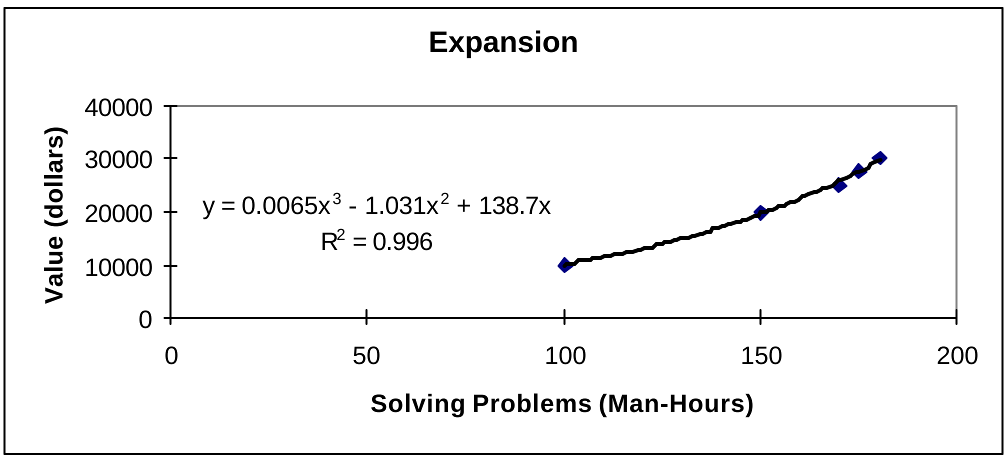

Figure 4.21. Expansion (Mr. Thai)

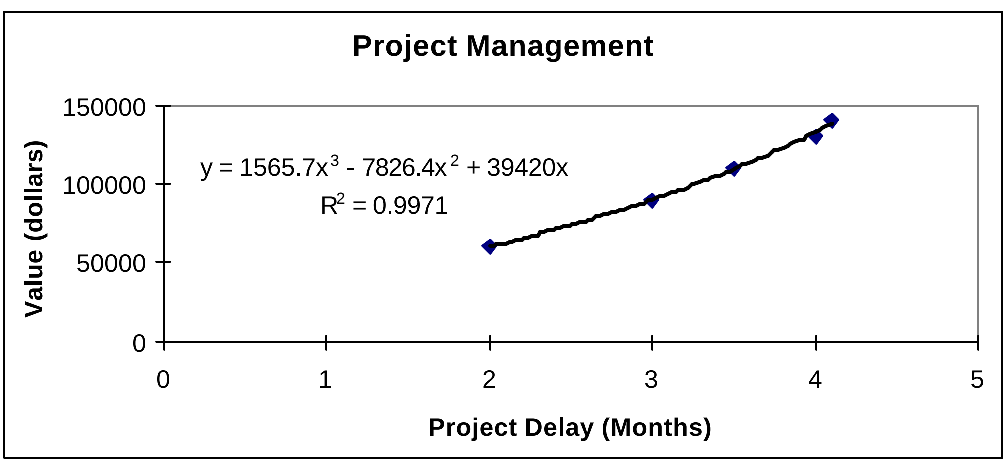

Figure 4.22. Project Management (Mr. Thai)

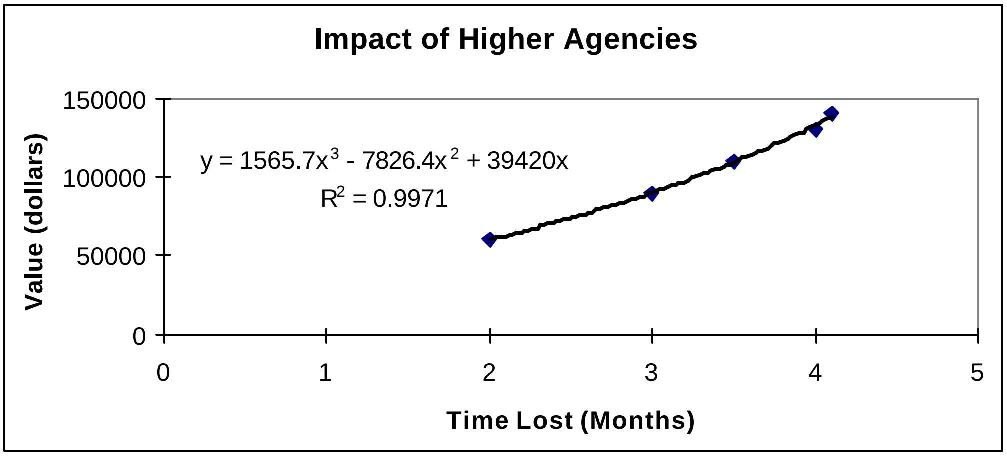

Figure 4.23. Impact of Higher Agencies (Mr. Thai)

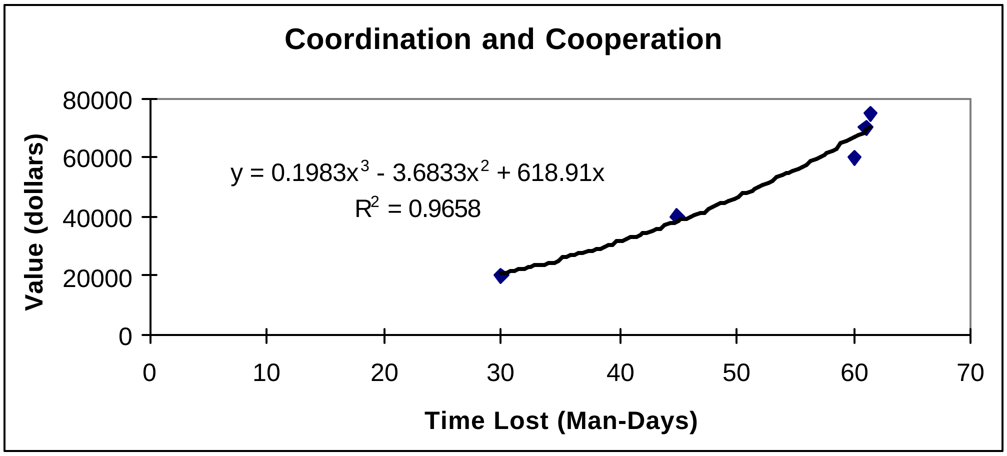

Figure 4.24. Coordination and Cooperation (Mr. Thai)

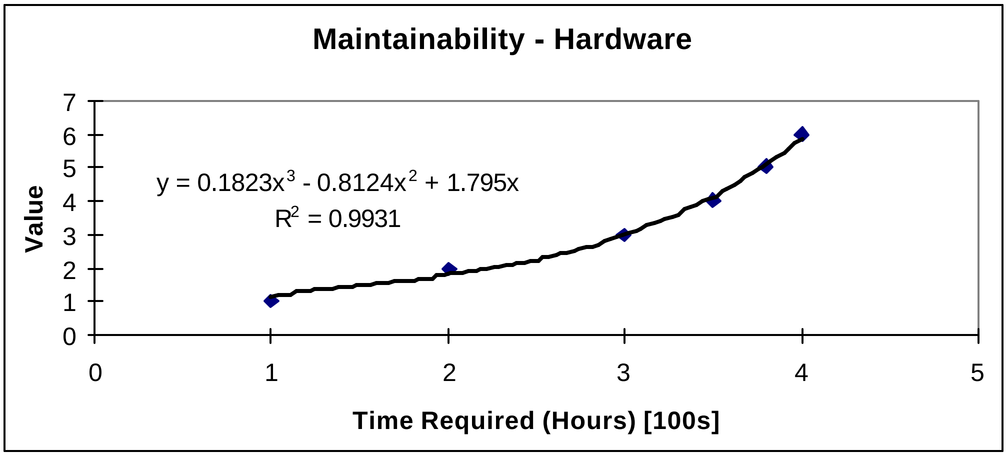

Figure 4.25. Maintainability - Hardware, Time Required (Mr. Thai)

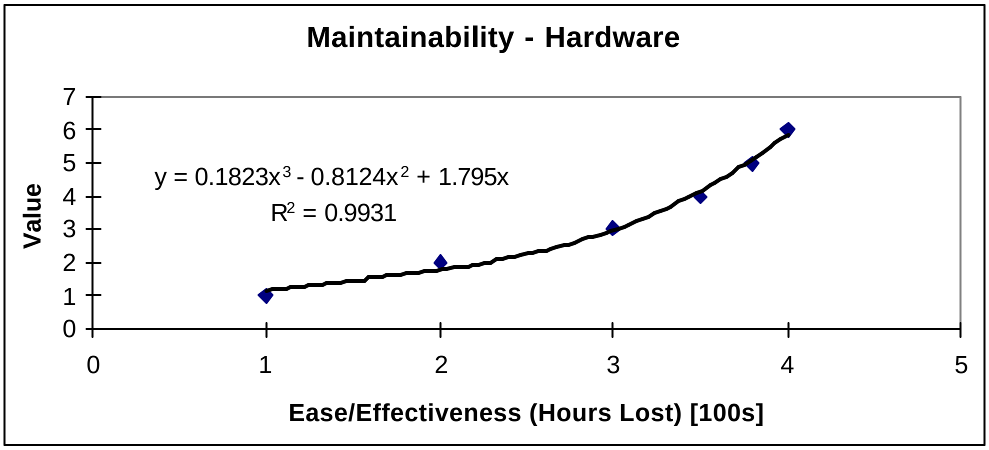

Figure 4.26. Maintainability - Hardware, Ease/Effectiveness (Mr. Thai)

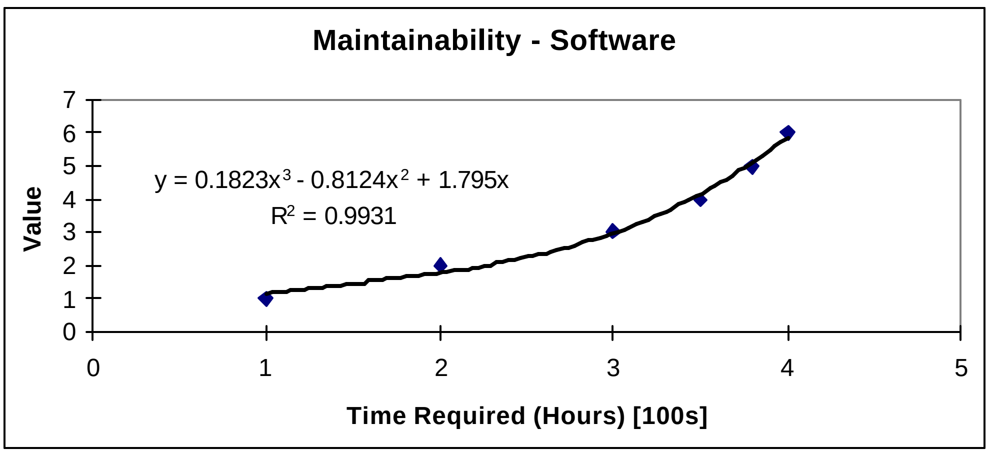

Figure 4.27. Maintainability - Software, Time Required (Mr. Thai)

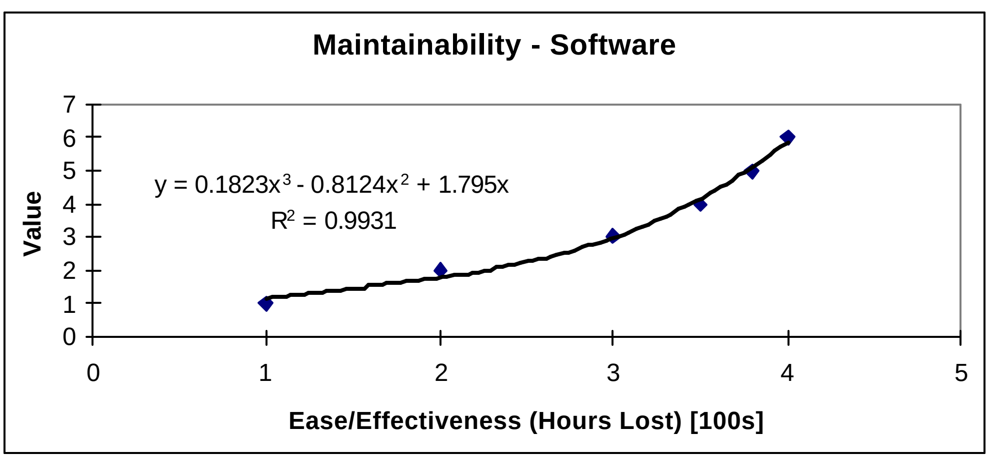

Figure 4.28. Maintainability - Software, Ease/Effectiveness (Mr. Thai)

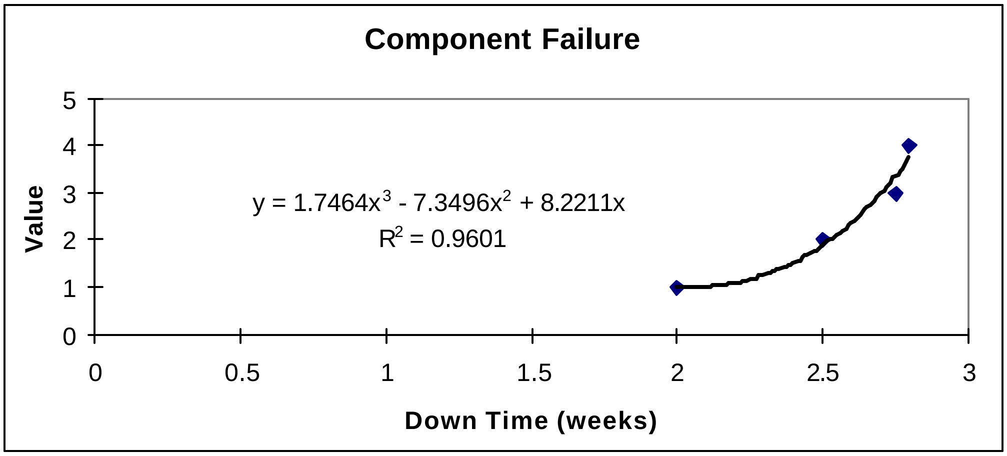

Figure 4.29. Component Failure - Down Time (Mr. Thai)

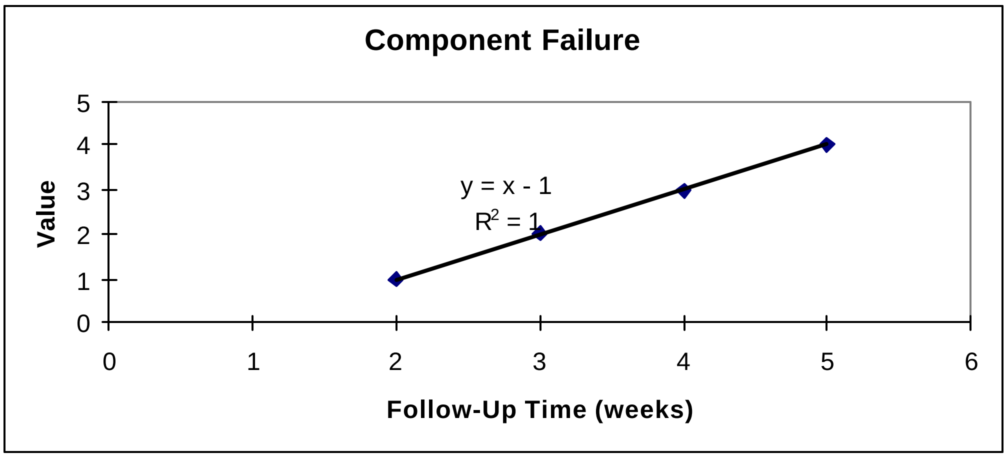

Figure 4.30. Component Failure - Follow-Up Time (Mr. Thai)

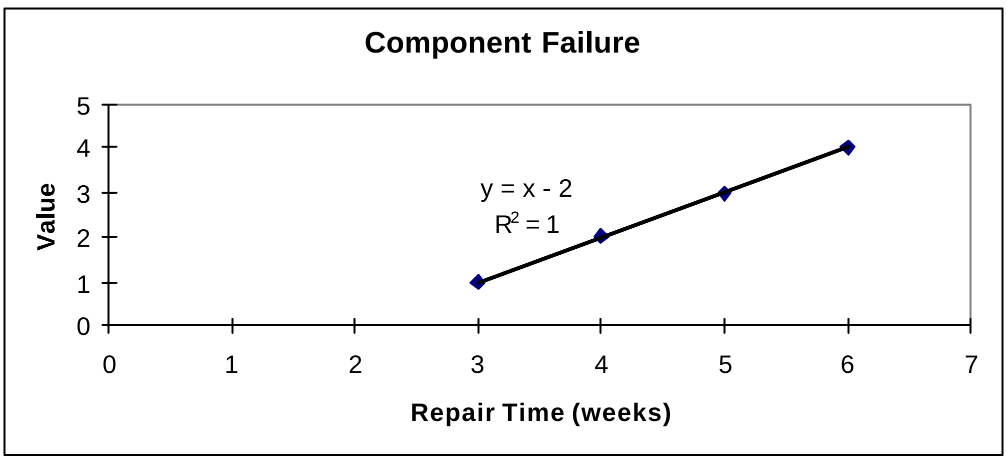

Figure 4.31. Component Failure - Repair Time (Mr. Thai)

After identifying all of John Thai's value functions, the value functions need to be transformed to a common scale USP. In this application, most of the attributes are directly assessed in term of the USP; however, a few are converted separately. The key attributes are identified and their proxy values, which are used for rescaling the value functions, are presented in Table 4.2. The attributes that are directly assessed in terms of the USP are denoted in the table with a "DA".

The user value functions present many previously discussed problems. Five respondents are selected (in this case, they happened to be acquaintances of the author, who often drive on the Anaheim network area), and the values functions of the five respondents are aggregated using equal weights for each. In this case, each individual value function is multiplied by 0.2 and added to the other value functions. The resultant value function is used to assess the user benefits of the network performance. These functions are presented below:

Stop Time

$$v(x) = 2178x^3 - 2261x^2 + 1882x - 295 \qquad (19)$$

Running Time

$$v(x) = -92x^3 + 533x^2 - 305x - 173 \qquad (20)$$

Intersection Delay

$$v(x) = 0.018x^3 - 0.58x^2 + 20x - 90 \qquad (21)$$

In all of the above equations, x represents the level of the attribute in question for an individual user. Figures 4.32 through 4.34 display the aggregated value functions that are used to assess user benefits. Appendix E presents the individual value function for all of the respondents.

Table 4.2. USP Proxy Information for John Thai

Leaf Key Attribute	USP (Dollars)
Change in Operating Needs Implementation (Man-Hours)	140
Inter-Agency Cooperation for Operations Operating Staff Hours Gained	DA
System Data Presentation Operating Staff Hours Gained	DA
Transitioning a Test System to Regular Operations Conversion Process (Man-Hours)	DA
Legal Road Blocks – Minor Solving the Road Blocks (Man Hours)	500
Legal Road Blocks (Major) Project Delay (Months)	DA
Robustness Under Component Failure Errors Due to Component Failure (# of errors)	DA
Network Performance – Floating Car Stop Time (Minutes/Miles)	DA
Running Time (Minutes Per Mile)	DA
Network Performance – Intersection Delay Average Delay Per Vehicle (Seconds)	DA
Training Initialization (Man-Hours)	10,000
Operators' Estimate of Effectiveness Distance from Reality (Distance Measure)	DA
Operators' Break-in Period Length of Break In (Months)	DA
Technology Interaction Solving Problems (Man-Hours/Problems)	DA
Transferability Solving Problems (Man-Hours)	DA
Expansion Solving Problems (Man-Hours)	DA
Project Management Time Saved/Lost (Months)	DA
Impact of higher agencies Time Saved/Lost (Months)	DA
All Coordination and Cooperation Time Saved/Lost (Man-Days)	DA
Maintainability-Hardware Time Required (Hours) (100s)	30,000
Maintainability – Software Time Required (Hours) (100s)	30,000
Component Failure (Total for Each Failure)	

Downtime (Weeks)	30,000

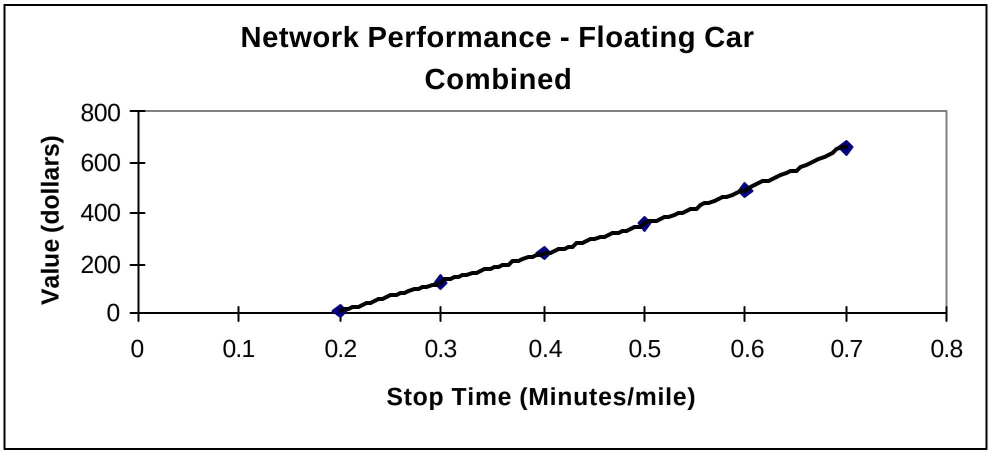

Figure 4.32. Network Performance - Floating Car Combined, Stop Time (User Defined)

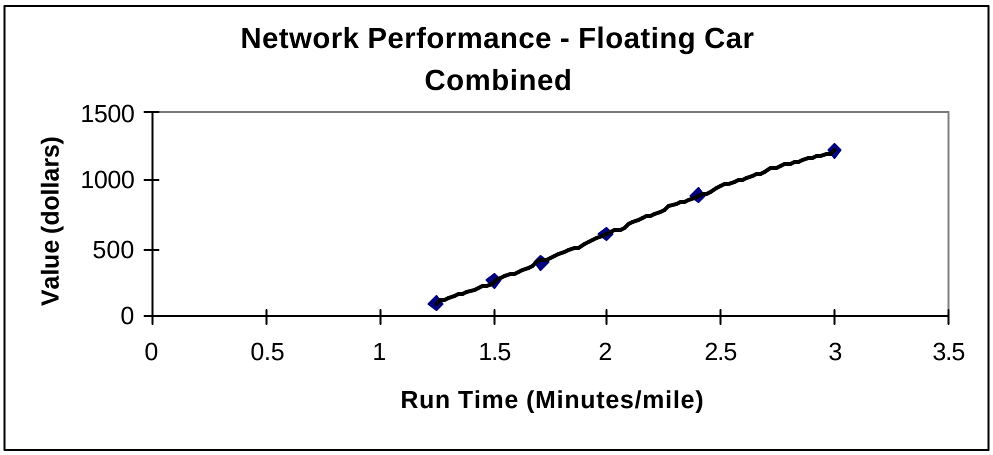

Figure 4.33. Network Performance - Floating Car Combined, Run Time (User Defined)

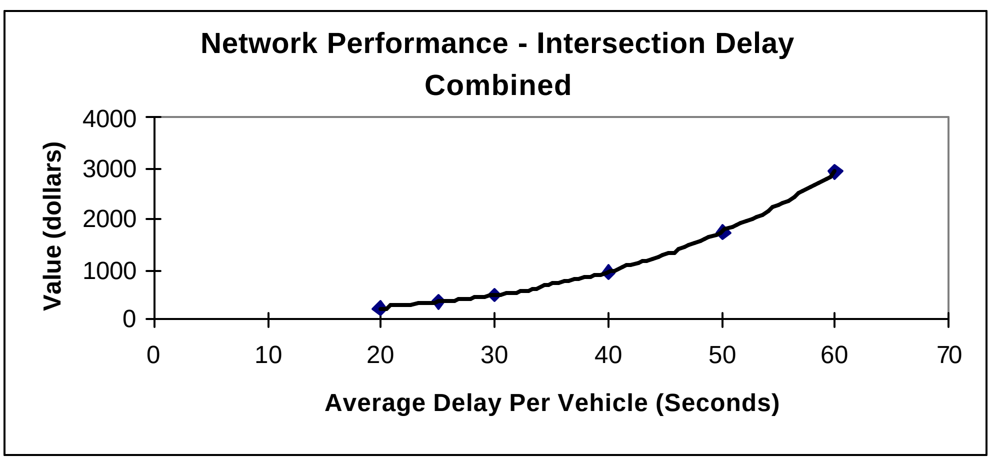

Figure 4.34. Network Performance – Intersection Delay Combined (User Defined)

4.3 Weighting Schemes

This application examines four different weighting schemes that are introduced in chapter two. Section 3.3.1.2 provides more insight into the weighting schemes as it describes the methods for determining them. Two of the approaches, ratio and 100-point, are rating techniques that come from MAVF. In the ratio technique, a decision-maker selects the least important objective, which is given an arbitrary weight of one, from a set of objectives and compares all other objectives to this least important one. For example, given a set of three objectives (O_1, O_2, O_3), the decision-maker decides that O_2 is the least important. Thus the weight for the other two objectives are given by the following equation because O_2 is set to a weight of one.

$$O_i = \frac{O_i}{O_2} \qquad \textit{where} \quad i = 1,3 \tag{22}$$

After finding the weights for all objectives, these weights must be standardized. Therefore, the final standardized weights are given in the following generalized equation where n represents the total number of objectives in a set:

$$O_i' = \frac{O_i}{\sum_{i=1}^{n} O_i} \qquad \forall i \tag{23}$$

The 100-point technique requires the decision-maker to allocate 100 points to the objectives in a given set. In this case, the standardized weight for an objective can simply be found by dividing an objective's point allocation by 100. These techniques are readily accepted in the MAVF community as appropriate techniques for finding weights.

The other two approaches that this research uses rely on AHP. The first, which is termed both AHP and regular AHP, uses the AHP techniques that are described in section 2.5. These are applied without any special questioning requirements for the decision-maker. The total number of comparisons for both AHP related schemes is given by the following equation where *n* represents the total number of objectives in a set:

$$number \quad of \quad comparisons = \sum_{i=1}^{n-1} i \qquad (24)$$

The difference between this regular AHP approach and the pairwise or pairwise AHP approach is simply in the in the technique used to question the decision-maker. In the pairwise approach, the decision-maker is asked to consider the possible range of the various objectives. Then, the decision-maker selects a preference matrix based on these possible changes. For example, the decision-maker must compare the following objectives, capital costs and operating and maintenance costs. In this case the decision-maker does not expect that much change in capital costs will occur within the system; however, a large change in operating and maintenance costs may occur. Therefore, the decision-maker will likely prefer the importance of operating and maintenance costs because its volatility makes its influence on the final outcome more significant. While the MAVF community does not generally accept the AHP techniques, they are widely accepted in the business community.

Each of these approaches identifies its own set of unique weights. Figures 4.35 through 4.50 display the hierarchy as well as the local weights at each level. The weights are presented in the following manner. The first row displays two techniques from value function theory, ratio then 100-point. The second row displays two AHP techniques, regular AHP followed by the pairwise comparison approach. Table 4.3 presents a few of the branches of the hierarchy that are not displayed as part of the hierarchy.

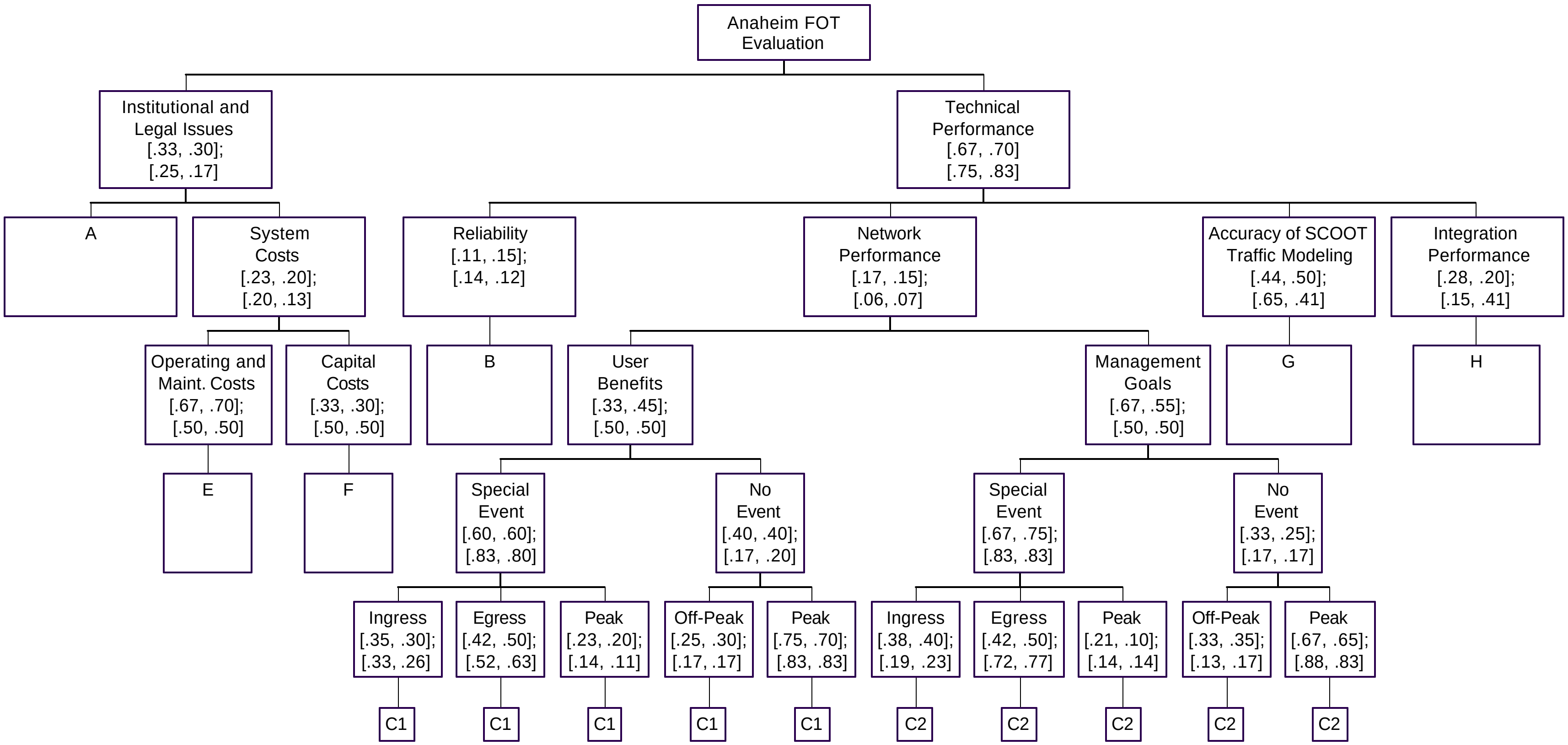

Figure 4.35. Anaheim FOT Hierarchy Local Weights for John Thai

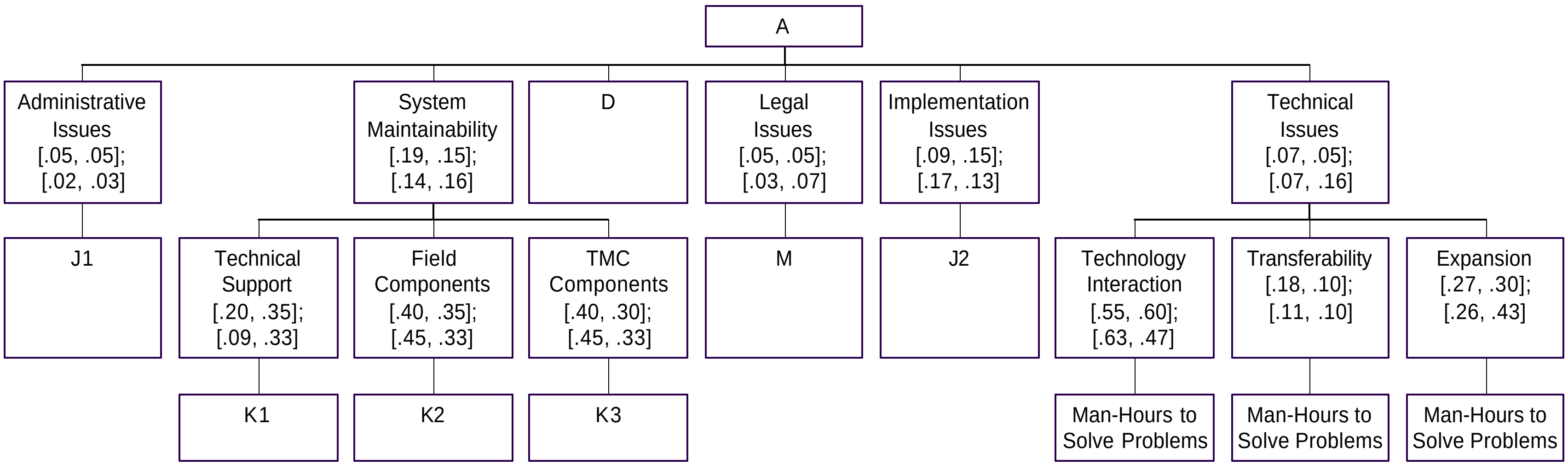

Figure 4.36. Institutional and Legal Issues (Mr. Thai)

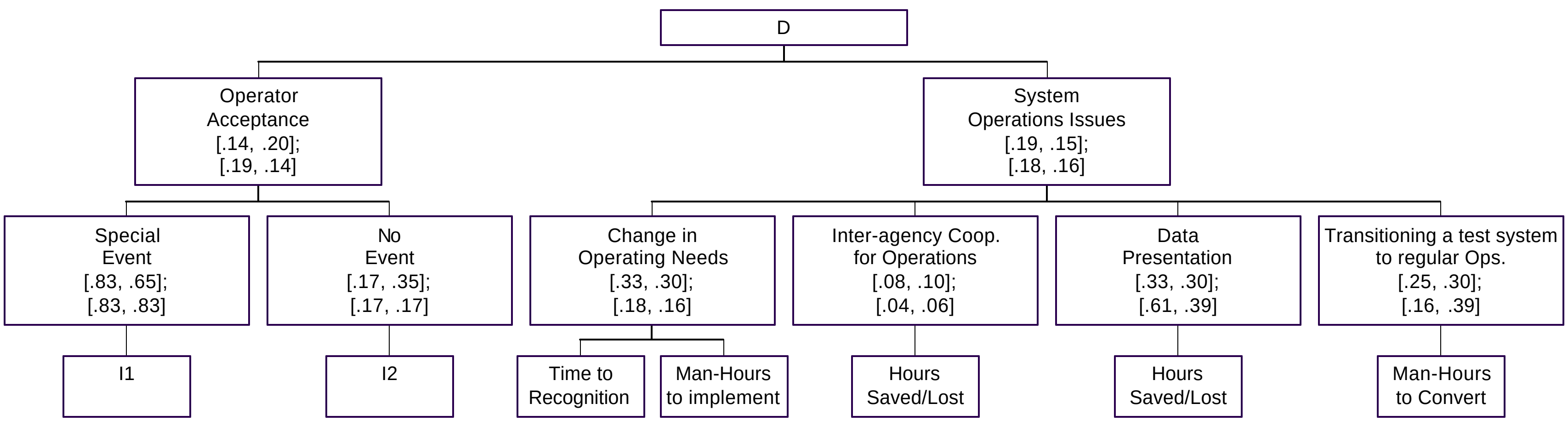

Figure 4.37. Operator Acceptance and System Operations Issues (Mr. Thai)

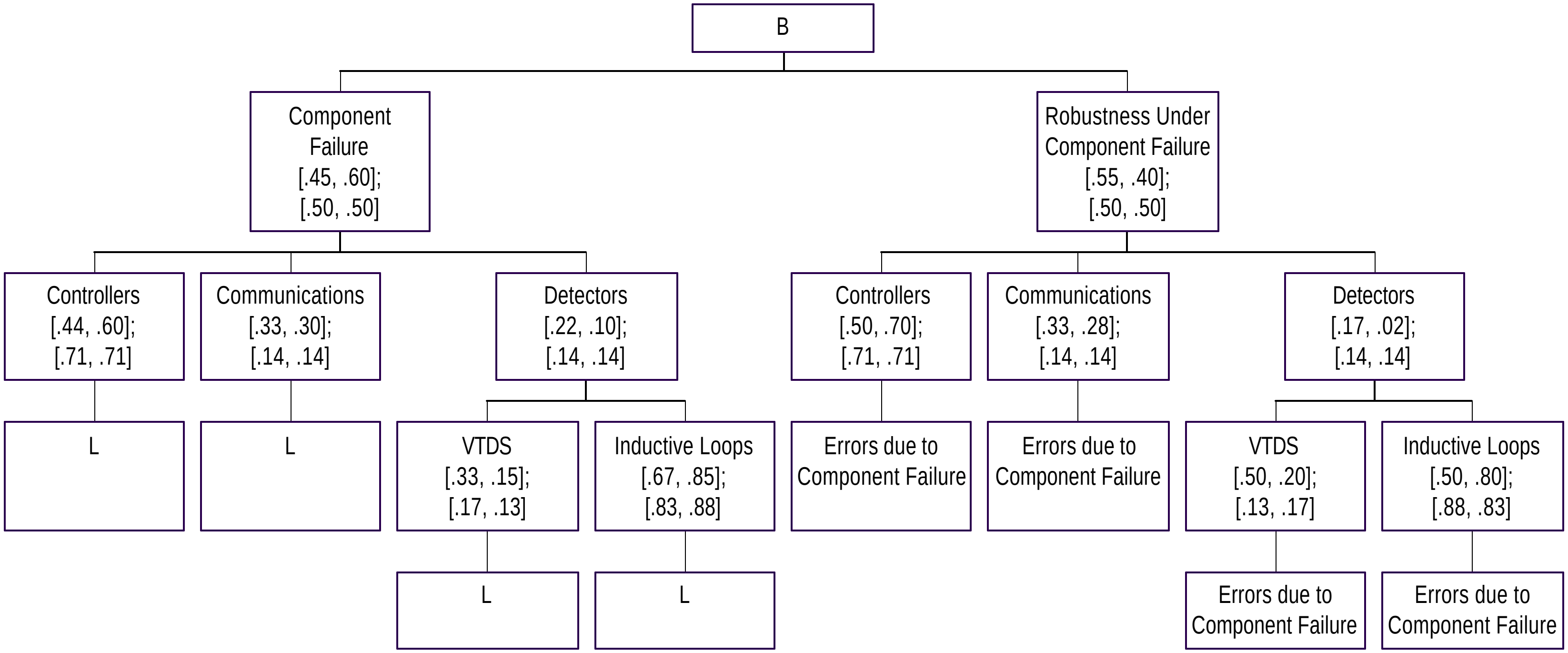

Figure 4.38. Reliability (Mr. Thai)

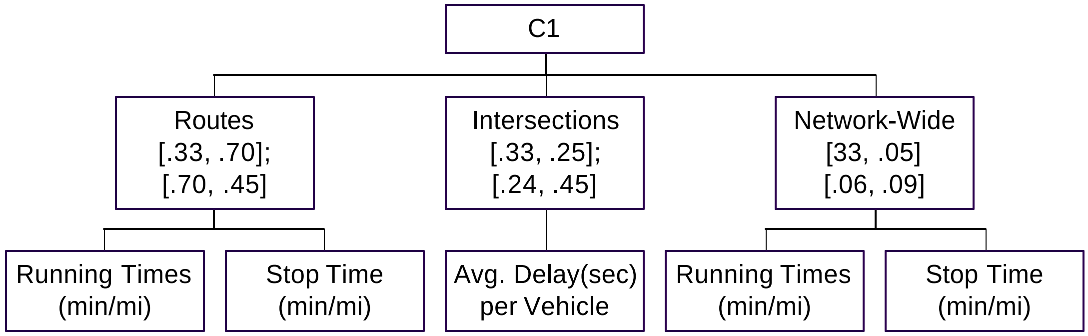

Figure 4.39. Traffic Network Performance - User Benefits (Mr. Thai)

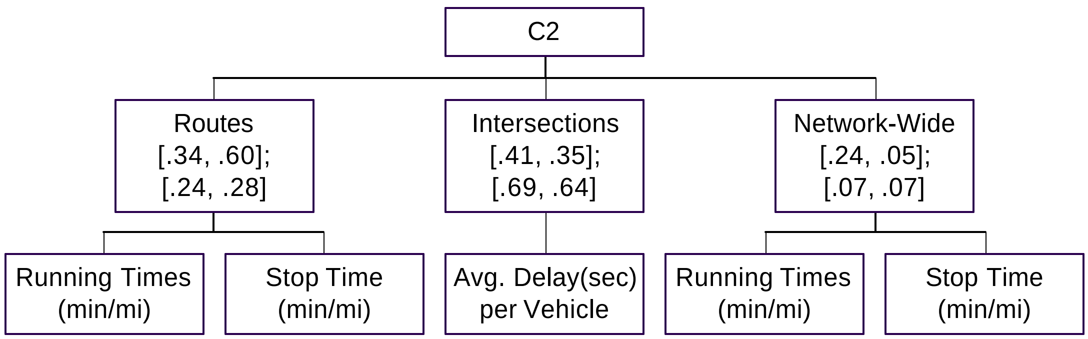

Figure 4.40. Traffic Network Performance – Management Goals (Mr. Thai)

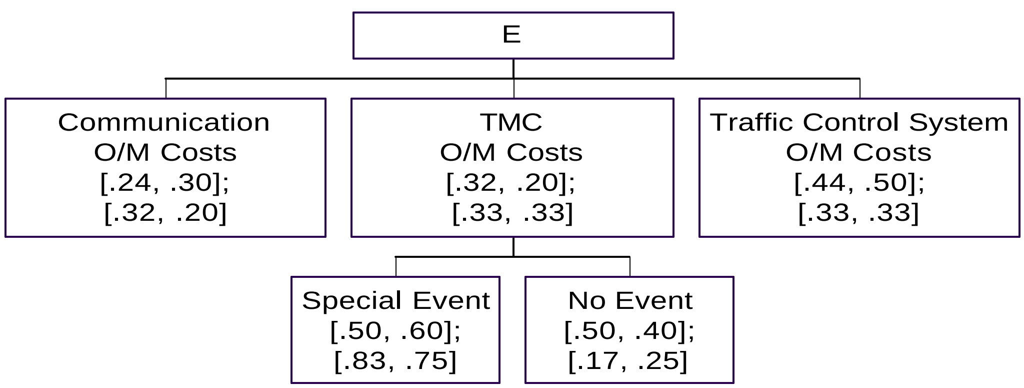

Figure 4.41. Operating and Maintenance Costs (Mr. Thai)

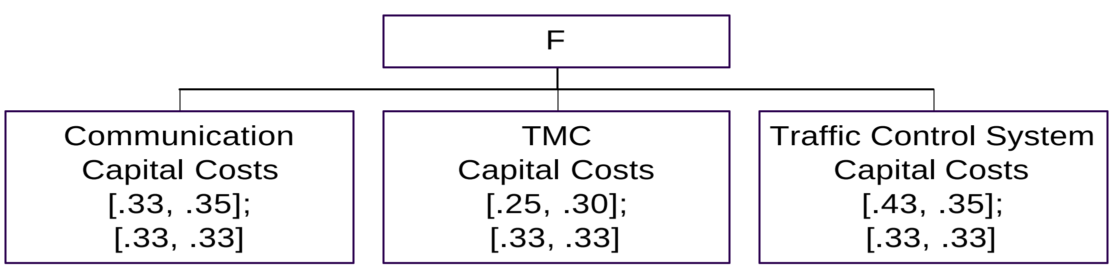

Figure 4.42. Capital Costs (Mr. Thai)

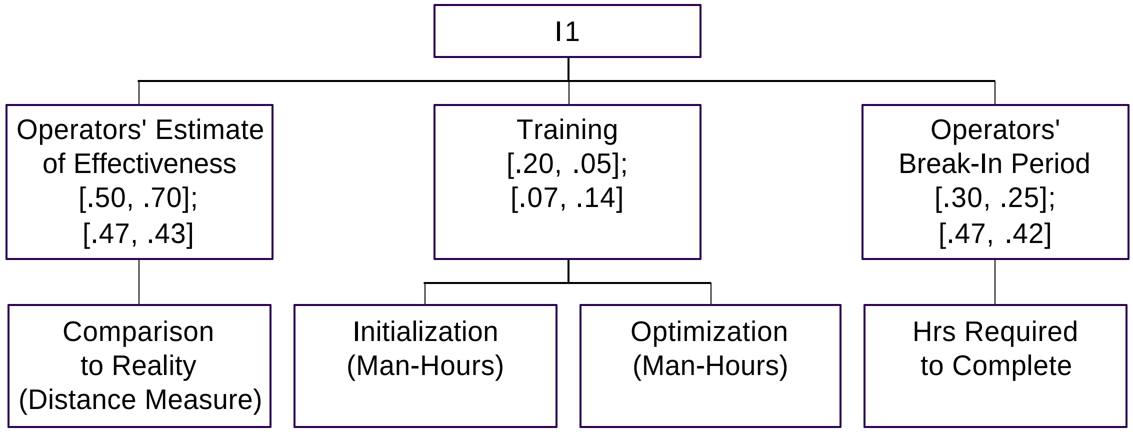

Figure 4.43. Operator Acceptance – Special Event (Mr. Thai)

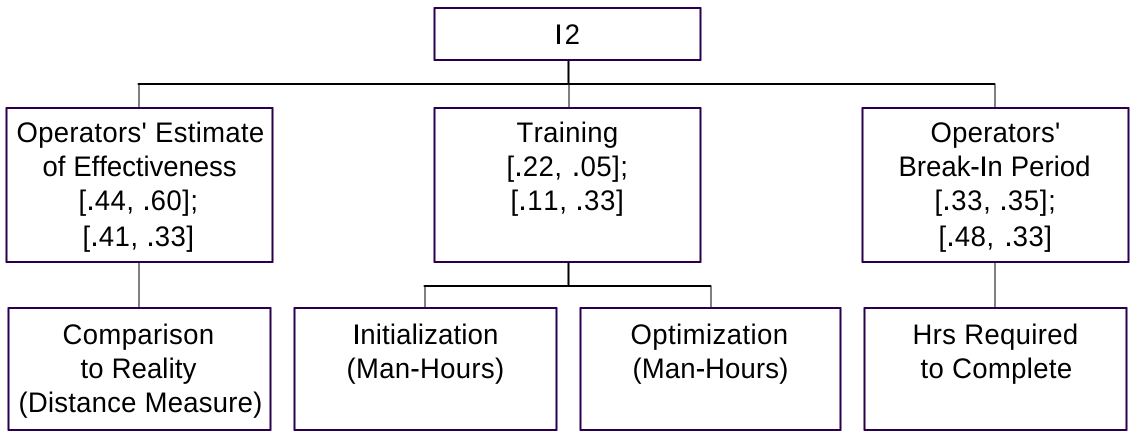

Figure 4.44. Operator Acceptance – No Event (Mr. Thai)

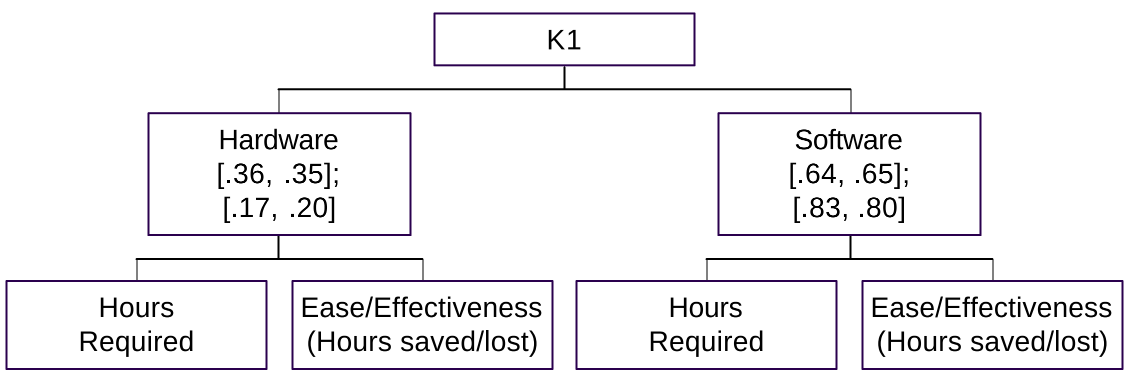

Figure 4.45. System Maintainability – Technical Support (Mr. Thai)

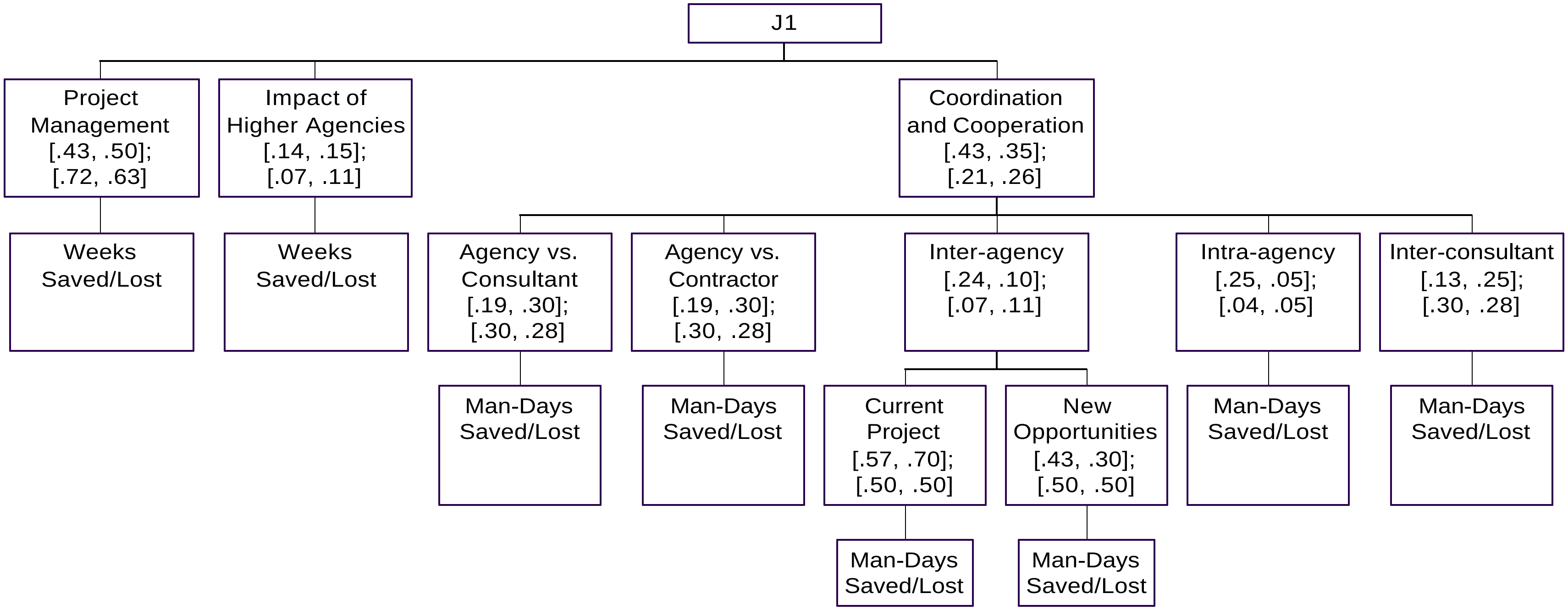

Figure 4.46. Administrative Issues (Mr. Thai)

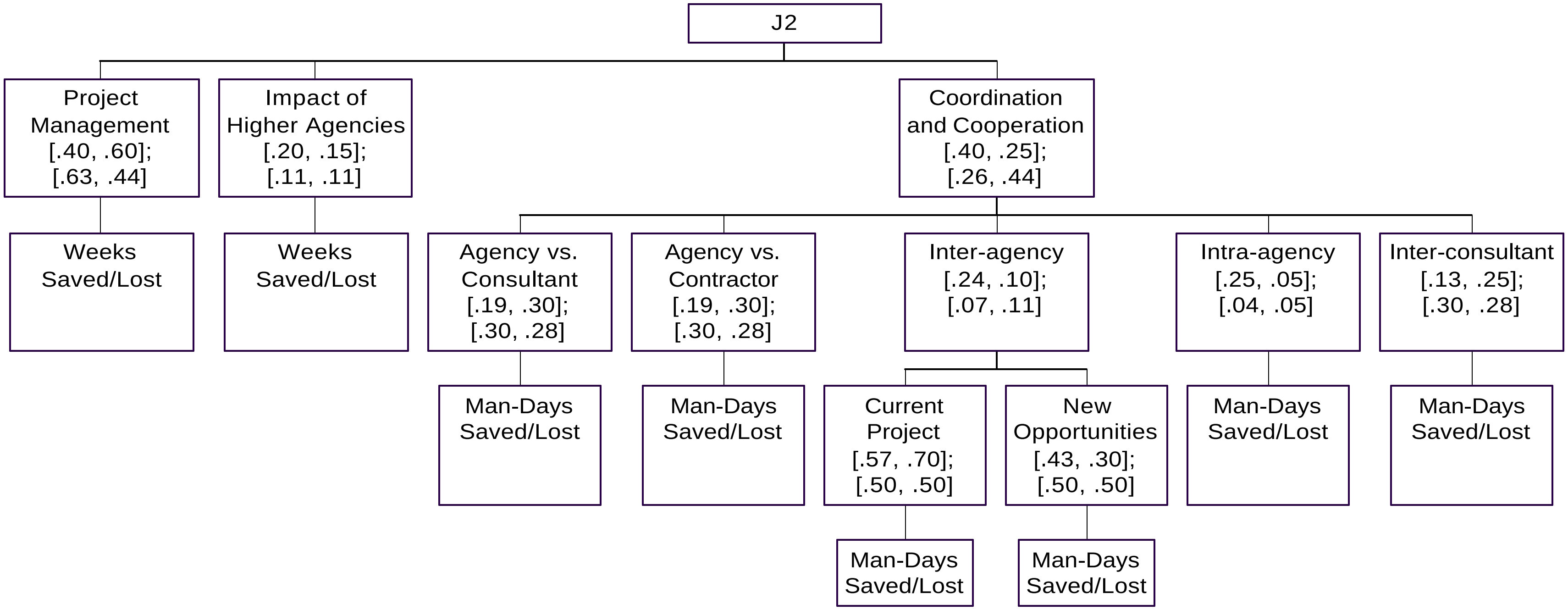

Figure 4.47. Implementation Issues (Mr. Thai)

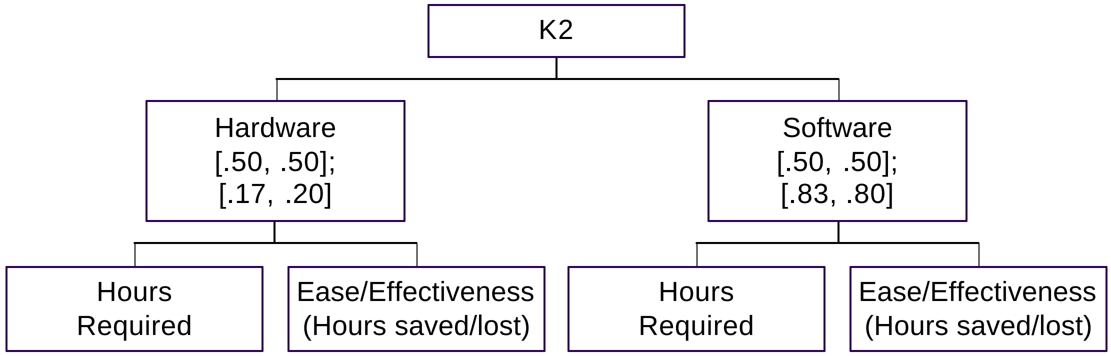

Figure 4.48. System Maintainability – Field Components (Mr. Thai)

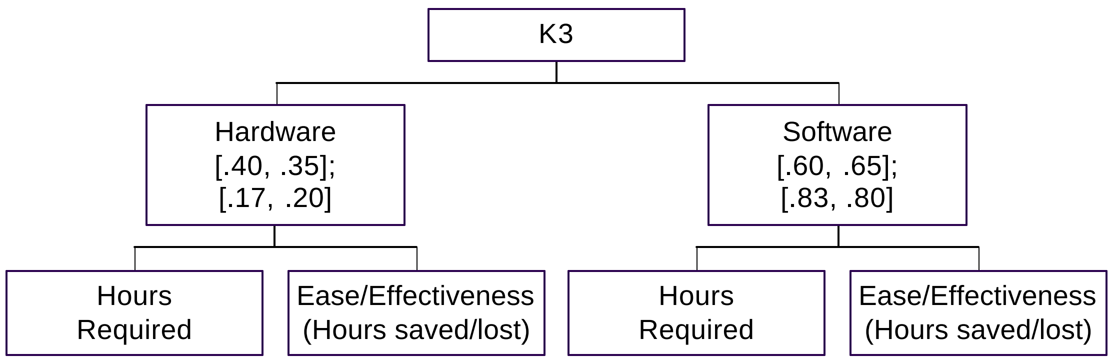

Figure 4.49. System Maintainability – TMC Components (Mr. Thai)

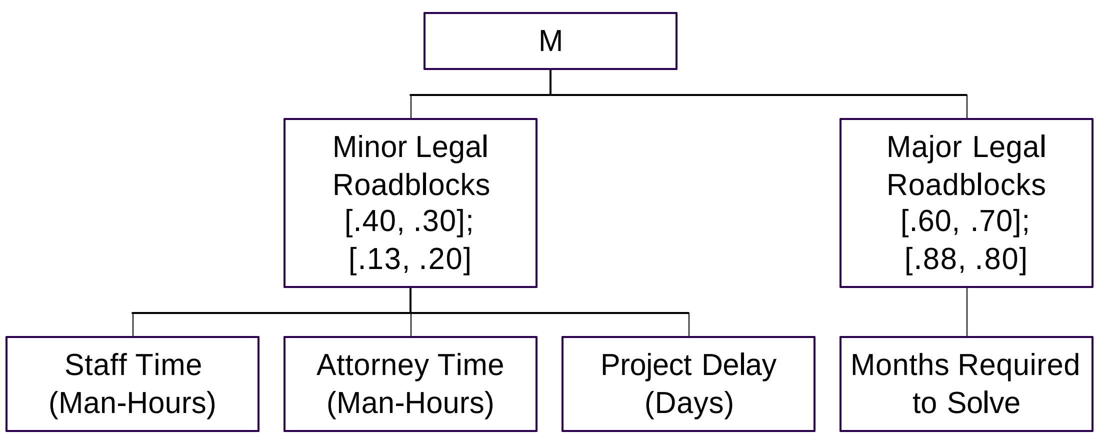

Figure 4.50. Legal Issues (Mr. Thai)

Table 4.3. Anaheim FOT Local Network Performance Weights for John Thai

User Benefits – Net. Performance - Routes	Ratio	100-point	AHP	Pairwise AHP
Route 1	0.2941	0.3500	0.4413	0.4330
Route 2	0.2941	0.5000	0.4413	0.4330
Route 3	0.1961	0.0500	0.0410	0.0644
Route 4	0.2157	0.1000	0.0765	0.0696
Management Goals - SE - Ingress - Routes				
Route 1	0.2923	0.4500	0.4450	0.4364
Route 2	0.3846	0.4500	0.4450	0.4364
Route 3	0.1538	0.0500	0.0439	0.0590
Route 4	0.1692	0.0500	0.0660	0.0681
Management Goals - SE - Egress - Routes				
Route 1	0.3008	0.3000	0.3080	0.4410
Route 2	0.3759	0.6000	0.5917	0.4410
Route 3	0.1504	0.0500	0.0498	0.0571
Route 4	0.1729	0.0500	0.0505	0.0610
Management Goals - SE - Peak - Routes				
Route 1	0.3143	0.2400	0.4472	0.4500
Route 2	0.3857	0.7000	0.4472	0.4500
Route 3	0.1429	0.0300	0.0512	0.0500
Route 4	0.1571	0.0300	0.0543	0.0500
Management Goals - NE - Offpeak - Routes				
Route 1	0.2885	0.4000	0.4466	0.3889
Route 2	0.3077	0.5000	0.4466	0.3889
Route 3	0.1923	0.0500	0.0465	0.0687
Route 4	0.2115	0.0500	0.0604	0.1535

Table 4.3. Anaheim FOT Local Network Performance Weights for John Thai (cont'd)

Management Goals - NE - Peak - Routes	Ratio	100-point	AHP	Pairwise AHP
Route 1	0.3220	0.3500	0.4472	0.4209
Route 2	0.3220	0.5500	0.4472	0.4209
Route 3	0.1695	0.0500	0.0512	0.0517
Route 4	0.1864	0.0500	0.0543	0.1064
User Benefits - NP - Intersections				
Ball/State College	0.2727	0.3500	0.3513	0.3455
Katella/State College	0.2727	0.4500	0.3513	0.3455
Cerritos/State College	0.0909	0.0500	0.0371	0.0326
Cerritos/Sunkist	0.0909	0.0500	0.0371	0.0675
Sunkist/Ball	0.1364	0.0500	0.1183	0.1045
Katella/Howell	0.1364	0.0500	0.1049	0.1045
Management Goals - SE - Ingress - Insctns.				
Ball/State College	0.1667	0.1500	0.2965	0.3114
Katella/State College	0.2500	0.3500	0.3568	0.3114
Cerritos/State College	0.0833	0.0500	0.0318	0.0348
Cerritos/Sunkist	0.1667	0.0500	0.0608	0.1141
Sunkist/Ball	0.1667	0.1000	0.1081	0.1141
Katella/Howell	0.1667	0.3000	0.1460	0.1141
Management Goals - SE - Egress - Insctns.				
Ball/State College	0.1287	0.1000	0.0894	0.1618
Katella/State College	0.1980	0.2000	0.0895	0.1618
Cerritos/State College	0.0990	0.0500	0.0427	0.0309
Cerritos/Sunkist	0.1782	0.1000	0.2568	0.2843
Sunkist/Ball	0.1980	0.1000	0.2499	0.1806
Katella/Howell	0.1980	0.4500	0.2718	0.1806

Table 4.3. Anaheim FOT Local Network Performance Weights for John Thai (cont'd)

Management Goals - NE - Offpeak - Insctns.	Ratio	100-point	AHP	Pairwise AHP
Ball/State College	0.2000	0.4000	0.3065	0.3003
Katella/State College	0.2000	0.3000	0.3065	0.3003
Cerritos/State College	0.1333	0.0500	0.0470	0.0528
Cerritos/Sunkist	0.1467	0.0500	0.1133	0.1155
Sunkist/Ball	0.1600	0.1000	0.1133	0.1155
Katella/Howell	0.1600	0.1000	0.1133	0.1155
Management Goals - NE - Peak - Insctns.				
Ball/State College	0.2418	0.4000	0.3154	0.3281
Katella/State College	0.2088	0.3000	0.3154	0.3281
Cerritos/State College	0.1099	0.0500	0.0400	0.0332
Cerritos/Sunkist	0.1099	0.0500	0.1098	0.0749
Sunkist/Ball	0.1648	0.1000	0.1098	0.1178
Katella/Howell	0.1648	0.1000	0.1098	0.1178

One key observation is about the lack of consistency between different weighting techniques. This is observed on an infrequent basis. This lack of consistency may have been caused by a number of factors. The analyst may have entered the decision-maker's responses incorrectly, or the decision-maker may have become confused. A more plausible reason may be that the decision-maker did not have stable opinions about each branch's weight. When inconsistencies were observed where only two objectives were compared, the analyst verified these imperfections. In almost all cases, the decision-maker wanted to reverse the previous response. Whenever inconsistencies were observed for a branch with more than two objectives they were processed without any adjustment. The previous set of figures and Table 4.3 present the local weights at each junction while Table 4.4 presents the overall weights for each level of the hierarchy. The overall weights are the exact weight in the overall evaluation attributable to each branch.

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai

Overall	Ratio	100-Point	Regular AHP	Pairwise AHP
Institutional and Legal Issues	0.33333	0.30000	0.25000	0.16667
Technical Performance	0.66667	0.70000	0.75000	0.83333
Institutional and Legal Issues				
Administrative Issues	0.01550	0.01500	0.00503	0.00570
System Operations Issues	0.06202	0.04500	0.04560	0.02709
System Maintainability	0.06202	0.04500	0.03468	0.02709
Technical Issues	0.02326	0.01500	0.01626	0.02709
Legal Issues	0.01550	0.01500	0.00651	0.01233
Implementation Issues	0.03101	0.04500	0.04303	0.02223
Operator Acceptance	0.04651	0.06000	0.04816	0.02292
System Costs	0.07752	0.06000	0.05073	0.02223
Technical Performance				
Reliability	0.07407	0.10500	0.10386	0.09775
Network Performance	0.11111	0.10500	0.04664	0.05573
Accuracy of Traffic modeling	0.29630	0.35000	0.48842	0.33993
Integration Performance (effects on exist. sys.)	0.18519	0.14000	0.11108	0.33993
Administrative Issues				
Project Management	0.00664	0.00750	0.00364	0.00361
Impact of Higher Agencies	0.00221	0.00225	0.00035	0.00061
Coordination and Cooperation	0.00664	0.00525	0.00104	0.00149
System Operations Issues				
Change in Operating Needs	0.02067	0.01350	0.00847	0.00423
Inter-agency Cooperation for Operations	0.00517	0.00450	0.00202	0.00168
Data Presentation	0.02067	0.01350	0.02771	0.01059
Transitioning a Test System to Regular Ops.	0.01550	0.01350	0.00562	0.01059
System Maintainability				
Technical Support	0.01240	0.01575	0.00315	0.00903
Field Components	0.02481	0.01575	0.01576	0.00903

TMC Components	0.02481	0.01350	0.01576	0.00903
Operator Acceptance				
Special Event	0.03876	0.03900	0.04014	0.01910
No-Event	0.00775	0.02100	0.00803	0.00382

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai (cont'd)

System Costs	Ratio	100-Point	Regular AHP	Pairwise AHP
Operating and Maintenance Costs	0.05168	0.04200	0.02537	0.01111
Capital Costs	0.02584	0.01800	0.02537	0.01111
Network Performance				
User Benefits	0.03704	0.04725	0.02332	0.02787
Management Goals	0.07407	0.05775	0.02332	0.02787
Technical Issues				
Technology Interaction	0.01268	0.00900	0.01030	0.01263
Transferability	0.00423	0.00150	0.00173	0.00273
Expansion	0.00634	0.00450	0.00424	0.01173
Implementation Issues				
Project Management	0.01240	0.02700	0.02725	0.00988
Impact of Higher Agencies	0.00620	0.00675	0.00457	0.00247
Coordination and Cooperation	0.01240	0.01125	0.01121	0.00988
User Benefits				
Special Event	0.02222	0.02835	0.01943	0.02229
No-Event	0.01481	0.01890	0.00389	0.00557
User Benefits - Special Event				
Ingress	0.00775	0.00851	0.00648	0.00581
Egress	0.00930	0.01418	0.01018	0.01412
Peak	0.00517	0.00567	0.00278	0.00237
User Benefits - No-Event				
Off-peak	0.00370	0.00567	0.00065	0.00093
Peak	0.01111	0.01323	0.00324	0.00464
Management Goals				
Special Event	0.04938	0.04331	0.01943	0.02322
No-Event	0.02469	0.01444	0.00389	0.00464
Management Goals - Special Event				
Ingress	0.01852	0.01733	0.00375	0.00541
Egress	0.02058	0.02166	0.01406	0.01781

Peak	0.01029	0.00433	0.00162	0.00217

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai (cont'd)

Management Goals - No-Event	Ratio	100-Point	Regular AHP	Pairwise AHP
Off-peak	0.00823	0.00505	0.00049	0.00077
Peak	0.01646	0.00938	0.00340	0.00387
Reliability				
Component Failure	0.03367	0.06300	0.05193	0.04887
Robustness under Component Failure	0.04040	0.04200	0.05193	0.04887
Component Failure				
Controllers	0.01496	0.03780	0.03709	0.03491
Communications	0.01122	0.01890	0.00742	0.00698
Detectors	0.00748	0.00630	0.00742	0.00698
Component Failure - Detectors				
VTDS	0.00499	0.00567	0.00618	0.00436
Inductive Loops	0.00998	0.03213	0.03091	0.03055
Robustness under Component Failure				
Controllers	0.02020	0.02940	0.03709	0.03491
Communications	0.01347	0.01176	0.00742	0.00698
Detectors	0.00673	0.00084	0.00742	0.00698
Robustness under Component Failure - Detectors				
VTDS	0.01010	0.00588	0.00464	0.00582
Inductive Loops	0.01010	0.02352	0.03246	0.02909
Operator Acceptance - Special Event				
Operators' Estimate of Effectiveness	0.01938	0.02730	0.01873	0.00819
Training	0.00775	0.00195	0.00268	0.00273
Operators' Break-in Period	0.01163	0.00975	0.01873	0.00819
Operator Acceptance - No-Event				
Operators' Estimate of Effectiveness	0.00345	0.01260	0.00325	0.00127
Training	0.00172	0.00105	0.00092	0.00127

Operators' Break-in Period	0.00258	0.00735	0.00385	0.00127

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai (cont'd)

Operating and Maintenance (O&M) Costs	Ratio	100-Point	Regular AHP	Pairwise AHP
Communication O&M Costs	0.01260	0.01260	0.00846	0.00370
TMC O&M Costs	0.01639	0.00840	0.00846	0.00370
Traffic Control System O&M Costs	0.02269	0.02100	0.00846	0.00370
TMC O&M Costs				
Special Events	0.00819	0.00504	0.00705	0.00278
No-Event	0.00819	0.00336	0.00141	0.00093
User Benefits - Network Performance				
Routes	n/a	n/a	n/a	n/a
Intersections	n/a	n/a	n/a	n/a
Network-Wide	n/a	n/a	n/a	n/a
Management Goals - Network Performance				
Routes	n/a	n/a	n/a	n/a
Intersections	n/a	n/a	n/a	n/a
Network-Wide	n/a	n/a	n/a	n/a
User Benefits - Network Performance - Routes				
Route 1	0.09804	0.24500	0.30946	0.19682
Route 2	0.09804	0.35000	0.30946	0.19682
Route 3	0.06536	0.03500	0.02876	0.02928
Route 4	0.07190	0.07000	0.05363	0.03162
Management Goals – SE - Ingress - Routes				
Route 1	0.00185	0.00468	0.00041	0.00067
Route 2	0.00243	0.00468	0.00041	0.00067
Route 3	0.00097	0.00052	0.00004	0.00009
Route 4	0.00107	0.00052	0.00006	0.00010
Management Goals - SE - Egress - Routes				
Route 1	0.00211	0.00390	0.00106	0.00222
Route 2	0.00264	0.00780	0.00203	0.00222
Route 3	0.00106	0.00065	0.00017	0.00029
Route 4	0.00122	0.00065	0.00017	0.00031

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai (cont'd)

Management Goals - SE - Peak - Routes	Ratio	100-Point	Regular AHP	Pairwise AHP
Route 1	0.00110	0.00062	0.00018	0.00028
Route 2	0.00136	0.00182	0.00018	0.00028
Route 3	0.00050	0.00008	0.00002	0.00003
Route 4	0.00055	0.00008	0.00002	0.00003
Management Goals - No-Event - Offpeak - Routes				
Route 1	0.00081	0.00121	0.00005	0.00009
Route 2	0.00086	0.00152	0.00005	0.00009
Route 3	0.00054	0.00015	0.00001	0.00002
Route 4	0.00059	0.00015	0.00001	0.00003
Management Goals - No-Event - Peak - Routes				
Route 1	0.00181	0.00197	0.00037	0.00046
Route 2	0.00181	0.00310	0.00037	0.00046
Route 3	0.00095	0.00028	0.00004	0.00006
Route 4	0.00105	0.00028	0.00005	0.00012
User Benefits - Network Performance - Intersections				
Ball/State College	0.09091	0.08750	0.08306	0.15704
Katella/State College	0.09091	0.11250	0.08306	0.15704
Cerritos/State College	0.03030	0.01250	0.00877	0.01481
Cerritos/Sunkist	0.03030	0.01250	0.00877	0.03068
Sunkist/Ball	0.04545	0.01250	0.02796	0.04749
Katella/Howell	0.04545	0.01250	0.02481	0.04749
Management Goals - SE - Ingress - Insctns.				
Ball/State College	0.00128	0.00091	0.00077	0.00108
Katella/State College	0.00192	0.00212	0.00092	0.00108
Cerritos/State College	0.00064	0.00030	0.00008	0.00012
Cerritos/Sunkist	0.00128	0.00030	0.00016	0.00040
Sunkist/Ball	0.00128	0.00061	0.00028	0.00040
Katella/Howell	0.00128	0.00182	0.00038	0.00040

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai (cont'd)

Management Goals - SE - Egress - Insctns.	Ratio	100-Point	Regular AHP	Pairwise AHP
Ball/State College	0.00110	0.00076	0.00087	0.00185
Katella/State College	0.00169	0.00152	0.00087	0.00185
Cerritos/State College	0.00084	0.00038	0.00041	0.00035
Cerritos/Sunkist	0.00152	0.00076	0.00249	0.00326
Sunkist/Ball	0.00169	0.00076	0.00242	0.00207
Katella/Howell	0.00169	0.00341	0.00263	0.00207
Management Goals - No-Event - Offpeak - Insctns.				
Ball/State College	0.00068	0.00071	0.00010	0.00015
Katella/State College	0.00068	0.00053	0.00010	0.00015
Cerritos/State College	0.00046	0.00009	0.00002	0.00003
Cerritos/Sunkist	0.00050	0.00009	0.00004	0.00006
Sunkist/Ball	0.00055	0.00018	0.00004	0.00006
Katella/Howell	0.00055	0.00018	0.00004	0.00006
Management Goals - No-Event - Peak - Insctns.				
Ball/State College	0.00165	0.00131	0.00074	0.00082
Katella/State College	0.00143	0.00099	0.00074	0.00082
Cerritos/State College	0.00075	0.00016	0.00009	0.00008
Cerritos/Sunkist	0.00075	0.00016	0.00026	0.00019
Sunkist/Ball	0.00113	0.00033	0.00026	0.00029
Katella/Howell	0.00113	0.00033	0.00026	0.00029
Capital Costs				
Communication Capital Costs	0.00840	0.00630	0.00846	0.00370
TMC Capital Costs	0.00646	0.00540	0.00846	0.00370
Traffic Control System Capital Costs	0.01098	0.00630	0.00846	0.00370
Coordination and Cooperation				
Agency vs. Consultant	0.00236	0.00338	0.00333	0.00277
Agency vs. Contractor	0.00236	0.00338	0.00333	0.00277
Inter-Agency	0.00298	0.00113	0.00081	0.00106
Intra-Agency	0.00314	0.00056	0.00042	0.00050
Inter-Consultant	0.00157	0.00281	0.00333	0.00277

Table 4.4. Anaheim FOT Evaluation Overall Hierarchy Weights for John Thai (cont'd)

Inter-Agency	Ratio	100-Point	Regular AHP	Pairwise AHP
Current Project	0.00169	0.00079	0.00040	0.00053
New Opportunites	0.00130	0.00034	0.00040	0.00053
Technical Support - System Maintainability				
Hardware	0.00443	0.00551	0.00053	0.00181
Software	0.00797	0.01024	0.00263	0.00722
Field Components - System Maintainability				
Hardware	0.01240	0.00788	0.00263	0.00181
Software	0.01240	0.00788	0.01314	0.00722
TMC Components - System Maintainability				
Hardware	0.00992	0.00473	0.00263	0.00181
Software	0.01488	0.00878	0.01314	0.00722
Legal Issues				
Minor	0.00620	0.00450	0.00081	0.00247
Major	0.00930	0.01050	0.00569	0.00986

4.4 Attribute Data

Once the preference data is elicited from the decision-maker, the next step is to do the actual *valuation*. This requires that use of the actual (observed) attribute levels that yield the values from the calibrated value functions. Many of the attribute levels in the before case are set at zero because they represent the status quo or current state of the system. Additionally, many of these attributes pertain directly to the project and its implementation of new technology. Obviously, the before system would not have a current level of these attributes. This research primarily uses the complete set of network performance data; however, an accident occurred on I-5 (see Figure 3.1) on November 12, the first of the "after" special event days. This accident resulted in a complete closure of I-5 and the subsequent rerouting of traffic through the Anaheim network. This had a tremendous impact on the special event peak data for this day. Therefore, this research also employs a second set of attribute data that eliminates this first day of special event peak data and relies exclusively on the data from November 19. Table 4.5 presents the complete attribute data set for both the "before" and "after" cases. The alternate data set only differs slightly from the original data set; the attributes that experience changes are presented in Table 4.6. When applying the alternate data set, all other attributes remain the same as the original data set.

The evaluators and internal data sources make every effort to report realistic attribute levels for both the "before" and "after" case. However, some errors may have been made, especially in the cases where the data has to be forecasted for upcoming years. Often times, the data is assumed to remain constant over the ten-year lifespan of the system while a few others either linearly increase or decrease during this period. Clearly, these represent large assumptions; however, given the ten-year time period, these estimates may be very accurate. However, the further into the lifespan of the system that the data covers the greater its uncertainty. At this time, this approach seems to be the most appropriate; however, it represents a key point for future improvements.

Table 4.5. Attribute Data

	Before Data	After Data
Network Performance – Special Event, Floating Car		
Stop Time (Minutes/Miles)		
-Ingress		
Route 1	1.138	0.957
Route 2	2.362	1.267
Route 3	1.402	1.332
Route 4	0.592	0.638
Network Wide	1.259	0.996
-Egress		
Route 1	0.797	0.785
Route 2	0.71	0.554
Route 3	0.869	1.266
Route 4	0.539	0.452
Network Wide	0.706	0.786
-Peak		
Route 1	1.39	2.012
Route 2	1.558	1.658
Route 3	1.368	1.554
Route 4	0.844	1.126
Network Wide	1.23	1.51
Running Time (Minutes per Mile)		
-Ingress		
Route 1	2.211	2.04
Route 2	1.612	1.831
Route 3	1.811	1.677
Route 4	1.76	1.832
Network Wide	1.837	1.824
-Egress		
Route 1	2.02	2.153
Route 2	1.621	1.683
Route 3	1.697	1.735
Route 4	1.762	1.825
Network Wide	1.759	1.793
-Peak		
Route 1	2.115	2.056
Route 2	1.656	1.766
Route 3	1.831	1.71
Route 4	1.677	1.842
Network Wide	1.7994	1.802

Table 4.5. Attribute Data (cont'd)

	Before Data	After Data
Network Performance – No-Event Floating Car		
Stop Time (Minutes/Miles)		
-Peak		
Route 1	1.346	1.503
Route 2	0.791	0.893
Route 3	1.218	1.13
Route 4	0.768	0.872
Network Wide	1.004	1.041
-Off Peak		
Route 1	0.73	0.725
Route 2	0.311	0.355
Route 3	0.833	0.739
Route 4	0.26	0.471
Network Wide	0.5	0.566
Running Time (Minutes per Mile)		
-Peak		
Route 1	2.036	2.075
Route 2	1.678	1.661
Route 3	1.745	1.787
Route 4	1.696	1.614
Network Wide	1.719	1.767
-Off Peak		
Route 1	2.011	2.062
Route 2	1.586	1.615
Route 3	1.745	1.834
Route 4	1.664	1.657
Network Wide	1.76	1.739

Operator Acceptance		
Special Event		
-Training		
Initialization	0	0
Optimization	0	80
-Operator's Break-In Period	0	8
No-Event		
-Training		
Initialization	0	0
Optimization	0	80
-Operator's Break-In Period	0	8

Table 4.5. Attribute Data (cont'd)

	Before Data	After Data
Network Performance – Special Event, Intersection Delay		
Average Delay per Vehicle (Seconds)		
-Ingress		
Ball/State College		
Katella/State College	43.98	55.92
Cerritos/State College	29.89	43.5
Cerritos/Sunkist	10.39	11.67
Sunkist/Ball	20.42	36.13
Katella/Howell	25.36	26.48
-Egress	21.06	17.16
Cerritos/Sunkist		
Katella/Howell	17.05	12.92
	29.5	17.47
Network Performance – No-Event, Intersection Delay		
Average Delay per Vehicle (Seconds)		
-Peak		
Ball/State College	47.12	48.68
Katella/State College	24.9	26.51
Cerritos/State College	7.73	10.43
Cerritos/Sunkist	5.54	20.65
-Off Peak		
Ball/State College	30.02	19.36
Katella/State College	13.85	15.43
Cerritos/State College	5.19	8.06

Cerritos/Sunkist	4.76	15.04
Change in Operating Needs		
Implementation (Man-Hours)	0	250
Time to Recognize (Hours)	0	40
Robustness Under Component Failure		
Errors Due to Component Failure (# of Errors)		
-Controllers	5	5
-Communications	15	100
-Detectors		
VTDS	0	12
Inductive Loops	25	100
Transitioning a Test System to Regular Operations		
Conversion Process (Man Hours)	0	160

Table 4.5. Attribute Data (cont'd)

	Before Data	After Data
Capital Costs (Dollars)		
Communication Costs	1,500,000	1,700,000
Traffic Control Systems	30,000,000	33,000,000
TRAFFIC MANAGEMENT CENTER	2,000,000	2,000,000

Integration Performance		
Effects on the Exist. System Modification Costs (Dollars)	0	220,000
Modification Time (Weeks)	0	12
System Down-Time (Days)	0	20
Technology Interaction		
Solving Problems (Man-Hours/Problems)	0	0
Transferability		
Solving Problems (Man-Hours)	0	40
Expansion		
Solving Problems (Man-Hours)	0	40
Administrative Issues		
Project Management [Time Saved/Lost (Months)]	0	15
Impact of Higher Agencies [Time Saved/Lost (Months)]	0	4
Agency vs. Consultant [Time Saved/Lost (Man-Days)]	0	25
Agency vs. Contractor [Time Saved/Lost (Man-Days)]	0	1
Inter-Agency – Curnt Proj [Time Saved/Lost (Man-Days)]	0	1
Inter-Agency – New Ops. [Time Saved/Lost (Man-Days)]	0	1
Intra-Agency [Time Saved/Lost (Man-Days)]	0	1
Inter-Consultant [Time Saved/Lost (Man-Days)]	0	20
IMPLEMENTATION ISSUES		
Project Management [Time Saved/Lost (Months)]	0	1.5
Impact of Higher Agencies [Time Saved/Lost (Months)]	0	0
Agency vs. Consultant [Time Saved/Lost (Man-Days)]	0	30
Agency vs. Contractor [Time Saved/Lost (Man-Days)]	0	0
Inter-Agency – Curnt Proj [Time Saved/Lost (Man-Days)]	0	0
Inter-Agency – New Ops. [Time Saved/Lost (Man-Days)]	0	0
Intra-Agency [Time Saved/Lost (Man-Days)]	0	0
Inter-Consultant [Time Saved/Lost (Man-Days)]	0	0
Operating and Maintenance (OM) Costs (Dollars)		
Communication Costs	50,000	75,000
Traffic Control Systems	150,000	180,000
Traffic Management Center		
No-Event	0	50,000
Special Event	0	20,000

Table 4.5. Attribute Data (cont'd)

	Before Data	After Data

System Maintainability- Technical Support		
Time Required (Hours) (100s)		
-Hardware	0.3	0.6
-Software	1	1
Ease/Effectiveness (Hours Saved/Lost) (100s)		
-Hardware	0	0
-Software	0	0
Field Components		
Time Required (Hours) (100s)		
-Hardware	0.2	0.5
-Software	1	1.5
Ease/Effectiveness (Hours Saved/Lost) (100s)		
-Hardware	0	0
-Software	0	0
TMC Components		
Time Required (Hours) (100s)		
-Hardware	0.2	0.8
-Software	0.5	1
Ease/Effectiveness (Hours Saved/Lost) (100s)		
-Hardware	0	0
-Software	0	0
Component Failure (Total for each Failure)		
Downtime (Weeks)		
-Controllers	0.075	0.075
-Communications	2	2
-Detectors		
--VTDS	0	0.75
--Inductive Loops	4	4
Follow Up Time (Weeks)		
-Controllers	0.5	0.24
-Communications	0.15	0.14
-Detectors		
--VTDS	0	0.13
--Inductive Loops	0.0075	0.0125
Repair Time (Weeks)		
-Controllers	0	0
-Communications	0	0
-Detectors		
--VTDS	0	0
--Inductive Loops	0.05	0.05

Table 4.5. Attribute Data (cont'd)

	Before Data	After Data
Legal Road Blocks (Major)		
Project Delay (Months)	0	3
Legal Road Blocks – Minor		
Solving the Road Blocks (Man-Hours)	0	8
Project Delay (Days)	0	1
Attorney Effort (Man-Hours)	0	1
Inter-agency Cooperation for Operations		
Operating Staff Hours Gained	1	2
System Data Presentation		
Operating Staff Hours Gained	0	200

Table 4.6. Alternate Attribute Data

	Before Data	After Data
Network Performance – Special Event, Floating Car		
Stop Time (Minutes/Miles)		
-Peak		
Route 1	1.39	1.427
Route 2	1.558	1.089
Route 3	1.368	1.063
Route 4	0.844	1
Network Wide	1.23	1.174
Running Time (Minutes per Mile)		
-Peak		
Route 1	2.115	1.968
Route 2	1.656	1.628
Route 3	1.831	1.489
Route 4	1.677	1.769
Network Wide	1.794	1.824
Network Performance – Special Event, Intersection Delay		
Average Delay per Vehicle (Seconds)		
-Ingress		
Ball/State College	43.98	55.92
Katella/State College	29.89	43.5
Cerritos/State College	10.39	11.67
Cerritos/Sunkist	20.42	36.13
Sunkist/Ball	25.36	26.48

Katella/Howell	21.06	17.16

4.5 Integrated Results

This section looks at the actual results from the overall evaluation of the system. This evaluation derives a majority of the value functions as cost functions; therefore, all the values that the evaluation reports are negative. As previously noted, the value functions are tied together with the universal scaling proxy. Thus, all of the reported values represent dollars. This section looks at not only the original scenario for data and weights, but also numerous alternative scenarios. The uniqueness of the value functions and weighting strategies make them incomparable directly with one another. The chief comparison of interest remains within a single scenario amongst different branches and/or between the "before" and "after" case. As previously discussed in chapter two, the values that are associated with each scenario have meaning on a ratio scale; therefore, the percentage change between the before and after case represents the key indicator for improvements and degradations associated with the project. The percentage change remains important at the overall level, the branch level, and the leaf level. Unless otherwise noted, all of the branch or leaf values that this section presents already include the appropriate weights.

4.5.1 *Base Case*

The first scenario represents the base case where there are no changes to the hierarchy and it utilizes the complete data set. While a complete presentation of the evaluation results may prove interesting, it would be extremely cumbersome. Therefore, this exposition focuses on examining specific branches of interest. Tables 4.7. through 4.10 display some selected "before" and "after" comparisons for this scenario. Each of these tables gives the results for a single weighting scheme.

These tables provide some valuable insight into the evaluation's results. For each of the weighting schemes, the overall worth of the system decreases from between three (3) and thirteen (13) percent. While this may appear to deem the project a failure, some key bright spots emerge that merit further investigation. This section attempts to identify these findings while the subsequent sections provide further investigation.

The final results' variance from weighting scheme to weighting scheme seems surprising. It is also apparent that small shifts in priorities between the different weighting schemes have a tremendous impact on the final results. The decision-maker preferences that are identified in section 4.3 fail to identify the magnitude of each branch's impact on the overall system value. This results from the uniqueness of each value function, where the values from some of the functions greatly eclipse the values that are generated by others. Table 4.11 identifies the percentage impact of numerous branches of the hierarchy. Section 4.6 discusses these dominant or major attributes in more detail. Additionally, the least critical parts of the problem receive attention as well. One observation is that small fluctuations that exist in the weights between the different schemes are magnified when they are combined with a major attribute or a branch that contains major attributes.

The impact of the institutional issues on the overall value is minimal when compared to technical issues because a majority of the major attributes are on the technical side, and some of the leaf values on the technical side exceeded those on the

Table 4.7. Base Case Results with Ratio Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-19,479,001	-21,007,968	-7.8
Institutional Issues	-388,101	-485,521	-25.1
Administrative Issues	0	-107,977	-
System Operations Issues	8	-28,938	-3,618.3
System Maintainability	-21,369	-35,628	-66.7
Technical Issues	0	-108	-
Legal Issues	0	-473	-
Implementation Issues	0	-804	-
Operator Acceptance	0	-9,355	-
System Costs	-1,142,941	-1,273,303	-11.4
Technical Performance	-19,090,900	-20,522,446	-7.5
Reliability	-3,917,127	-5,005,450	-27.8
Network Performance	-24,719,224	-25,156,006	-1.8
User Benefits	-98,425,635	-109,629,973	-11.4
Special Event	-146,810,312	-166,013,080	-13.1
Ingress	-104,727,249	-58,564,109	+44.1
Egress	-25,743,987	-30,516,504	-18.5
Peak	-114,212,618	-187,607,854	-64.3
No-Event	-148,466,592	-162,876,839	-9.7
Off-Peak	-31,649,213	-34,608,077	-9.3
Peak	-339,517,266	-372,584,021	-9.7
Management Goals	-49,889,707	-41,306,064	+17.2
Special Event	-61,170,913	-46,117,519	+24.6
Ingress	-63,279,410	-22,740,629	+64.1
Egress	-9,606,103	-11,372,435	-18.4
Peak	-18,870,857	-35,063,214	-85.8
No-Event	-13,663,647	-15,841,576	-15.9
Off-Peak	-5,335,832	-5,660,565	-6.1
Peak	-35,655,109	-41,864,165	-17.4
Integration Performance	0	-622,213	-

Table 4.8. Base Case Results with 100-Point Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-21,414,153	-22,079,024	-3.1
Institutional Issues	-238,719	-319,681	-33.9
Administrative Issues	0	-135,196	-
System Operations Issues	8	-21,536	-2,693.0
System Maintainability	-18,764	-28,736	-53.1
Technical Issues	0	-75	-
Legal Issues	0	-571	-
Implementation Issues	0	-863	-
Operator Acceptance	0	-12,283	-
System Costs	-776,974	-866,344	-11.5
Technical Performance	-21,175,435	-21,759,343	-2.8
Reliability	-4,010,402	-5,108,216	-27.4
Network Performance	-26,240,218	-25,528,567	+2.7
User Benefits	-129,565,755	-141,379,082	-9.1
Special Event	-143,251,165	-153,508,722	-7.2
Ingress	-106,049,451	-53,856,023	+49.2
Egress	-30,476,440	-34,650,405	-13.7
Peak	-102,226,051	-167,341,443	-63.7
No-Event	-144,672,734	-160,667,017	-11.1
Off-Peak	-38,194,431	-41,474,987	-8.6
Peak	-323,487,404	-360,192,555	-11.3
Management Goals	-45,369,035	-28,811,363	+36.5
Special Event	-72,179,081	-40,195,826	+44.3
Ingress	-74,208,907	-24,208,700	+76.4
Egress	-11,814,299	-12,180,435	-3.1
Peak	-10,215,569	-17,205,300	-68.4
No-Event	-10,310,073	-12,188,471	-18.2
Off-Peak	-5,687,357	-5,871,782	-3.2
Peak	-35,552,936	-42,882,102	-20.6
Integration Performance	0	-447,994	-

Table 4.9. Base Case Results with Regular AHP Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-10,761,481	-11,880,223	-10.4
Institutional Issues	-299,008	-363,050	-21.4
Administrative Issues	0	-78,550	-
System Operations Issues	4	-21,499	-5,375.8
System Maintainability	-19,304	-31,226	-61.8
Technical Issues	0	-87	-
Legal Issues	0	-355	-
Implementation Issues	0	-1,033	-
Operator Acceptance	0	-19,452	-
System Costs	-1,176,733	-1,299,999	-10.5
Technical Performance	-10,462,473	-11,517,173	-10.1
Reliability	-4,311,173	-5,485,311	-27.2
Network Performance	-9,638,791	-9,539,177	+1.0
User Benefits	-125,408,253	-129,121,892	-3.0
Special Event	-181,974,605	-181,245,381	+0.4
Ingress	-113,067,114	-58,654,781	+48.1
Egress	-32,270,246	-36,602,344	-13.4
Peak	-73,032,166	-122,237,333	-67.4
No-Event	-68,841,901	-76,998,403	-11.8
Off-Peak	-21,498,445	-23,267,509	-8.2
Peak	-391,552,959	-438,722,909	-12.0
Management Goals	-29,586,601	-24,271,136	+18.0
Special Event	-50,556,035	-38,065,068	+24.7
Ingress	-35,857,294	-12,522,831	+65.1
Egress	-16,797,180	-17,627,747	-4.9
Peak	-8,012,769	-15,528,151	-93.8
No-Event	-8,617,167	-10,476,665	-21.6
Off-Peak	-2,035,551	-2,134,995	-4.9
Peak	-49,667,453	-60,724,995	-22.3
Integration Performance	0	-331,744	-

Table 4.10. Base Case Results with Pairwise AHP Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-11,521,900	-13,094,004	-13.6
Institutional Issues	-132,898	-173,132	-30.3
Administrative Issues	0	-117,045	-
System Operations Issues	5	-16,764	-3,353.8
System Maintainability	-23,989	-35,334	-47.3
Technical Issues	0	-337	-
Legal Issues	0	-938	-
Implementation Issues	0	-1,281	-
Operator Acceptance	0	-12,343	-
System Costs	-773,407	-854,749	-10.5
Technical Performance	-11,389,001	-12,920,872	-13.5
Reliability	-3,833,300	-4,874,818	-27.2
Network Performance	-9,833,501	-9,716,516	+1.2
User Benefits	-113,824,898	-118,561,804	-4.2
Special Event	-145,047,556	-144,912,590	+0.1
Ingress	-87,938,234	-45,820,852	+47.9
Egress	-39,094,291	-44,630,111	-14.2
Peak	-54,276,920	-90,689,774	-67.1
No-Event	-82,602,240	-92,211,018	-11.6
Off-Peak	-21,535,802	-23,297,519	-8.2
Peak	-391,475,396	-437,757,569	-11.8
Management Goals	-33,214,265	-26,728,093	+19.5
Special Event	-58,200,976	-43,505,691	+25.2
Ingress	-42,858,749	-15,210,833	+64.5
Egress	-17,968,738	-19,561,762	-8.7
Peak	-8,993,684	-17,434,235	-93.8
No-Event	-8,227,555	-9,950,495	-20.9
Off-Peak	-2,663,155	-2,820,395	-5.9
Peak	-46,702,172	-56,882,572	-21.8
Integration Performance	0	-913,713	-

Table 4.11. Percentage Impact on Overall Value: The Base Case

Branch	Ratio Weights	100 Point Weights	AHP Regular	AHP Pairwise
Institutional Issues	2.31	1.45	3.06	1.32
Administrative Issues	.17	.18	.17	.15
System Operations Issues	.05	.03	.05	.02
System Maintainability	.06	.04	.07	.05
Technical Issues	.00	.00	.00	.00
Legal Issues	.00	.00	.00	.00
Implementation Issues	.00	.00	.00	.00
Operator Acceptance	.02	.02	.04	.02
System Costs	2.02	1.18	2.74	1.09
Technical Performance	97.69	98.55	96.94	98.68
Reliability	15.88	16.20	34.63	31.02
Network Performance	79.83	80.94	60.22	61.84
User Benefits	57.98	67.24	50.69	50.46
Special Event	29.27	32.85	35.58	30.84
Ingress	6.20	6.92	9.60	7.80
Egress	3.23	4.45	5.99	7.60
Peak	19.85	21.49	20.00	15.44
No-Event	28.72	34.38	15.11	19.62
Off-Peak	2.44	3.55	.76	.99
Peak	26.28	30.83	14.35	18.63
Management Goals	21.85	13.70	9.53	11.38
Special Event	16.26	10.51	7.47	9.26
Ingress	5.35	4.75	2.05	2.70
Egress	2.67	2.39	2.88	3.47
Peak	8.24	3.38	2.54	3.09
No-Event	5.59	3.19	2.06	2.12
Off-Peak	.67	.38	.07	.10
Peak	4.92	2.80	1.99	2.02
Integration Performance	1.98	1.42	2.09	5.82

institutional side by ten-fold. The variations in the weights allow institutional issues to account from 1.3% (AHP-Pairwise) to 3.1% (AHP-Regular) of the overall system value. This represents almost a 250% increase in overall impact between the different schemes; however, it has little impact on the relative split of value between technical and institutional issues. A scenario that focuses more attention on institutional issues appears in section 4.5.6. While the percentage of overall value divided between institutional issues and technical performance, remains essentially stable, the divisions of overall impact at lower levels of the hierarchy fluctuate more widely. This is clearly due to the combined effect of the weights as observed in Table 4.4 that displays the overall weights for each attribute. At the level of the hierarchy beneath technical performance, the branches begin to show these variations. The contributions of overall value for both reliability and network performance vary by as much as twenty percent. Reliability ranges from 15.9% (ratio) to 34.6% (AHP-Regular) while network performance varies from 60.2% (AHP-Regular) to 80.9% (100-Point). Although the overall impact of user benefits continues to display these severe swings from 67.2% (100-Point) to 50.5% (AHP-Pairwise), its special event impacts remain fairly stable with the overall shifts not exceeding seven percent. The remainder of the branches beneath network performance and user benefits: special events continue to display significant fluctuations. Thus, the variations in contributions at the lowest level carry forward to emphasize different portions of the hierarchy. These points of different emphasis have a dramatic effect on the final evaluation results.

As previously mentioned, the overall worth of the system varies from one weighting scheme to another, and all of the schemes provide results where the overall worth of the system decreases from the “before” to “after” case. The amount of loss associated with the new system ranges from –13.6% (AHP-pairwise) to –3.1% (100-Point). While the technical performance branch dominates the institutional branch, its results still influence the final project outcomes and exhibit more substantial decreases in value than technical performance. Most of the participants expected a significant cost on the institutional side of the project because implementing a new system poses many difficulties. Additionally, the new system has greater costs that are associated with not only its installation, but its operations and maintenance. The other implementation concerns that appear during the project include poor administrative project management and operating concerns with switching operations to a new system. The results for the institutional branch range from -33.9% (100-Point) to –21.4% (AHP-regular).

Since technical performance dominates the hierarchy, its results closely mirror those for overall worth, ranging from –13.5% (AHP-pairwise) to –2.8% (100-Point). The three branches (reliability, network performance, and integration performance) beneath technical performance remain essentially stable across the different weighting styles. Integration performance experiences no change with alternative approaches because a single leaf resides below it that contains three inter-related value functions. Reliability's percentage change is approximately –27.5% plus or minus 0.3% while network performance varies from –1.8% (ratio) to +2.7% (100-Point). Thus, reliability represents a significant concern for the new system as it suffers a substantial degradation in value. The majority of this concern focuses on the requirements for all of the inductive loops to remain operating properly in order to obtain proper functionality. The different operating conditions beneath user benefits exhibit great stability.

Ingress appears immensely successful while the special event peak suffers under the new system. This shows some signs of encouragement for the special event performance of SCOOT because the peak data is severely affected by the I-5 accident. Section 4.5.2 explores the alternate data set. The performance in other periods, such as special event egress, no-event peak and off-peak, decrease in value, but their losses remain between eight and twenty percent. The losses associated with egress indicate that the system can not adapt to that many cars at once, but handles the variable conditions of ingress much better. In the user benefit branch, system value under no-event conditions remains stable across weighting schemes; furthermore, the users fail to identify a significant difference between off-peak and peak in the "before" and "after" cases. The no-event operations may have suffered because of operational errors within the test system. These errors can not be identified specifically; therefore, their effects may have been captured. The Management goals' branch experiences an overall increase in value between 18.0% (AHP-regular) and 36.5% (100-point) while the special event conditions carry this increase with its improvement ranging from 24.6% (ratio) to 44.3% (100-point). The three special event operations show the same relationship as that found in the user benefits branch with ingress performing well, peak performing poorly, and egress falling in between the two. This success with management goals and with special events in particular led to two more alternative scenarios. Section 4.5.3 eliminates user benefits while section 4.5.4 looks exclusively at special event operations. The system performs poorly under no-event conditions. The management goal branch observes fluctuations for the no-event case, which experiences slides between 21.6% (AHP-regular) and 15.9% (ratio). Peak performance dominates this branch where off-peak performance looks fairly good with decreases of six percent or less, and the peak values shrink by at least seventeen percent in the "after" case. Network performance seems to indicate a small improvement in operations; however, these gains are easily overshadowed by all of the other costs associated with implementing a new system.

4.5.2 *Alternate Data Set*

As previously discussed in section 4.4, some of the "after" data is adversely affected by an accident on I-5. The base case results indicate that the overall worth of the system decreases as a result of the SCOOT implementation. Additionally, the "after" system seems to deteriorate over time with respect to the existing system. However, the branches of the hierarchy most affected by the accident, the special event-peak for both user benefits and management goals, contribute somewhere between eighteen (18) and twenty-eight (28) percent of the overall system worth. Thus, an improvement for these branches can improve the apparent results of the evaluation. Table 4.12 focuses on the branches affected by utilizing the alternate data set.

Table 4.13 outlines the comparisons between the results of this scenario and the base case. In the results, overall worth increases at least 12.2% (AHP-pairwise) and as much as 17.5% (ratio). Clearly, the accident data has a dramatic affect on the final evaluation results. Three of the four weighting schemes now indicate that the project increases the overall system worth from between 3.9% (AHP-regular) to 11.8% (100-point). The new percentage increases in network performance values remain fairly stable amongst the different weighting approaches, but technical performance continues to experience wide fluctuations as a result of the difference in local weights at this level of the hierarchy. The evaluation results from using this alternative data set indicates that the new system clearly has merit and should not be abandoned.

Table 4.12. Results Using Alternate Data Set

Branch	Before Value	After Value	Pct. Change
Overall: Ratio Weights	-19,479,001	-17,592,349	+9.7
Technical Performance	-19,090,900	-17,106,827	+10.4
Network Performance	-24,719,224	-20,032,578	+19.0
User Benefits: Special Event	-146,810,312	-104,379,039	+28.9
Management Goals: Special Event	-61,170,913	-30,823,684	+49.6
Overall: 100-Point Weights	-21,414,153	-18,891,364	+11.8
Technical Performance	-21,175,435	-18,571,683	+12.3
Network Performance	-26,240,218	-20,974,767	+20.1
User Benefits: Special Event	-143,251,165	-97,622,784	+31.9
Management Goals: Special Event	-72,179,081	-30,723,107	+57.4
Overall: AHP-Regular Weights	-10,761,481	-10,341,970	+3.9
Technical Performance	-10,462,473	-9,978,920	+4.6
Network Performance	-9,638,791	-7,488,172	+22.3
User Benefits: Special Event	-181,974,605	-124,372,566	+31.7
Management Goals: Special Event	-50,556,035	-28,976,800	+42.7
Overall: AHP-Pairwise Weights	-11,521,900	-11,678,124	-1.4
Technical Performance	-11,389,001	-11,504,992	-1.0
Network Performance	-9,833,501	-8,017,461	+18.5
User Benefits: Special Event	-145,047,556	-104,397,468	+28.0
Management Goals: Special Event	-58,200,976	-33,209,269	+42.9

Table 4.13. Base Case vs. Alternate Data Case

Branch	Base Case	Alternate Data Case
Overall: Ratio Weights	-7.8	+9.7
Technical Performance	-7.5	+10.4
Network Performance	-1.8	+19.0
User Benefits: Special Event	-13.1	+28.9
Management Goals: Special Event	+24.6	+49.6
Overall: 100-Point Weights	-3.1	+11.8
Technical Performance	-2.8	+12.3
Network Performance	+2.7	+20.1
User Benefits: Special Event	-7.2	+31.9
Management Goals: Special Event	+44.3	+57.4
Overall: AHP-Regular Weights	-10.4	+3.9
Technical Performance	-10.1	+4.6
Network Performance	+1.0	+22.3
User Benefits: Special Event	+0.4	+31.7
Management Goals: Special Event	+24.7	+42.7
Overall: AHP-Pairwise Weights	-13.6	-1.4
Technical Performance	-13.5	-1.0
Network Performance	+1.2	+18.5
User Benefits: Special Event	+0.1	+28.0
Management Goals: Special Event	+25.2	+42.9

In fact, it may prove to be a system worthy of usage in other locations, especially if they reduce some of the more controllable costs, such as poor project management. The weighting scheme (AHP-pairwise) that still indicates a decrease in overall worth would likely improve its small deficit (-1.4%) by improving a few other components or limiting SCOOT operations to special events only. The AHP approaches indicate smaller overall improvements because they did not emphasize traffic performance to the extent that both ratio and 100-point weighting schemes did. Finally, improved SCOOT operations should only have positive effect on any of the system. SCOOT operations would likely improve because the operators would become more experienced with its operations and recognize when errors occur and how to quickly correct them.

4.5.3 *Eliminating User Benefits*

Many difficulties exist when attempting to ascertain user benefits, and determining user value functions may prove more challenging. This research experiences significant difficulties combining just five divergent users into a single coherent function. It is true that these problems may be reduced with a well formulated sampling plan and perhaps a larger number of respondents from the driving public; however, the combination of multiple users together during the evaluation phase may not be appropriate without extensive organization. The stability of the user value functions outside the peak period remains highly suspect. Many of the respondents in this research's small sample express a difference in their values during the peak and off-peak periods. Additionally, users typically lack the knowledge of the costs associated with improving a given network. A better approach may be the adoption of a benevolent dictator or oligarchy that can establish the value function for the overall network based on their knowledge of the prevailing conditions, number of users during varying time periods, and user expectations. This scenario examines precisely the aforementioned approach by eliminating the user benefits branch from network performance. Table 4.14 presents some selected "before" and "after" comparisons for this scenario while Table 4.15 compares the percentage change between the "before" and "after" cases in the base scenario to the change in this scenario.

Table 4.14. Results Using Only Management Goals

Branch	Before Value	After Value	Pct. Change
Overall: Ratio Weights	-11,314,470	-11,121,641	+1.7
Technical Performance	-10,926,369	-10,636,120	+2.7
Network Performance	-12,472,427	-10,326,516	+17.2
Overall: 100-Point Weights	-11,707,362	-9,709,379	+17.1
Technical Performance	-11,468,643	-9,389,968	+18.1
Network Performance	-12,373,373	-7,857,645	+36.5
Overall: AHP-Regular Weights	-6,292,276	-6,989,894	-11.1
Technical Performance	-5,993,268	-6,626,844	-10.6
Network Performance	-3,679,852	-3,018,738	+18.0
Overall: AHP-Pairwise Weights	-7,029,419	-7,976,053	-13.5
Technical Performance	-6,896,520	-7,802,922	-13.1
Network Performance	-4,442,524	-3,574,976	+19.5

Two of the weighting approaches enjoy noticeable improvement under this scenario while the remaining two undergo little change at all. The overall system worth improves by 9.5% using the ratio weights, and the overall worth using 100-point weights undergoes an increase of 20.2%. Although the value of network performance improves for both of the AHP approaches, the overall system worth remains approximately the same. In both of these approaches, the weight attributed to network performance limits the impact it can affect on the overall value. In fact, this scenario reduces the overall impact of the network performance branch with respect to the other branches that are

Table 4.15. Base Case vs. No User Benefits Scenario

Branch	Base Case	No User Benefits Scenario
Overall: Ratio Weights	-7.8	+1.7
Technical Performance	-7.5	+2.7
Network Performance	-1.8	+17.2
Overall: 100-Point Weights	-3.1	+17.1
Technical Performance	-2.8	+18.1
Network Performance	+2.7	+36.5
Overall: AHP-Regular Weights	-10.4	-11.1
Technical Performance	-10.1	-10.6
Network Performance	+1.0	+18.0
Overall: AHP-Pairwise Weights	-13.6	-13.5
Technical Performance	-13.5	-13.1
Network Performance	+1.2	+19.5

attached to technical performance because the user benefits' values are at least three times greater than management goals' values. Under the AHP-regular weighting scheme, the overall impact of network performance reduces to such a degree that even though its percentage change in value increases by 17 % from the base case, technical performance and overall value decreases with respect to the base case by 0.5% and 0.7%. Network performance and technical performance values both improve in the ratio and 100-point schemes where network performance value for the 100-point weights increases by 33.8%. This dramatic improvement allows this scheme to note the largest increase in overall value for this scenario. The improvement in network performance fluctuates between 17.0% (AHP-regular) and 33.8% (100-point) and technical performance varies from a decrease of 0.5% (AHP-regular) to an increase of 20.9% (100-point). While the contributions to the overall value drop for network performance and two of the schemes note significant improvements, the other schemes remain relatively stable. Thus, the adoption of a benevolent dictator or oligarchy may prove to be a worthwhile approach to use in order to limit the difficulties with thoroughly assessing the user value functions.

4.5.4 *Special Event Only*

The next scenario isolates the special event case. Since the special events' network performance results are superior to the no-event results, a case may be made for implementing the system for only special events. This is examined by removing all of the branches pertaining to regular, no-event operations, including its network performance, operations and maintenance costs, and operator acceptance branches. The remainder of the hierarchy is left intact; therefore, the overall worth of a special event system can be ascertained. Table 4.16 present some selected "before" and "after" comparisons for this scenario while Table 4.17 compare the percentage change between the "before" and "after" cases in the base scenario to the change in this scenario.

This scenario demonstrates noticeable improvements over the base case. Since these improvements are found across all of the weighting schemes, the data indicates that the new system functions better under special event conditions than non-event conditions. In fact, the network performance under all weighting schemes now increases between the "before" and "after" cases. This finding remains consistent with the results

Table 4.16. Results for Special Event Only Scenario

Branch	Before Value	After Value	Pct. Change
Overall: Ratio Weights	-18,858,148	-19,607,134	-4.0
Institutional Issues	-387,597	-483,468	-24.7
Technical Performance	-18,470,551	-19,123,665	-3.5
Network Performance	-23,788,700	-23,057,835	+3.1
User Benefits	-81,561,285	-92,229,489	-13.1
Management Goals	-61,170,913	-46,117,519	+24.6
Overall: 100-Point Weights	-19,884,612	-19,391,650	+2.5
Institutional Issues	-238,512	-318,413	-33.5
Technical Performance	-19,646,100	-19,073,237	+2.9
Network Performance	-24,055,455	-21,691,272	+9.8
User Benefits	-107,438,374	-115,131,541	-7.2
Management Goals	-52,931,326	-29,476,939	+44.3
Overall: AHP-Regular Weights	-10,039,558	-10,862,784	-8.2
Institutional Issues	-298,921	-362,682	-21.3
Technical Performance	-9,740,637	-10,500,102	-7.8
Network Performance	-8,676,343	-8,183,082	+5.7
User Benefits	-109,184,763	-108,747,229	+0.4
Management Goals	-30,333,621	-22,839,365	+24.7
Overall: AHP-Pairwise Weights	-10,325,649	-11,499,056	-11.4
Institutional Issues	-132,841	-172,978	-30.2
Technical Performance	-10,192,807	-11,326,078	-11.1
Network Performance	-8,398,069	-7,802,764	+7.1
User Benefits	-90,654,723	-90,570,368	+0.1
Management Goals	-34,920,585	-26,103,415	+25.2

Table 4.17. Base Case vs. Special Event Only Scenario

Branch	Base Case	Special Event Only
Overall: Ratio Weights	-7.8	-4.0
Institutional Issues	-25.1	-24.7
Technical Performance	-7.5	-3.5
Network Performance	-1.8	+3.1
User Benefits	-11.4	-13.1
Management Goals	+17.2	+24.6
Overall: 100-Point Weights	-3.1	+2.5
Institutional Issues	-33.9	-33.5
Technical Performance	-2.8	+2.9
Network Performance	+2.7	+9.8
User Benefits	-9.1	-7.2
Management Goals	+36.5	+44.3
Overall: AHP-Regular Weights	-10.4	-8.2
Institutional Issues	-21.4	-21.3
Technical Performance	-10.1	-7.8
Network Performance	+1.0	+5.7
User Benefits	-3.0	+0.4
Management Goals	+18.0	+24.7
Overall: AHP-Pairwise Weights	-13.6	-11.4
Institutional Issues	-30.3	-30.2
Technical Performance	-13.5	-11.1
Network Performance	+1.2	+7.1
User Benefits	-4.2	+0.1
Management Goals	+19.5	+25.2

found in the base case. The strong network performance only counteracts the institutional issues and other branches of technical performance under a single weighting scheme, 100-point. In all of the remaining weighting approaches, the overall system value still decreases between the "before" and "after" cases. The improvement over the base case in overall value varies from 2.2% (AHP-regular) to 5.6% (100-point). Changing to special event only operations has little effect on institutional issues, but its value increases slightly over the base case because all no-event operating costs are eliminated. The improvements over the base case for this scenario continues with technical performance improvements between 2.3% (AHP-regular) and 5.7% (100-point) and network performance increases between 4.7% (AHP-regular) and 7.1% (100-point). The percentage change between cases improves under all weighting schemes for management goals and all except one (ratio) for user benefits. The case that fails to show improvement is the performance during special event peak. While SCOOT performs well under special event conditions, by-and-large these improvements fail to counteract the costs associated with implementing and maintaining SCOOT. However, an improvement of reliability and administrative issues may have made enough of a difference to show an increase in overall value under all weighting schemes.

4.5.5 *Changing the Interest Rate*

Although the previous discussion of the evaluation results fails to focus on the effects of extending certain branches of the hierarchy beyond this initial evaluation, this feature remains critical to the final outcome of the project. While the initial implementation of a new system may include numerous one-time costs or benefits, the lifetime of the project contributes a great deal of its overall value. Anywhere between eighty-five and ninety-five percent of the overall value derives from the attributes that continue to effect the system following implementation, such as network performance, reliability, operating costs, and system maintainability. Thus, the discounting rate that is applied to system performance in all years other than the base year can greatly influence the overall system value. In order to illustrate this fact, this research substitutes the discounting rate identified by the decision-maker with an annual interest rate of ten percent that is compounded annually. In all cases, this change in interest rates increases the actual values of the effected attributes. These increases magnified their impacts on their "branches'" final values. Likewise, extending the life span of the system may have a dramatic affect on its overall valuation because the gulf between the two cases tends to widen over time with the "after" case decreasing with respect to the "before" case. Each of the branches in this evaluation maintains its own pattern. The percentage change between the "before" and "after" case increases over time for system operations issues and reliability, decreases over time for system costs, behaves erratically for system maintainability, and remains constant for network performance. Table 4.18 presents "before" and "after" comparisons for the affected branches while Table 4.19 compares the percentage change between the "before" and "after" cases in the base scenario to the change in this scenario.

The results from this scenario at times seem paradoxical; however, closer examination helps explain these outcomes. The percentage change between the "before" and "after" cases improves in this scenario; however, the difference between the base case and this scenario is almost always 0.5% or less, which is precisely the same change in overall value and technical performance under all weighting conditions. This occurs in spite of degradations in institutional issues and reliability, and no variation in the

Table 4.18. Results from Changing the Interest Rate

Branch	Before Value	After Value	Pct. Change
Overall: Ratio Weights	-24,395,637	-26,216,637	-7.5
Institutional Issues	-397,132	-498,134	-25.4
System Maintainability	-27,187	-45,323	-66.7
System Costs	-1,164,220	-1,301,451	-11.8
Technical Performance	-23,998,505	-25,718,503	-7.2
Reliability	-4,983,916	-6,393,692	-28.3
Network Performance	-31,013,842	-31,561,849	-1.8
Overall: 100-Point Weights	-26,864,321	-27,632,180	-2.9
Institutional Issues	-249,697	-330,186	-33.8
System Maintainability	-23,846	-36,558	-53.3
System Costs	-798,488	-893,544	-11.9
Technical Performance	-26,617,624	-27,301,995	-2.6
Reliability	-5,103,027	-6,525,576	-27.9
Network Performance	-32,922,150	-32,029,280	+2.7
Overall: AHP-Regular Weights	-13,486,876	-14,848,416	-10.1
Institutional Issues	-303,286	-369,113	-21.7
System Maintainability	-24,482	-39,665	-62.0
System Costs	-1,188,667	-1,315,814	-10.7
Technical Performance	-13,183,590	-14,479,304	-9.8
Reliability	-5,484,863	-7,005,718	-27.7
Network Performance	-12,093,257	-11,968,277	+1.0
Overall: AHP-Pairwise Weights	-14,480,635	-16,285,159	-12.5
Institutional Issues	-135,284	-176,482	-30.5
System Maintainability	-30,419	-44,918	-47.7
System Costs	-781,291	-865,273	-10.7
Technical Performance	-14,345,351	-16,108,676	-12.3
Reliability	-4,876,871	-6,225,924	-27.7
Network Performance	-12,337,550	-12,190,775	+1.2

Table 4.19. Base Case vs. Fixed Interest Rate Scenario

Branch	Base Case	Fixed Interest Rate
Overall: Ratio Weights	-7.8	-7.5
Institutional Issues	-25.1	-25.4
System Maintainability	-66.7	-66.7
System Costs	-11.4	-11.8
Technical Performance	-7.5	-7.2
Reliability	-27.8	-28.3
Network Performance	-1.8	-1.8
Overall: 100-Point Weights	-3.1	-2.9
Institutional Issues	-33.9	-33.8
System Maintainability	-53.1	-53.3
System Costs	-11.5	-11.9
Technical Performance	-2.8	-2.6
Reliability	-27.4	-27.9
Network Performance	+2.7	+2.7
Overall: AHP-Regular Weights	-10.4	-10.1
Institutional Issues	-21.4	-21.7
System Maintainability	-61.8	-62.0
System Costs	-10.5	-10.7
Technical Performance	-10.1	-9.8
Reliability	-27.2	-27.7
Network Performance	+1.0	+1.0
Overall: AHP-Pairwise Weights	-13.7	-12.5
Institutional Issues	-30.3	-30.5
System Maintainability	-47.3	-47.7
System Costs	-10.5	-10.7
Technical Performance	-13.5	-12.3
Reliability	-27.2	-27.7
Network Performance	+1.2	+1.2

network performance. These surprising results happen when an increase in the overall impact of network performance overshadows all of the other degradations. This increase occurs because all of the continuing branches increase their actual values under this new interest rate, which helps them reduce the effects of the other branches. Paradoxically, institutional issues' variation between trials improves for a single weighting structure, 100-point, while decreasing for the other three. Furthermore, the three leafs effected by the change in interest rates exhibits degradations between the base case and this scenario under all weighting conditions. This fascinating result happens because the unaffected attributes contribute 14 % of the overall value while the other weighting schemes have a high point of almost 12%. After the change in interest rates, the unaffected attributes represent a smaller 13.5% of the overall value. Similarly, under the AHP-pairwise scheme network performance remains unchanged between the base case and this scenario, but the increase in overall impact of network performance allows it to generate an increase in the change value of 1.2%. Thus, while the interest rate can have a significant affect on the outcome of the evaluation by changing the impact of the continuing branches, the other scenarios under investigation seem to have a greater effect on the final outcome.

4.5.6 *Emphasizing Institutional Issues*

As previously stated, the decision-makers in this evaluation all have decided to emphasize the technical performance of the new system over its institutional issues. This scenario reverses the decision-maker's preferences for these two branches. This helps to demonstrate the magnitude of possible change in the overall value of the system as a result of varying the local weights at the highest level of the hierarchy. Additionally, this scenario helps identify the magnitude of potential influence each branch may have under this scenario. This remains important because the technical performance values clearly dominate the institutional, but the effects are exacerbated by the weighting structures. Table 4.20 highlights the change in overall value between the "before" and "after" cases. Table 4.21 demonstrates that the percentage change between the "before" and "after" case in overall value can change between the base case and this scenario without varying the percentage change in either institutional issues or technical performance.

Table 4.20. Results for Emphasized Institutional Scenario

Branch	Before Value	After Value	Pct. Change
Overall: Ratio Weights	-10,321,651	-11,232,266	-8.8
Institutional Issues	-776,201	-971,042	-25.1
Technical Performance	-9,545,450	-10,261,223	-7.5
Overall: 100-Point Weights	-9,632,197	-10,071,355	-4.6
Institutional Issues	-557,011	-745,922	-33.9
Technical Performance	-9,075,186	-9,325,433	-2.8
Overall: AHP-Regular Weights	-4,384,515	-4,928,208	-12.4
Institutional Issues	-897,024	-1,089,150	-21.4
Technical Performance	-3,487,491	-3,839,058	-10.1
Overall: AHP-Pairwise Weights	-2,942,721	-3,450,315	-17.2
Institutional Issues	-664,465	-865,624	-30.3
Technical Performance	-2,278,256	-2,584,691	-13.5

In this scenario, the contributions of the leafs that are attached to the technical performance branch decrease. This helps show the impact of reversing a single comparison in the uppermost branches of the hierarchy. A reversal can easily occur as a result of decision-maker error or confusion. Numerous reversals are observed during this evaluation. Even though the percentage change in institutional issues and technical performance does not change from the base case to this scenario, the overall value of the system decreases. The losses that range from 1.0% (ratio) to 3.6% (AHP-pairwise) result fom a swing in the impacts of the various branches in the hierarchy. Table 4.22 shows these impacts for the base case as well as this scenario.

Table 4.21. Base Case vs. Emphasized Institutional Scenario

Branch	Base Case	Emphasized Institutional
Overall: Ratio Weights	-7.8	-8.8
Institutional Issues	-25.1	-25.1
Technical Performance	-7.5	-7.5
Overall: 100-Point Weights	-3.1	-4.6
Institutional Issues	-33.9	-33.9
Technical Performance	-2.8	-2.8
Overall: AHP-Regular Weights	-10.4	-12.4
Institutional Issues	-21.4	-21.4
Technical Performance	-10.1	-10.1
Overall: AHP-Pairwise Weights	-13.6	-17.2
Institutional Issues	-30.3	-30.3
Technical Performance	-13.5	-13.5

The percentage impacts for the various branches differ significantly across all of the weighting schemes, especially the AHP schemes. The AHP schemes differ more extensively because the priority between institutional issues and technical performance is more dramatic than for the other two weighting approaches. In the AHP-pairwise approach, the five primary branches that are attached to institutional issues increase their percentage impact by a multiple of at least fifteen and as much as twenty. The AHP-regular scheme sees large increases, but they fall short of those enjoyed by the other AHP scheme. The remaining approaches, ratio and 100-point, see the same branches increase by multiples of three and four. All these increases occur at the expense of the technical performance branches, which all see some shrinkage in their overall impact, but remain dominant. Even in the AHP-pairwise case, technical performance contributes almost seventy-five percent of the overall value while the 100-point scheme makes up over ninety-two percent of the overall value. Changing preferences could have a tremendous impact on the final results of an evaluation as well as the impacts associated with each leaf; therefore, the final priorities need to be arrived at in a careful manner.

Table 4.22. Percentage of Overall Value:
Base Case vs. Emphasized Institutional Scenario

Branch	Ratio Weights		100 Point Weights		AHP Regular		AHP Pairwise	
	Base Case	Inst. Case	Base Case	Inst. Case	Base Case	Inst. Case	Base Case	Inst. Case
Institutional Issues	2.3	8.6	1.4	7.4	3.1	22.1	1.3	25.1
Administrative Issues	.17	.64	.18	.94	.17	1.2	.15	2.8
System Operations Issues	.05	.17	.03	.15	.05	.33	.02	.41
System Maintainability	.06	.21	.04	.20	.07	.48	.05	.85
Operator Acceptance	.02	.06	.02	.09	.04	.30	.02	.30
System Costs	2.0	6.9	1.2	6.0	2.7	19.8	1.1	20.6
Technical Performance	97.7	91.4	98.6	92.6	96.9	77.9	98.7	74.9
Reliability	15.9	14.9	16.2	15.2	34.6	27.8	31.0	23.6
Network Performance	79.8	74.7	80.9	76.0	60.2	48.4	61.8	46.9

Integration Performance	2.0	1.8	1.4	1.3	2.1	1.7	5.8	4.4

4.6 Sensitivity Analysis/Key Issues

As noted during the previous investigation of the evaluation results, altering the priorities of the attributes has a profound effect on the final evaluation outcomes. The same effects can be noted when altering attribute levels. Certain attributes overwhelm most of the other attributes, and changes to these drive the overall evaluation process. Others are so insignificant that changing their attribute levels may not have had any impact on the final results. The importance of these attributes relates closely not only to its own value function but also its weight and position in the hierarchy. The hierarchical positioning remains critical when one or more attributes within a leaf dominate the others. While this section has not undertaken an in-depth sensitivity analysis, it provides a description of the dominant and insignificant attributes, as well as some potential reasons behind this behavior. Overall small changes in attribute levels can have an impact on the final results, but these will by and large be relatively insignificant. However, moderate to large change in many of the attributes may cause major shifts.

As previously stated the final overall value has little meaning without being able to reference it to a known state; however, within a single state, the values of the various leafs play a significant role in determining this final value. Certain attributes dominate the process and contribute a majority of the value; furthermore, these attributes dominate the changes to the system between the "before" and "after" case. While weighting reduces each individual attribute's dominance, the network performance attributes dominate the evaluation. Specifically, the stop time and user benefits attributes dominate the evaluation because the value functions that are associated with these attributes overwhelm the others. Within the reliability branch, the downtime of inductive loops dominates the other attributes in its leaf because its attribute levels are significantly greater than those of the other attributes are. Additionally, at this elevated level, small changes in the attribute level affect large changes in its value. Similarly, project management has an elevated level that helps it make an impact even though its weight is quite small. The project management attribute dominates the administrative issues leaf. The integration performance leaf is dominated by system downtime because its value function returns large values for low attribute levels. The system costs branch and the robustness under component failure leaf contain attributes that have both value functions and attribute levels that allow them to make major contributions to the final evaluation.

Many of the institutional attributes make little impact on the final evaluation results. Three entire branches (technical issues, legal issues, and implementation issues) could be dropped from the hierarchy without noticing their departure; however, the dropping of these branches would increase the impact of the remaining institutional branches. The overwhelmed branches require further attention because the reasons behind this state must be ascertained. In other instances, an attribute within a leaf could not compete against its fellow attributes, which results for any number of reasons. Some have value functions that are insignificant when compared to those of other attributes, for example minor legal roadblocks, inter-agency cooperation for operations, and transitioning a test system to regular operations. Most likely, these attributes need to be dropped altogether. Others have low attribute levels in this system, which render them unimportant. In a few instances, these attributes seem unnecessary altogether when compared to the other attribute in its leaf, for example the ease or effectiveness of system maintainability is unimportant when compared to the time required for system maintainability. Although the weights and value function may have indicated otherwise, this overwhelming nature of the time required for maintenance appears during the determination of attribute levels. Another example, where a low attribute level reduces its importance may simply be an attribute that plays a small role in this system, such as the attributes attached to the implementation issues' branch. In this evaluation, the implementation proceeds as planned with no major changes from the timeline; therefore, no significant values materialize for the implementation issues. Finally, a leaf's weight can reduce its significance. Taken individually, this is the case for each of the attributes at the end of the network performance branch; however, when these are combined together they become the most dominant factor in the evaluation.

Finally, the attributes that are unassessed for this evaluation should be examined to see if an effort should be devoted to determining these or could another set of attributes be developed that capture their effects. This decision would have a significant impact on the outcome of the evaluation because the different weighting schemes allocated thirty to fifty percent of the overall priority to the accuracy of SCOOT modeling branch, and they allocated two to seven percent to the operators' estimate of effectiveness. Clearly, their inclusion, substitution, or complete elimination would make an impact on the final outcome.

While all of the attributes are initially included to provide a complete picture of the system, some play more important roles in the overall evaluation than others. Ultimately, the combination of hierarchical structure, weights, value functions, and attribute levels work together to determine the values for this evaluation. None of these key components can be ignored;

therefore, they all require continued scrutiny to firmly establish an effective and consistent evaluation tool. Furthermore, adjustments and modifications may prove to be necessary for all usages of this evaluation system. If this proves to be true, a standardized approach should be developed to guide this process.

4.7 Institutional Relationship

Currently, the evaluation does not indicate any large institutional difficulties that this project encountered because the network performance seems to overwhelm the institutional components. This occurs for a number of reasons primary reasons, the value functions and the attribute levels for the technical performance results in high levels for the technical performance attributes. The weights for the key institutional concerns are potentially inappropriate for their impact on the project. Eliminating some of the insignificant institutional components, which will increase the weights of the remaining objective branches, can reduce this effect. The most important aspect, however, may have been that the decision-makers emphasize technical performance compared to the institutional issues. Chapter six covers all of the institutional issues in great detail.

The aforementioned comments not withstanding, two key institutional concerns rise to the forefront, administrative issues and system costs. The change from the "before" to "after" case results in similar impacts from both with each contributing almost $108,000 towards the overall increase in institutional costs. The most significant finding from the institutional evaluation is the need for effective project management, which is included in administrative issues. This project suffered through numerous delays when project management failed to keep the project on-track. This lack of project management results directly in at least fifteen months of delay to the project and indirectly contributes to another seven to nine months of project delay. The project struggles to maintain its calendar because little, if any, communication amongst the partners occurs between meetings. Thus, each concern usually requires at least one month to receive any response. As evidenced by the evaluation results, the system costs remains a critical concern for the City of Anaheim because they do not know if they would be able to obtain the necessary money to operate and maintain the new system. The evaluation effectively captures these two key points even if they fail to have a large impact on the overall project value.

Three areas of concern do not seem to have a major impact; however, the institutional study observes "significant" concerns. One potential component of operator acceptance, the operators' estimate of effectiveness, is dropped during the evaluation (as explained in section 4.2). This lessens the overall impact of operator acceptance. According to John Thai, operator break-in period is the only one of the three attributes with any "real" importance. Another objective branch, system operations issues, has a sizeable impact on the overall evaluation. These issues when combined with operator acceptance may be even more significant than the evaluation indicates. Past observations and current conditions tend to support this contention. During the field test for the evaluation, numerous problems occurred with SCOOT operations that went undetected by the City staff. Both system operations issues and operator acceptance plays a significant role in this failure. Additionally, SCOOT has not been regularly used in the City since the field test, which occurred two years ago. Finally, system maintenance would be crucial for the new SCOOT system; however, at the beginning of the project only about 20% of the City's existing system detectors were functional. Although, the City appears to lack a tradition of maintaining their system, the evaluation fails to adequately capture its effects on the overall system. Furthermore, the ease or effectiveness of maintainability appears to have no importance, and should be eliminated from future evaluations. These branches require additional effort to improve their representation in the evaluation.

The three remaining institutional issues (technical issues, legal issues, and implementation issues) have little, if any, effect. Since the project fails to encounter any significant technical issues, there is practically no impact. Technical issues could have a significant impact on another project; however, the evaluation effectively captures their impact on this one. The impact of legal issues may be debated amongst the participants; however, the evaluators believe that the legal issues, while significant, may have been readily solved if the project management had been more effective from the beginning. In fact, when a change in project management occurred approximately two years into the project, all legal problems disappeared within two months. Although the original proposal fails to adequately account for potential legal issues, their impact on the overall project is insignificant. Furthermore, legal issues appear to represent the most likely branch of the hierarchy to eliminate because they had no "real" impact until after they exceeded four months. Finally, one of the chief successes of the project is the implementation of the new system. According to the evaluation, it still increases the overall cost of the "after" system, but this increase is insignificant and to be expected given the difficulties of implementing a new system. All three of these objective branches is insignificant in the overall evaluation, but they could have a significant impact on another project.

The evaluation seems to handle the institutional issues quite effectively. In fact, in one the hypothetical examples from section 4.5 a switch in priorities from technical to institutional makes their impact on the overall value approximately the same. Changes to decision-maker priorities, as well as the elimination of insignificant branches, can serve to increase this impact. These include any leafs where the level of an attribute can be termed insignificant. Future evaluations should be able to build on the successes of this one and improve the handling of the institutional issues.

4.8 Decision-Maker Questionnaires

As part of the examination of the new evaluation scheme, the decision-makers provide feedback on their experiences. Decision-maker insight may assist in the continuing improvement of the process. The research conducts two different types of decision-maker interviews, individual and group. The results from these interview formats are presented separately. The questionnaires, which were distributed at the conclusion of the interview, include a quantitative portion and open-ended questions to elicit decision-maker experiences. This section starts by examining the results of the quantitative assessment and concludes by discussing specific comments provided by the decision-makers.

The decision-makers respond to a series, twenty-five for individual and twenty-four for group, of quantitative questions based on a seven-point scale. In this scale, one is the weakest or worst response and seven is the strongest or best. The research conducts two individual interviews with John Thai and Richard Macaluso. The results from their responses are presented in Table 4.23.

4.23. Decision-Maker Feedback – Individual Format

Question	JT	RM	Average
Ease of Understanding: Ratio Approach	5	5	5
100-point Approach	6	7	6.5
Regular AHP	2	3	2.5
AHP-Pairwise Comparisons	1	1	1
Ease of Selecting: Ratio Approach	7	5	6.5
100-point Approach	7	7	7
Regular AHP	2	3	2.5
AHP-Pairwise Comparisons	1	1	1
Suitability of Final Results: Ratio Approach	6	7	6.5
100-point Approach	6	7	6.5
Regular AHP	5	6	5.5
AHP-Pairwise Comparisons	4	5	4.5
Overall Desire to Use in Future: Ratio Approach	7	5	6
100-point Approach	7	7	7
Regular AHP	2	1	1.5
AHP-Pairwise Comparisons	1	1	1
Ease of Understanding Value Function Technique	1	5	3
Ease of Selecting Value Function Technique	1	3	2
Suitability of Final Value Function Technique	2	5	3.5
Applicable of Monetary Terms for Comparing Attributes	5	4	4.5
Agreement with Overall Grouping of Attributes	6	3	4.5
Ease of Understanding Overall Technique	3	4	3.5
Ease of Overall Interview Process	3	3	3
Suitability of Final Values	5	5	5
Interview’s affect on understanding the issues for this problem	5	4	4.5

Looking at the weighting approaches first, both Mr. Thai and Mr. Macaluso find that the two rating techniques, ratio and 100-point, are both easy to understand and use, but the two AHP techniques are both difficult to understand and use. The regular AHP scheme appears slightly easier than the pairwise approach on both accounts. Similarly, both respondents indicate their preference for using both rating techniques in the future while they have no desire to use either AHP technique. Overall the decision-makers appear to prefer the 100-point approach to the ratio approach by a slight margin, primarily because it is the easiest to understand. The respondents believe that all of the weights seem fairly suitable with the rating techniques appearing the most suitable. Both respondents indicate their difficulty with the value function approach. While the suitability of the final value functions appears fair, the decision-makers find the technique difficult to understand and cumbersome to apply. For the rest of the questions, the decision-makers are fairly ambivalent. Overall, they indicate a slight preference for the final outcomes, but feel slightly uncomfortable with the process. Perhaps a reduction in the number of value functions may improve decision-maker acceptance.

In the group interview, some of the techniques did not receive as much attention, specifically, the two AHP techniques and the value function technique. Frank Cechini and Richard Macaluso participated in the group decision-maker interview. Mr. Cechini's does not provide responses to all of the questions since he has not developed an opinion on those topics. Table 4.24 looks at the group interview format and presents the decision-maker's responses. Once again, the rating techniques appear easier to use, but they are not as dominant in the group setting. Mr. Macaluso finds the AHP techniques more conducive to a group setting than in an individual interview. However, the respondents still seem more comfortable with the results from the two rating techniques than AHP. The rating techniques still appear to be overwhelmingly preferred for future applications of this new evaluation technique. Surprisingly, both respondents believe the group setting is better for assessing value functions than individually.

4.24. Decision-Maker Feedback – Group Format

Question	FC	RM	Average
Ease of Selecting: Ratio Approach	4	6	5
100-point Approach	6	6	6
Regular AHP	-	4	4
AHP-Pairwise Comparisons	-	4	4
Suitability of Final Results: Ratio Approach	4	7	5.5
100-point Approach	6	7	6.5
Regular AHP	-	6	6
AHP-Pairwise Comparisons	-	5	5
Individual vs. Group: Ratio Approach (group preferred = 7)	6	2	4
100-point Approach	3	2	2.5
Regular AHP	-	6	6
AHP-Pairwise Comparisons	-	6	6
Overall Desire to Use in Future: Ratio Approach	6	5	5.5
100-point Approach	5	7	6.5
Regular AHP	-	1	1
AHP-Pairwise Comparisons	-	1	1
Ease of Selecting Value Function Technique	2	5	3.5
Suitability of Final Value Function Technique	3	5	4
Individual vs. Group for Value Function Technique	7	6	6.5
Ease of Overall Interview Process	6	5	5.5
Suitability of Final Values	6	5	5.5
Individual vs. Group: Overall Preference	7	5	6
Interview’s affect on understanding the issues for this problem	6	4	5
Group vs. Individual: Interview’s affect on understanding	7	4	5.5

However, one must note that both respondents are very familiar with one another and did not have disparate values. Overall, the group interview appears to be preferred to the individual interview with final results seeming reasonable, and the interview process increasing decision-maker understanding of the problem. Judicious organization of groups may simplify the overall process.

Mr. Thai and Mr. Macaluso disagreed about the ease of understanding the value function technique. Mr. Macaluso finds it easy to understand while Mr. Thai finds it extremely difficult. They both find the value functions difficult to quantify, but Mr. Macaluso believes the final value functions are useful while Mr. Thai remains skeptical. Mr. Thai shows a stronger deference for the grouping and organization of the hierarchy than Mr. Macaluso because the hierarchy is created in consultation with Mr. Thai. Mr. Macaluso expresses a concern about redundancy within the hierarchy. Mr. Thai finds the AHP process extremely unpleasant, especially in reference to the other weighting approaches; he recommends changing the whole AHP process or eliminating it. Similarly, he wants to see an overall simplification and condensation of the process to make it user-friendlier for practitioners. Possible uncertainty about quantifying the costs and benefits of some attributes concerns Mr. Macaluso, but he still finds all of the attributes quantifiable in monetary terms. Although Mr. Macaluso finds the overall process a struggle, he is pleased with the final results and gives them credence. Finally, Mr. Macaluso remains concerned about trying to quantify qualitative conditions.

The group interview seems to generate fewer decision-maker comments because the decision-makers appear more comfortable with the group setting than the individual setting. This may occur because the decision-makers can feel some validation in their responses.

Overall, Mr. Macaluso and Mr. Cechini share many of the same opinions with both recommending the 100-point technique for individual use. However, they disagree about the ratio approach with Mr. Macaluso believing that it is more suitable for and individual interview and Mr. Cechini believing it works best in a group setting. The primary reason for this occurrence appears to be Mr. Cechini's belief that the ratio technique fosters good discussion in the group setting and that it provides sharper analysis. Mr. Cechini feels very strongly that the interview and the group interview in particular provides a comprehensive understanding of the problem and its particular issues. Mr. Cechini believes an example may increase initial understanding for decision-makers.

The decision-makers believe that the AHP techniques are difficult to understand and apply while finding the rating techniques easy to understand and apply. Based on the decision-maker responses, future research needs to focus on the reliability of decision-maker responses with reference to the rating techniques because the level of comfort that a decision-maker experiences can have a dramatic effect on the results. The decision-makers have mixed feelings about the value functions. The decision-makers seem to believe they are useful, but they remain difficult to assess. The evaluation technique requires further improvements so that it will become user-friendlier, but the decision-maker responses from this first application seem at least somewhat favorable.

4.9 Findings

The results from the evaluation, that Table 4.25 displays, vary amongst the different scenarios as well as the different weighting schemes. Use of the alternate data set has the most universal improvement and shows an improvement in overall value in three of the four weighting schemes. The elimination of user benefits works well when the weighting structure gives network performance equal or greater value than reliability; however, when reliability has a greater preference than network performance the elimination of user benefits has little effect. The noticeable improvement in the special event only scenario highlights two facts, that the system operates more efficiently under special event conditions but that even accounting for the improved network performance the system may not be worth implementing for only special event operations. However, the combination of two of the scenarios, special event only using the alternate data set, appeared to suggest an increase in value across all weighting approaches. The final two scenarios deal more with the overall procedure rather than improvements in the system's value. Altering the interest rate demonstrated that the new interest rate improves the value of the system by weighting the earlier years more strongly than the later years. This seems appropriate because the gulf in the value between the "before" and "after" case increases with time. As expected, the value of the system decreases with respect to the base case when the institutional issues are featured. This occurs because the institutional issues are all costs. This wide variety of scenarios provides valuable insight into the evaluation results, the expected behavior of the results under alternative conditions, and the behavior of the combined system.

Table 4.25. Overall Results of the Evaluation for all Scenarios

Scenarios	Ratio	100-point	AHP-regular	AHP-pairwise
Base Case	-7.8	-3.1	-10.4	-13.6
Alternate Data Set	+9.7	+11.8	+3.9	-1.4
No User Benefits	+1.7	+17.1	-11.1	-13.5

Special Event Only	-4.0	+2.5	-8.2	-11.4
Altered Interest Rate	-7.5	-2.9	-10.1	-12.5
Emphasized Institutional	-8.8	-4.6	-12.4	-17.2

As observed in Table 4.25, the weighting schemes experience great variations in all of the scenarios. One reason for this variation is the size of the hierarchy where small preferences magnify when combined with more preferences at the next junction. Additionally, the differences in the weighting schemes lend themselves towards different responses from the decision-maker. This fact when coupled with the observed variation makes finding a weighting scheme that meets decision-maker needs while establishing consistency of paramount importance. In order for the evaluation results to have meaning, a decision-maker needs to be able to nearly replicate his (her) preference structure at a later time. Additionally, the decision-maker needs to find the procedure comprehensible and relatively easy. Further investigation may be required to identify such a weighting scheme.

It is possible that the hierarchy may require restructuring because the initial hierarchy may have contained too many attributes of little importance. This fact serves to limit the impact of the other attributes that join it in the same leaf. Perhaps, to assist with user-friendliness, the hierarchy may be reduced to only the dominant attributes; however, this would prohibit other non-dominant attributes, which experience an increase in their attribute level to rejoin the hierarchy. In general, the detailed hierarchy seems to bear more merit, but any clearly insignificant attributes should be eliminated when identified. The attributes that dominate the evaluation tend to attach to the technical performance branch, such as stop time, running time, intersection delay, downtime of inductive loops, and system downtime associated with integration performance. A few dominant attributes are attached to institutional issues, but the institutional issues have a far greater quantity of insignificant attributes, such as minor legal roadblocks, inter-agency cooperation for operations, and transitioning a test system to regular operations.

Institutional issues may have dominated the insignificant attributes because both determining their attribute level as well as assessing their value functions proves extremely difficult. While these components prove to be elusive, the evaluation scheme does a good job capturing the institutional issues related to this project and models them well. As observed in the institutional evaluation (see chapter six), project management and the delays associated with mismanagement dominated the early portions of this project. The evaluation does an excellent job capturing this affect with project management showing up as one of the two dominant institutional issues. The other dominant issue, system costs, appears as one of the foremost concerns for the City of Anaheim. While the evaluation of institutional issues may continue to prove difficult, this technique provides a good opportunity to determine the effects, and overall importance of these issues.

All of the components (hierarchical structure, weights, value functions and attribute levels) combine together to form the evaluation, and changing any of these components may change the context of the evaluation altogether. As a result, each of these components needs to be determined carefully. Where an attribute is placed in the hierarchy has a significant impact on its overall impact because its placement determines the weights that will effect it. Clearly, the weights are capable of causing tremendous variation as observed by the differences between weighting schemes. Finally, the combination of attribute level and value function determines the initial value associated with each attribute. These factors have the most significant impact on its final contribution to the system because many of the value functions and the resulting values are hundreds of times greater than others.

CHAPTER 5
ANAHEIM FOT EVALUATION RESULTS - THE ADMINSTRATORS' POINT-OF-VIEW

5.1 Problem Presentation

While the problem remains the same as the previous chapter and described in section 4.1, this material uses the evaluation framework in a different manner. This chapter looks specifically at the two administrators for the FOT. These administrators represented the state and national stakeholders, Caltrans and FHWA. As both are stationed in Sacramento, California, as opposed to the decision-maker of Chapter 4, Mr. John Thai of City of Anaheim who is in Southern California, there are more constraints on time availability for both of these busy administrators. Although time constraints prohibited a fully exhaustive examination of their values and weights, this study investigates many key components.

This chapter looks at the results from a group forum where two decision-makers arrived at the final weights in consultation with one another. Additionally, one of the decision-makers from the forum, Richard Macaluso, completely identifies his hierarchical weights for four different weighting techniques. These two separate sets of data allow comparisons between the two cases that examine the impacts of including a second person in the decision-making process.

Combining the value functions of two individuals is also attempted in this chapter. This is a useful technique in practical applications. It is possible that at any time when a project's worth is examined, multiple actors at different levels of the administration may need to be involved. Therefore, an administrator may defer to others in the hierarchy more familiar with the details of specific attributes to elicit the values involved in those. This is a very attractive and useful aspect of the framework developed here, and thus an examination of the effect of such multiple-actor value structures is also studied in this chapter.

5.2 Value Functions

This chapter borrows many value functions from the previous chapter. In the group results, the decision-makers do not identify any value functions; therefore, this evaluation uses the same value functions as chapter four. The assessment of value functions is limited because the administrators lacked the time to develop a complete inventory of the value functions. Furthermore, many of the attributes have little meaning for the administrators and they would have found it extremely difficult to make the proper value judgments.

Figures 5.1 through 5.6 display the selected value functions of Richard Macaluso assessed in this research. As in chapter four, each graphical representation of the value functions displays the attribute's actual value function. For all of these y term in the equation of the curve represents its value, v.

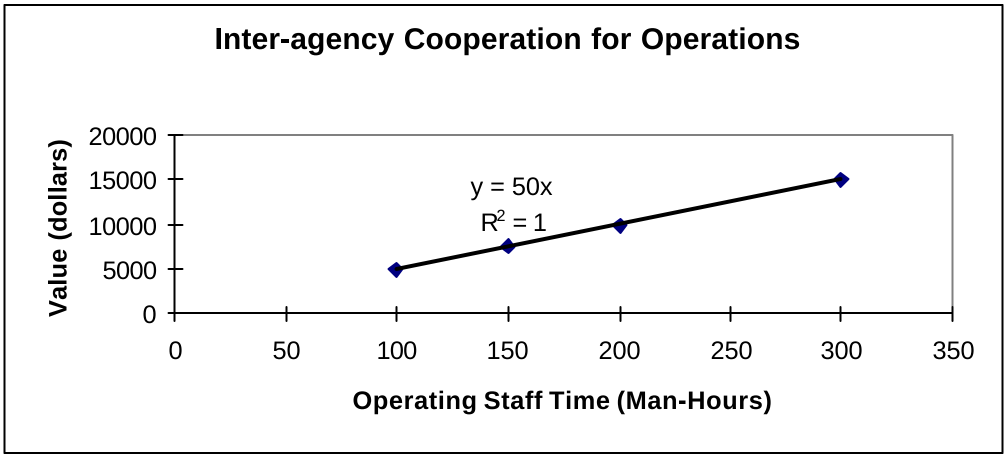

Figure 5.1. Inter-agency Cooperation for Operations (Mr. Macaluso)

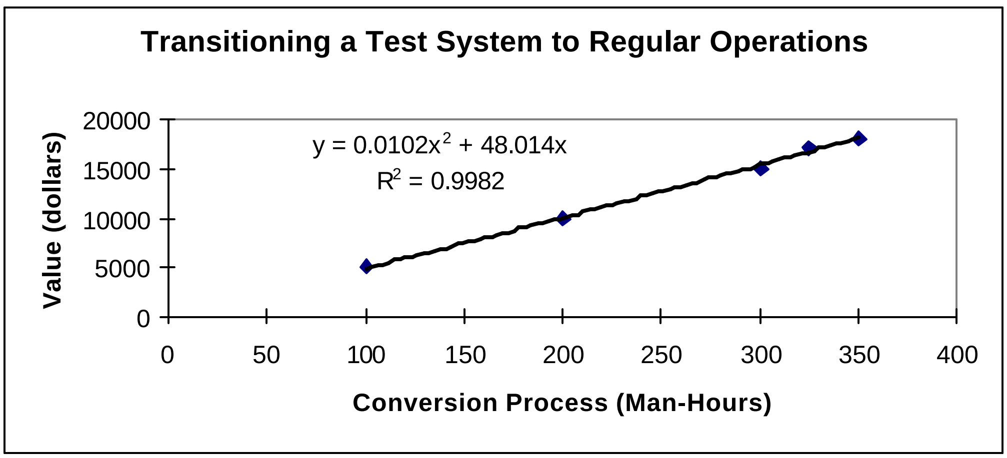

Figure 5.2. Transitioning a Test System to Regular Operations (Mr. Macaluso)

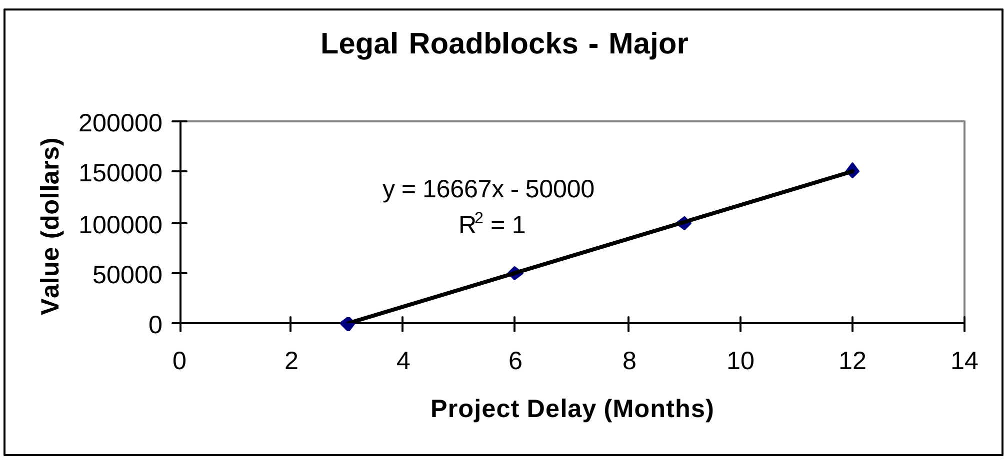

Figure 5.3. Legal Roadblocks - Major, Project Delay (Mr. Macaluso)

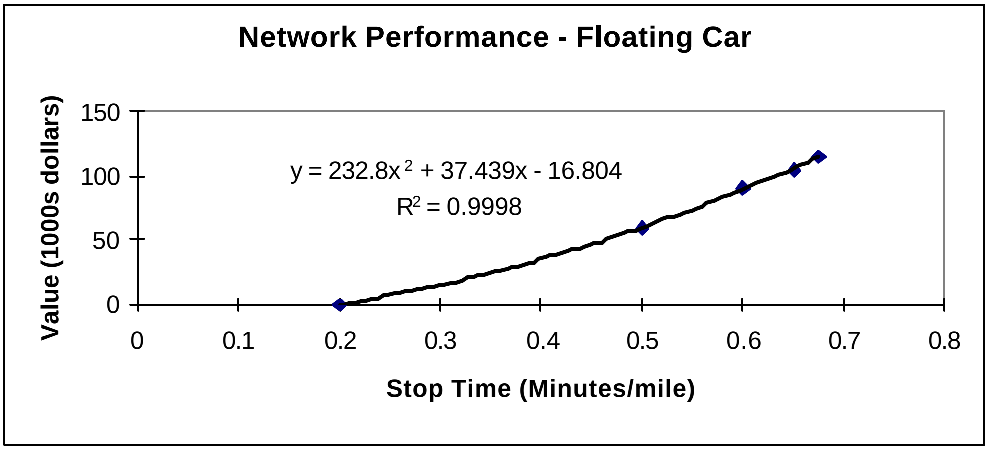

Figure 5.4. Network Performance - Floating Car, Stop Time (Mr. Macaluso)

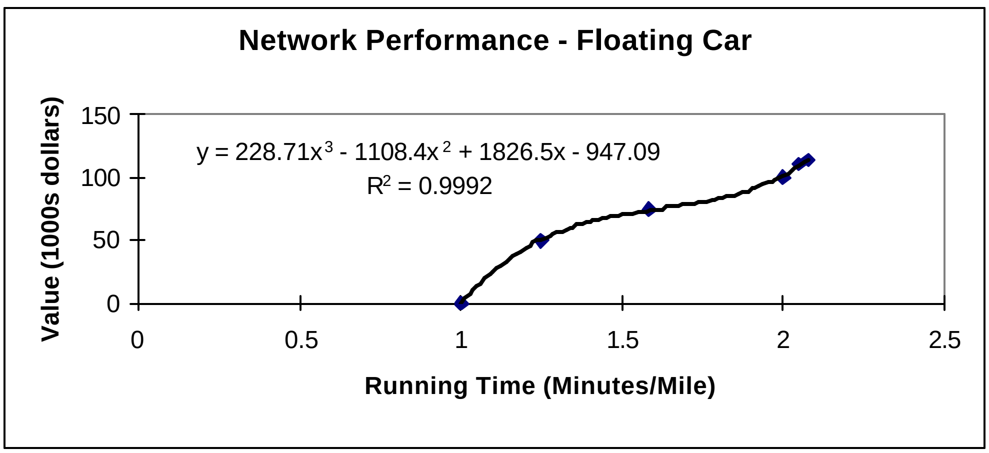

Figure 5.5. Network Performance - Floating Car, Running Time (Mr. Macaluso)

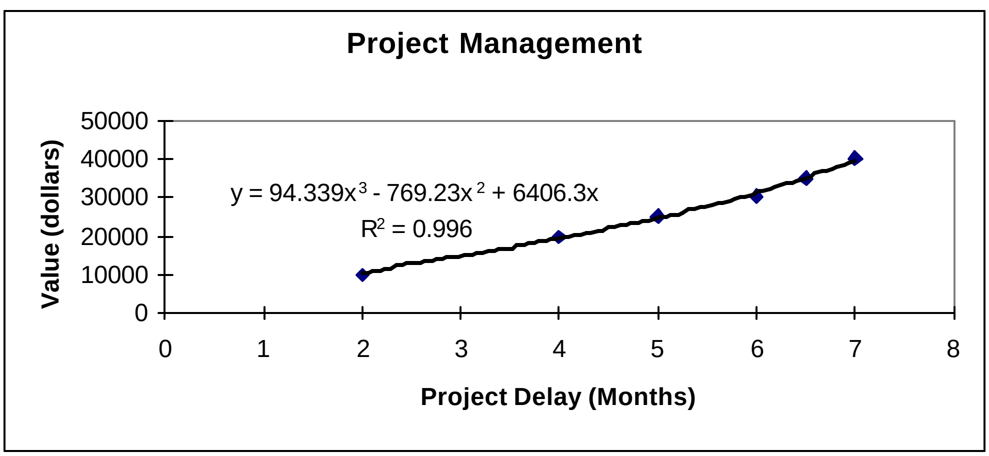

Figure 5.6. Project Management (Mr. Macaluso)

5.3 Weighting Schemes

As previously mentioned, many of the attributes remain outside the expertise of the two administrators. Additionally, they lack the knowledge to form a preference structure for the detailed analysis of network performance. For the portion of the hierarchy that they fail to enumerate, this research uses two different approaches. In the first one, a standard approach of equally weighting all alternative objectives is used. This approach represents most upper-level decision-makers' philosophies by attributing no difference between objectives for which they lack adequate knowledge. The second approach represents another philosophy of delegating this responsibility to a subordinate that has greater knowledge. In this situation, the subordinate or qualified person (in this case John Thai, as he was a qualified personnel though not a subordinate) assigns the priorities for the portions of the hierarchy under question. The local weights for most of these leafs is presented in Table 4.4 while Figures 4.35 through 4.50 present the remainder.

Similar to the application in chapter four this application examines four different weighting schemes; however, only two, ratio weighting and 100-point weighting, are examined for the group setting. Each of above six approaches identifies its own set of unique weights. Figures 5.7 through 5.18 display Richard Macaluso's individual hierarchy as well as the local weights at each level. The weights are presented in the following manner, as in chapter four (see section 4.3 for explanations). The first row displays two techniques from value function theory, ratio then 100-point. The second row displays two AHP techniques, regular AHP followed by the pairwise comparison approach.

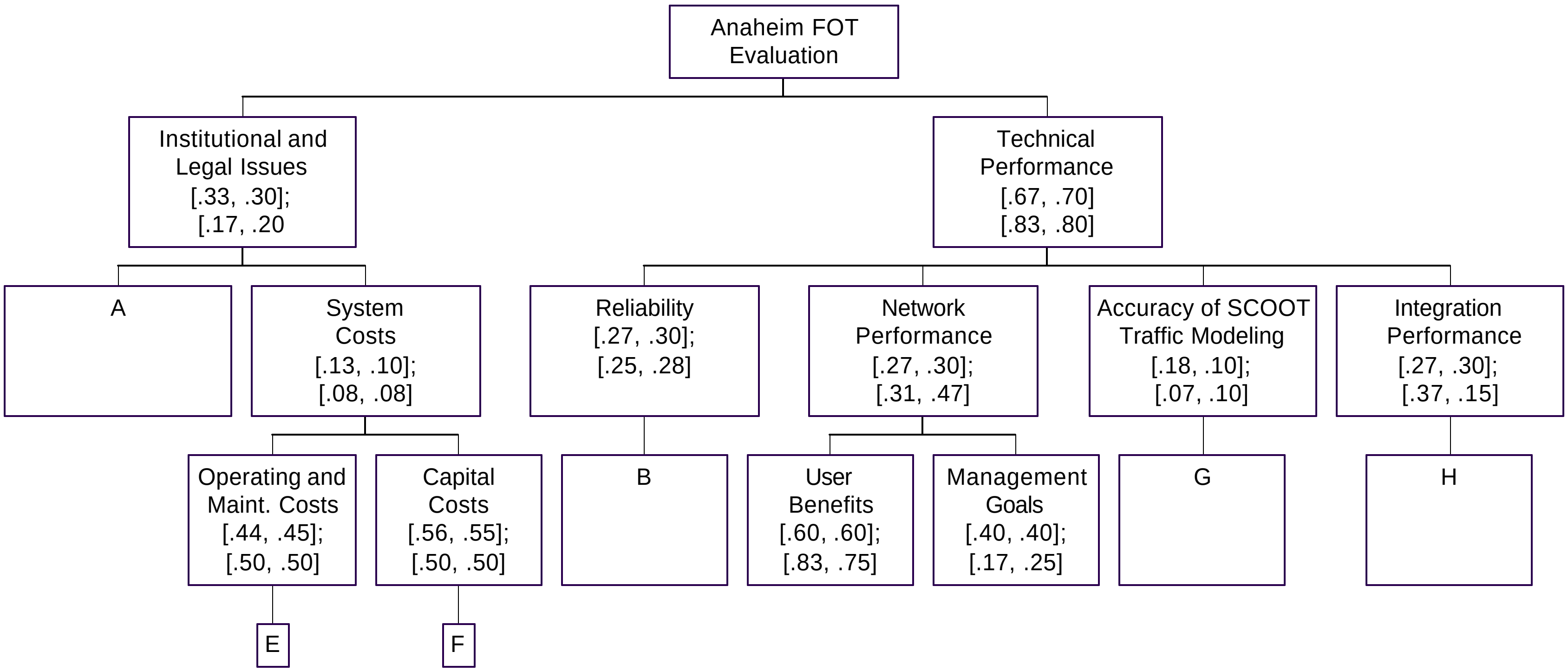

Figure 5.7. Anaheim FOT Hierarchy Local Weights for Richard Macaluso

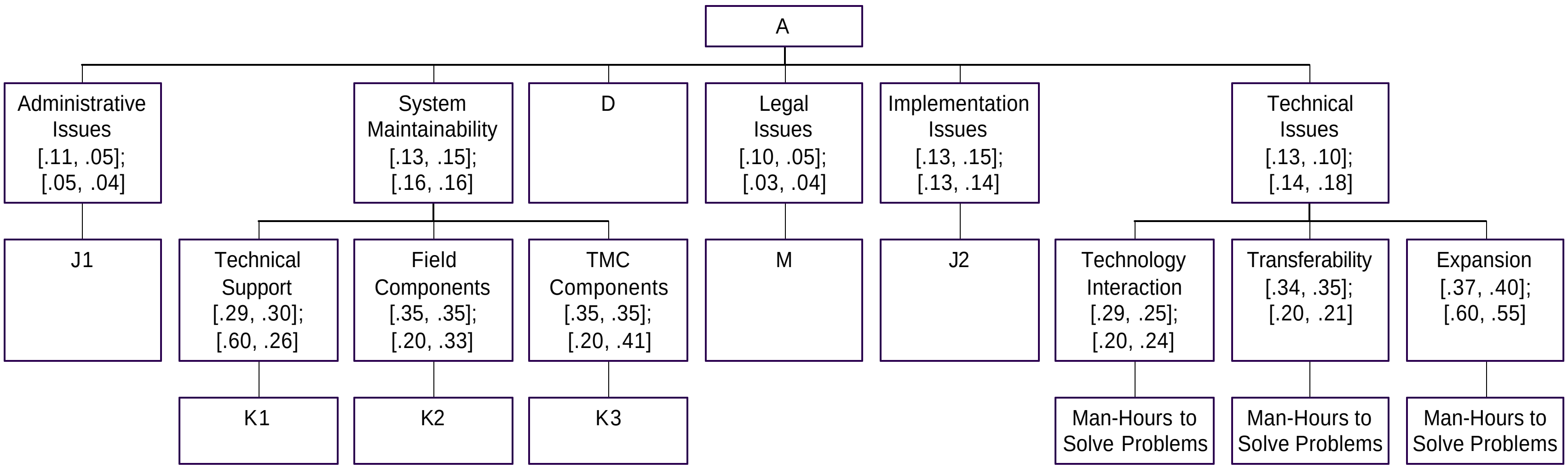

Figure 5.8. Institutional Issues (Mr. Macaluso)

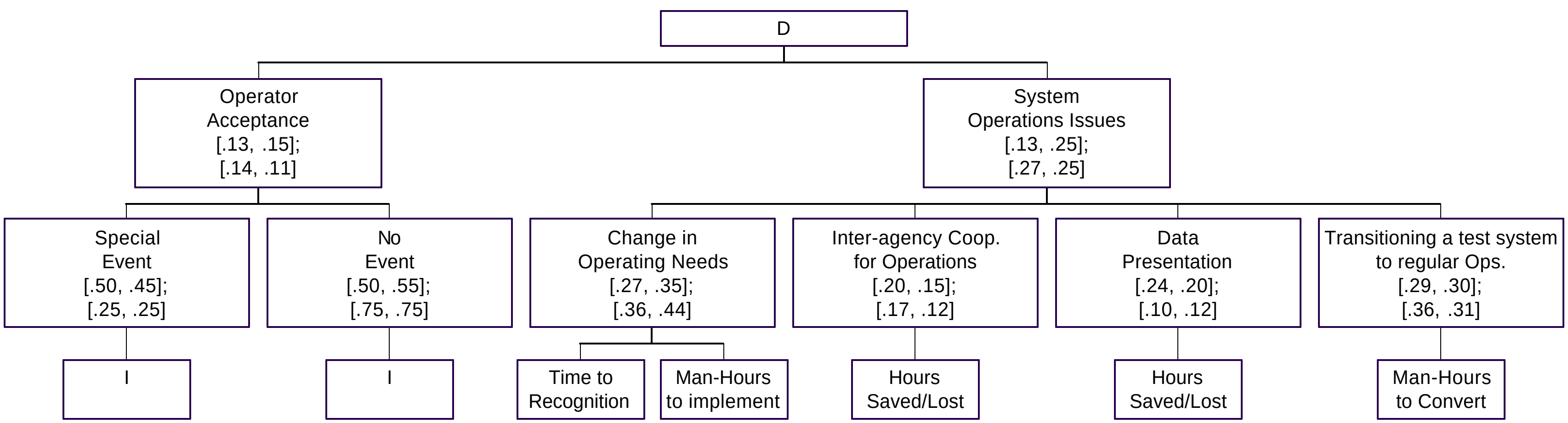

Figure 5.9. Operator Acceptance and System Operations Issues (Mr. Macaluso)

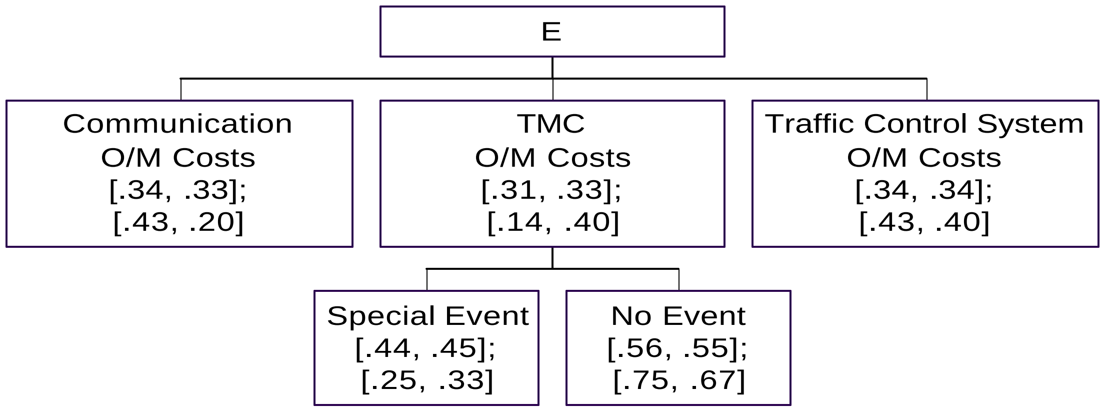

Figure 5.10. Operating and Maintenance Costs (Mr. Macaluso)

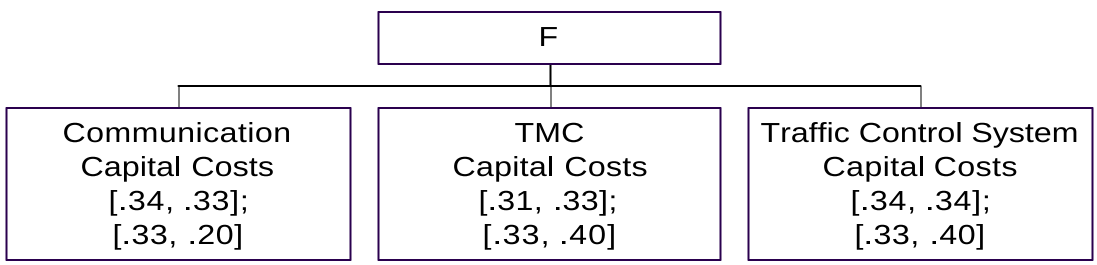

Figure 5.11. Capital Costs (Mr. Macaluso)

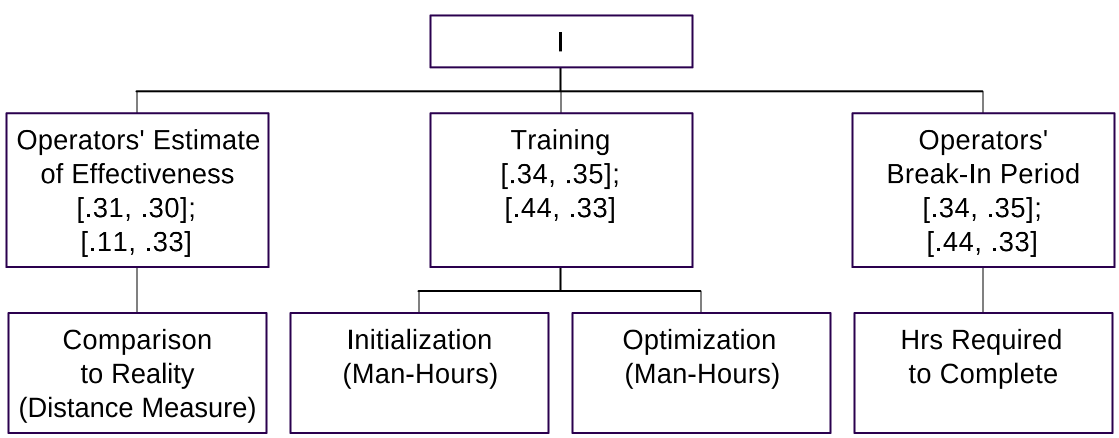

Figure 5.12. Operator Acceptance (Mr. Macaluso)

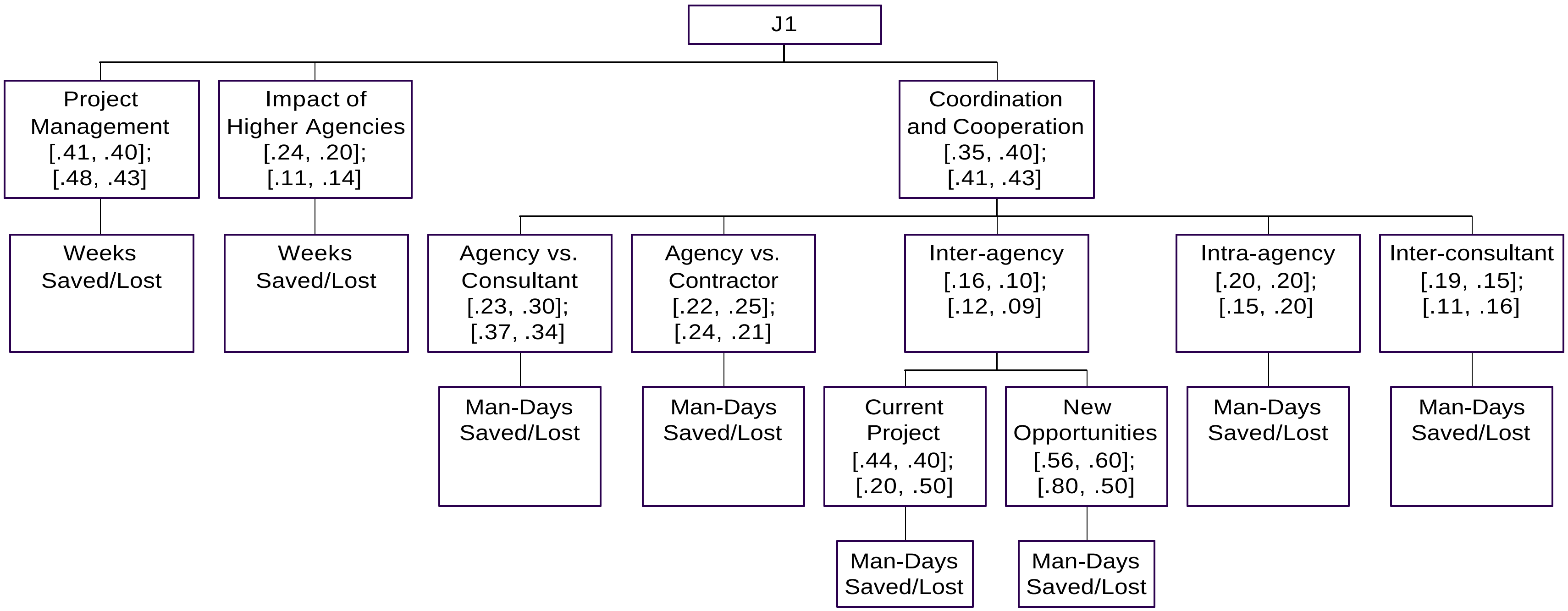

Figure 5.13. Administrative Issues (Mr. Macaluso)

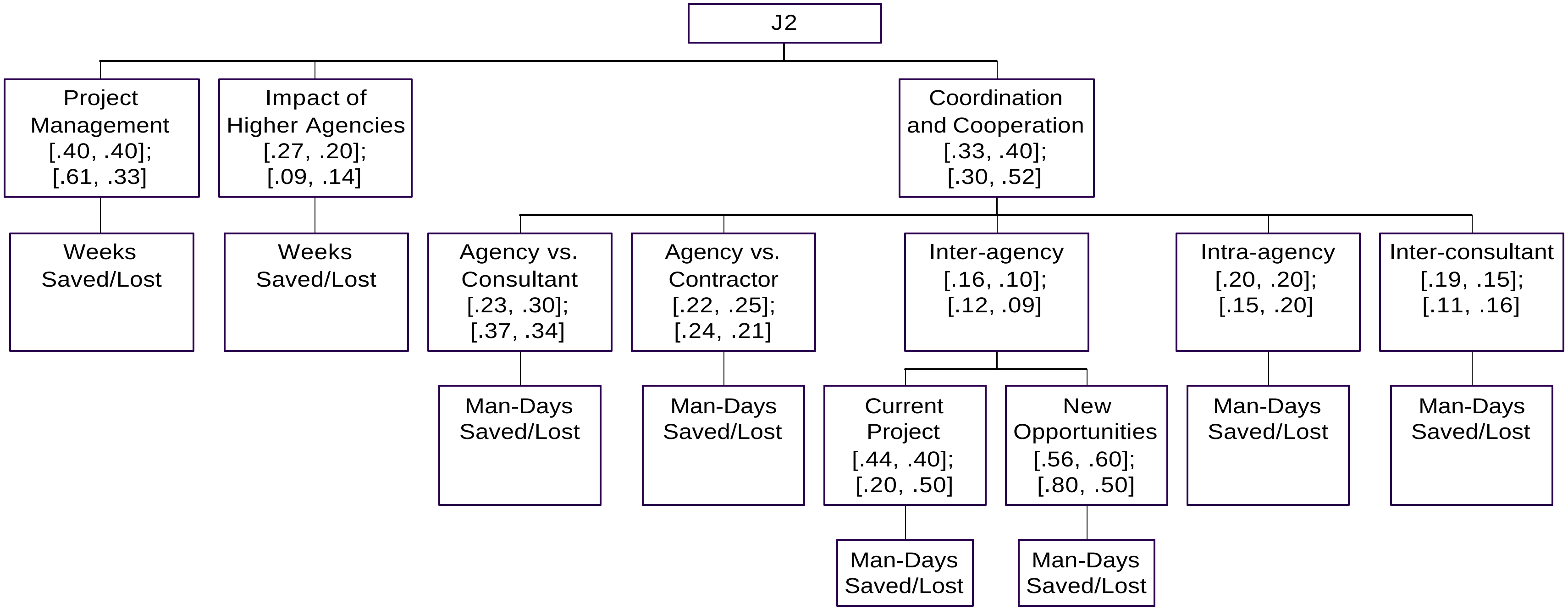

Figure 5.14. Implementation Issues (Mr. Macaluso)

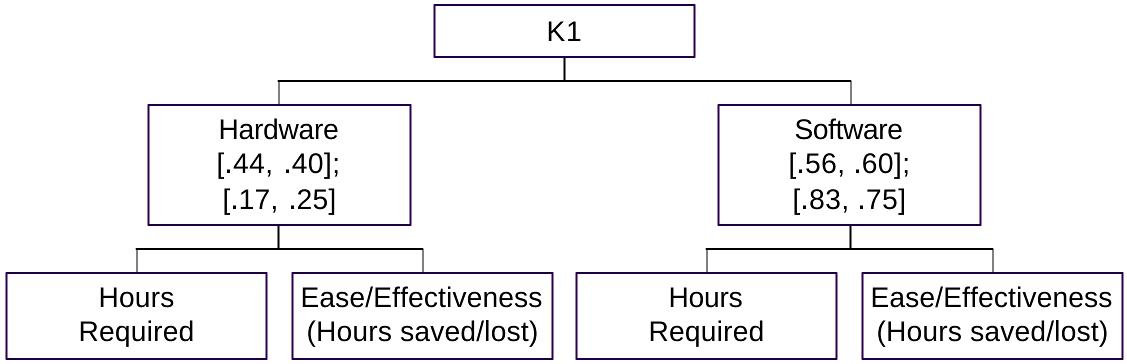

Figure 5.15. System Maintainability – Technical Support (Mr. Macaluso)

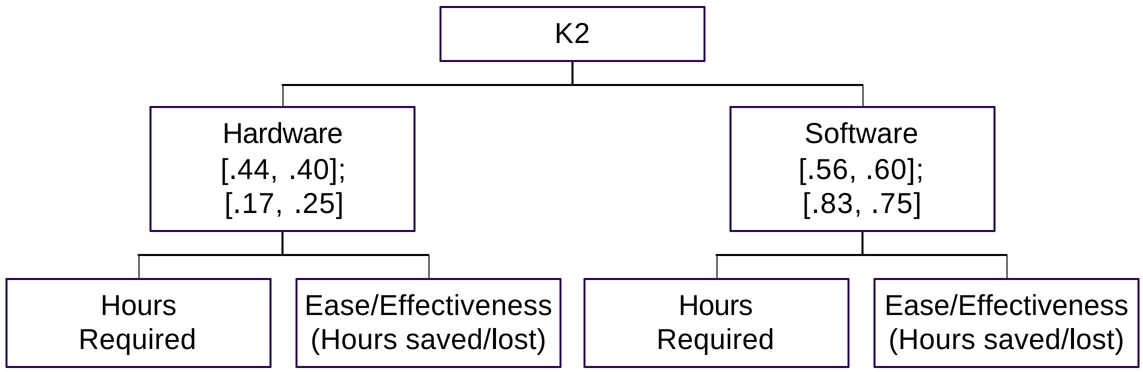

Figure 5.16. System Maintainability – Field Components (Mr. Macaluso)

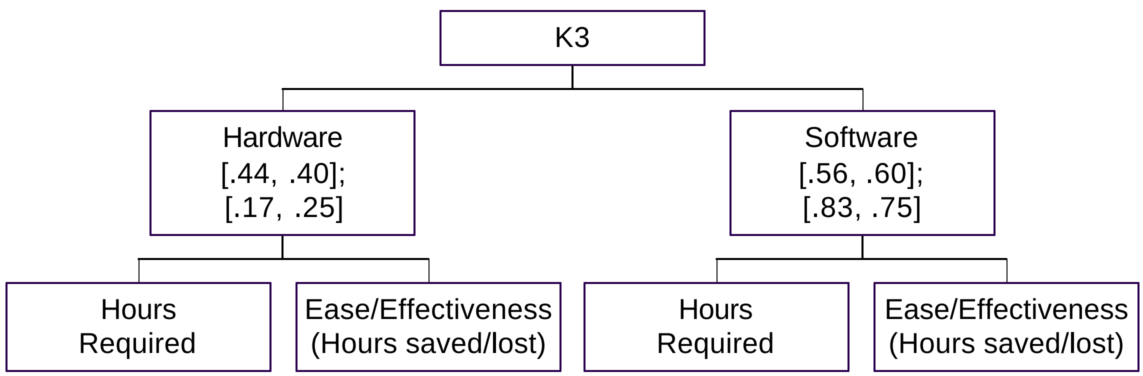

Figure 5.17. System Maintainability – TMC Components (Mr. Macaluso)

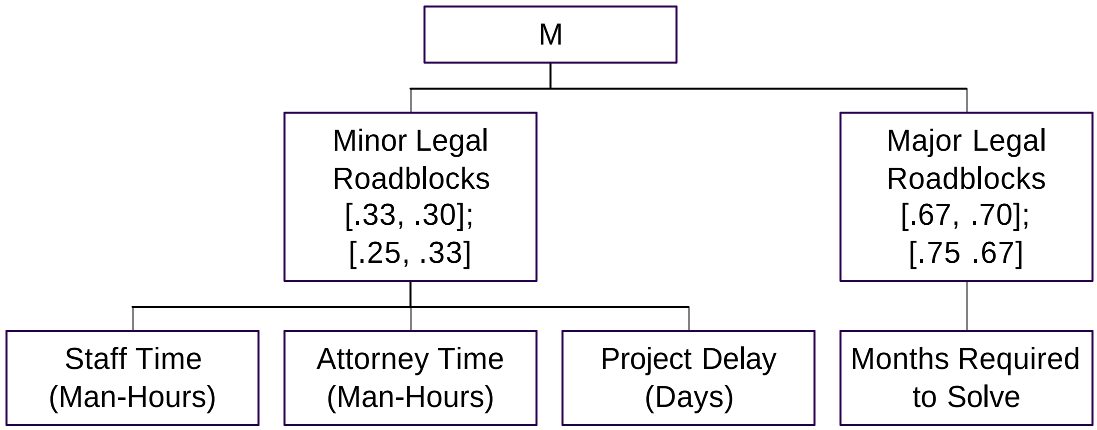

Figure 5.18. Legal Issues (Mr. Macaluso)

Figures 5.19 through 5.30 display the combined priorities for both administrators. For these figures, only the first row with the ratio weight and 100-point weight is required.

Roughly-speaking the weights that are provided by the group forum and Mr. Macaluso are very similar; however, some variation occurs and these differences show forth in the evaluation results. When these differences are compared to those found between different weighting schemes, they seem fairly inconsequential. Mr. Macaluso tends to have less variability or a lack of preference over the different objective branches while the group forum tends to decide on a more distinctive preference structure. In three simple pairwise comparisons, a reversal of preference is noted between the single respondent and the group forum. The group forum gives preference to operating and maintenance costs over capital costs, and it gives preference to special event operations over no-event operations. Meanwhile, Mr. Macaluso prefers the exact opposite. Two other items of particular note remain; namely the group forum's interest in implementation issues, and its emphasis on network performance at the expense of reliability. The increased role of network performance proves to be the determining

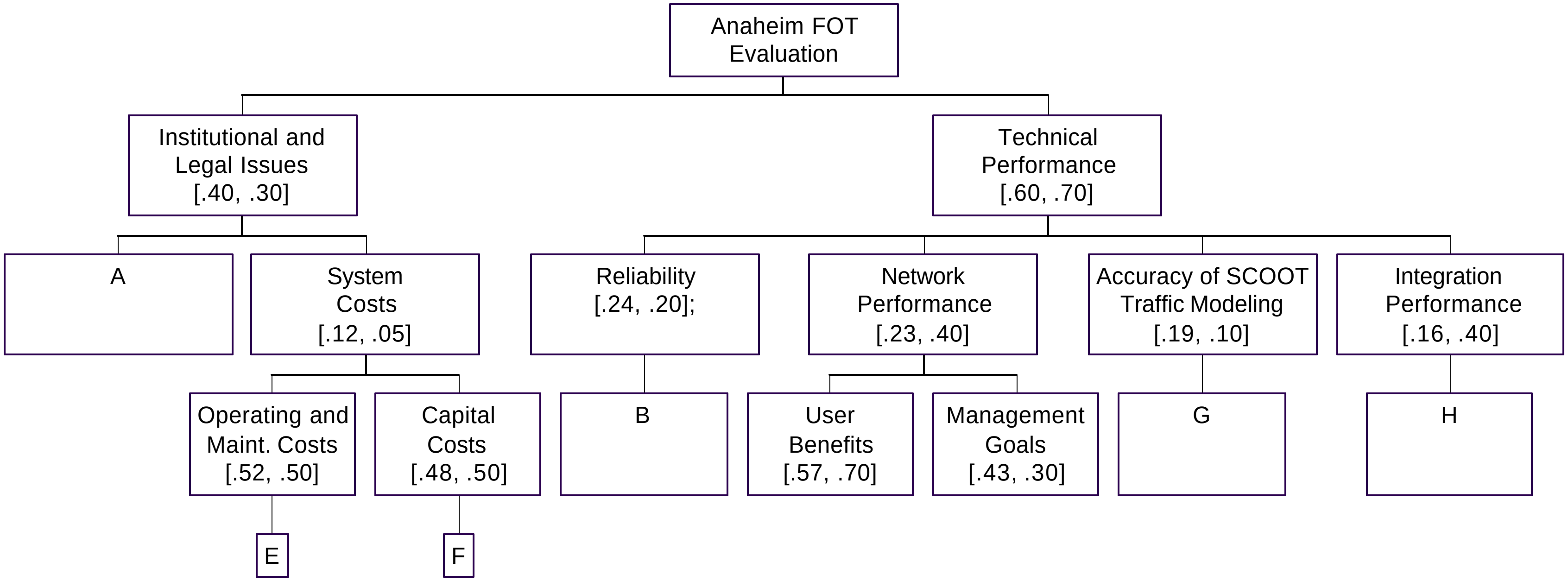

Figure 5.19. Anaheim FOT Hierarchy Local Weights Combined for Richard Macaluso and Frank Chechini

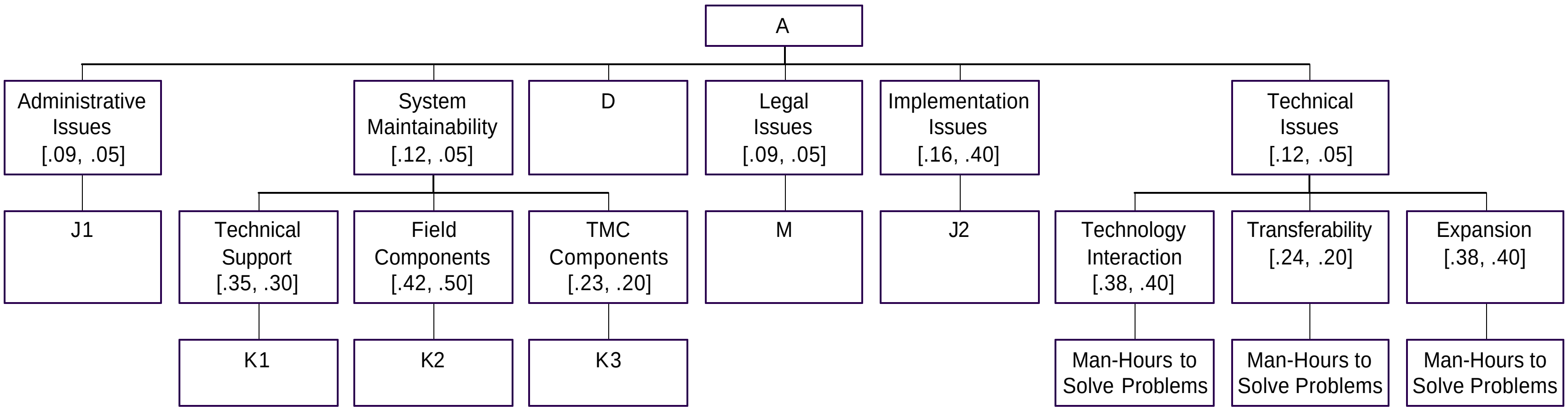

Figure 5.20. Institutional Issues (Macaluso/Chechini)

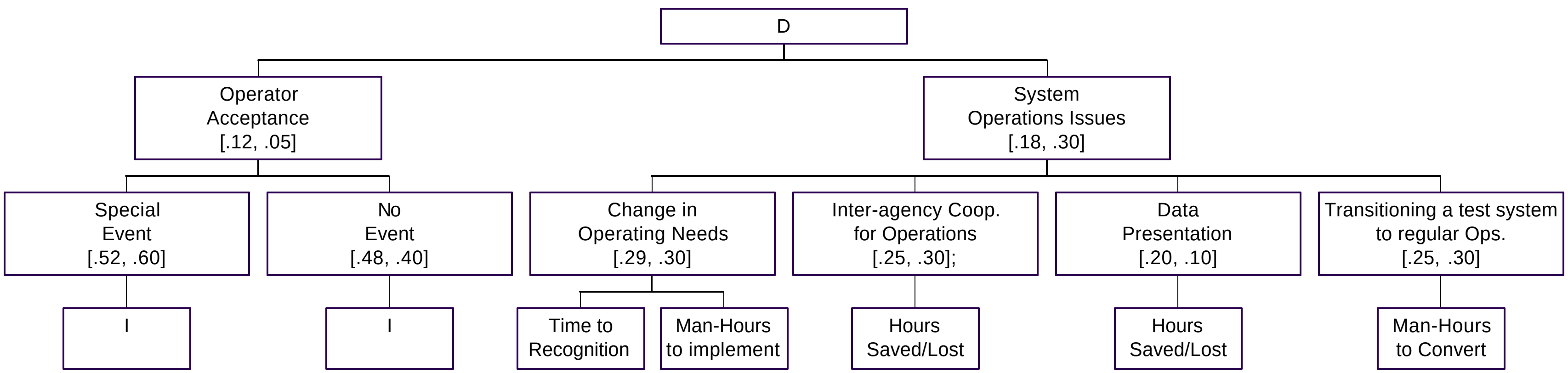

Figure 5.21. Operator Acceptance and System Operations Issues (Macaluso/Chechini)

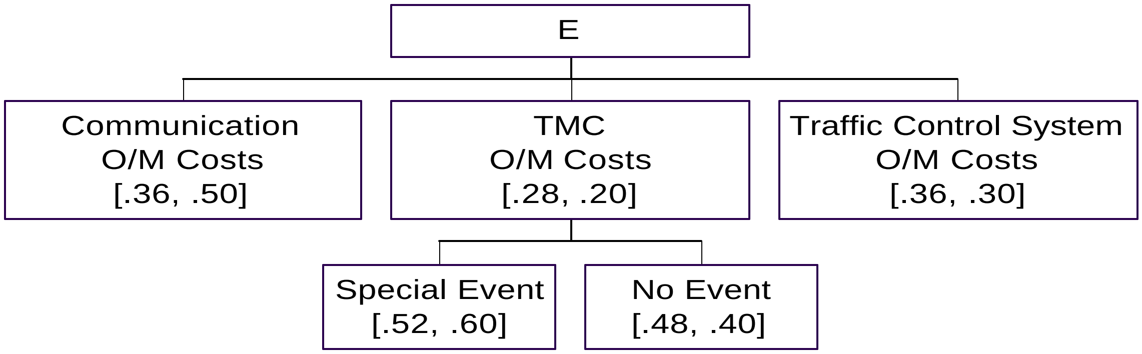

Figure 5.22. Operating and Maintenance Costs (Macaluso/Chechini)

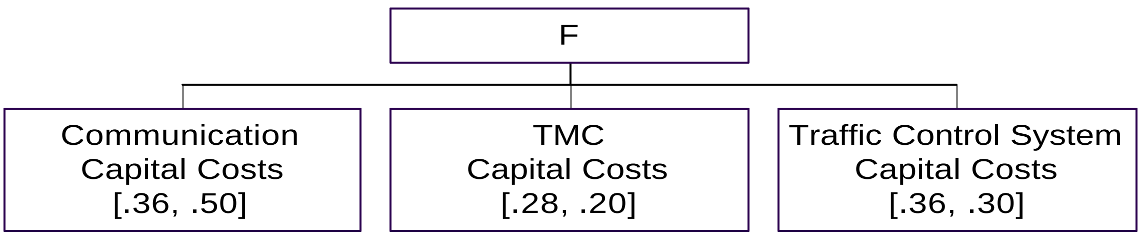

Figure 5.23. Capital Costs (Macaluso/Chechini)

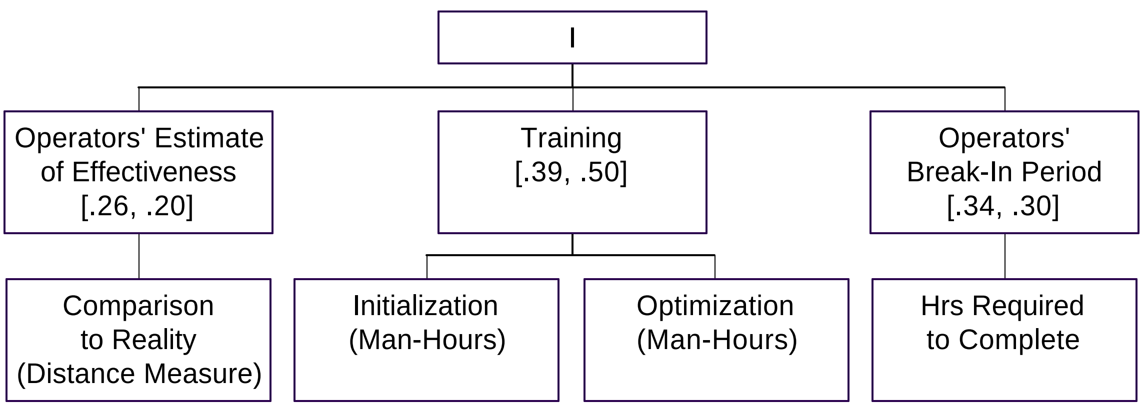

Figure 5.24. Operator Acceptance (Macaluso/Chechini)

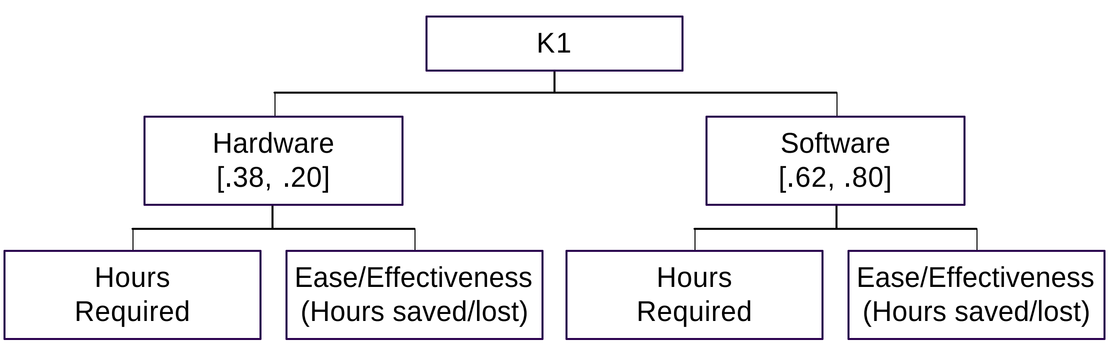

Figure 5.25. System Maintainability – Technical Support (Macaluso/Chechini)

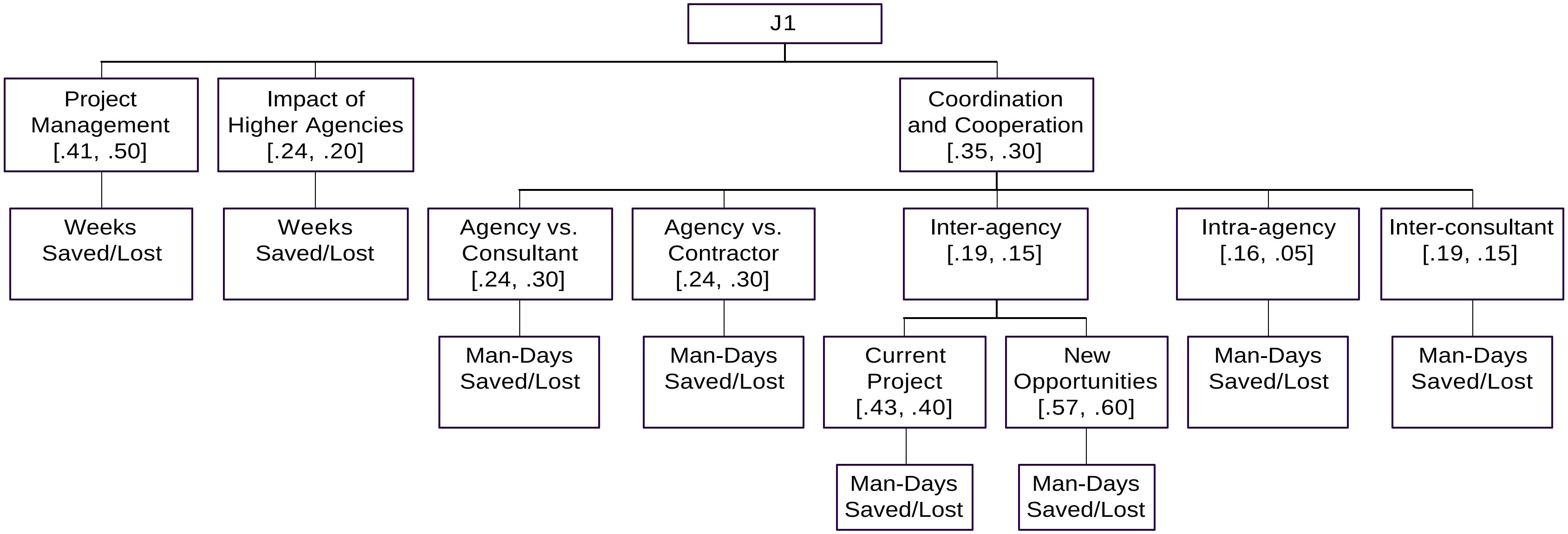

Figure 5.26. Administrative Issues (Macaluso/Chechini)

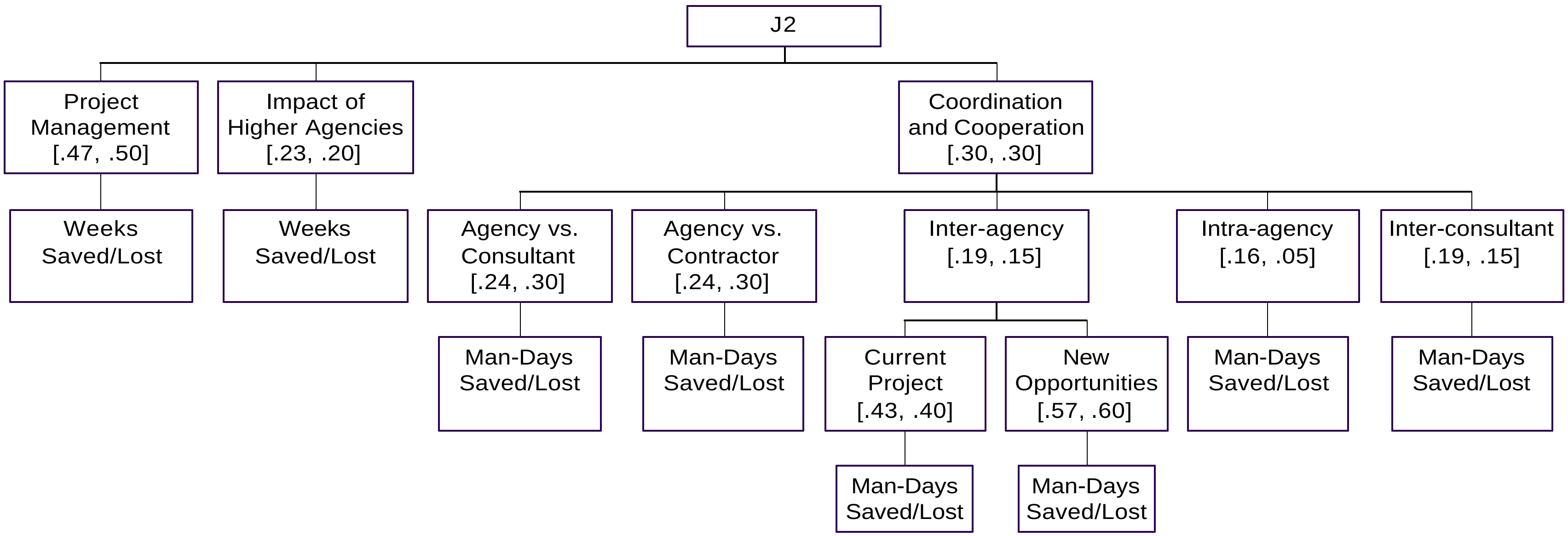

Figure 5.27. Implementation Issues (Macaluso/Chechini)

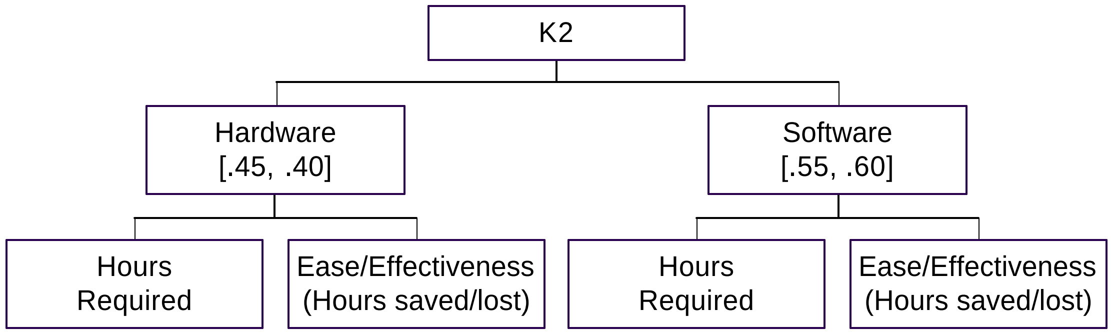

Figure 5.28. System Maintainability – Field Components (Macaluso/Chechini)

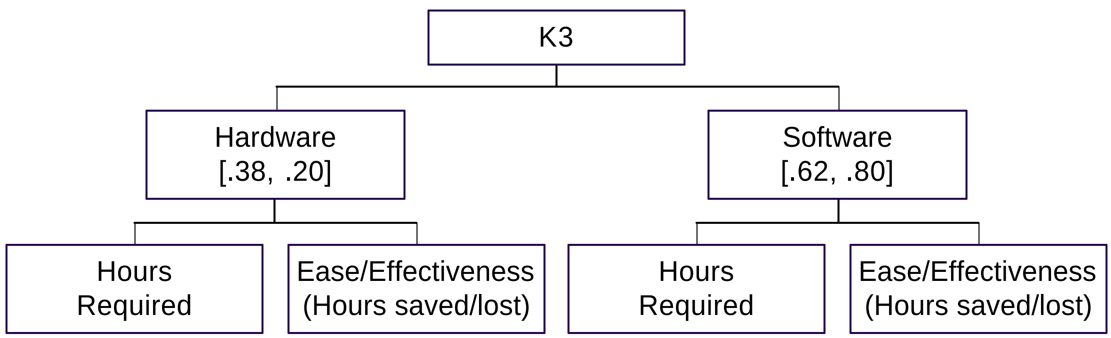

Figure 5.29. System Maintainability – TMC Components (Macaluso/Chechini)

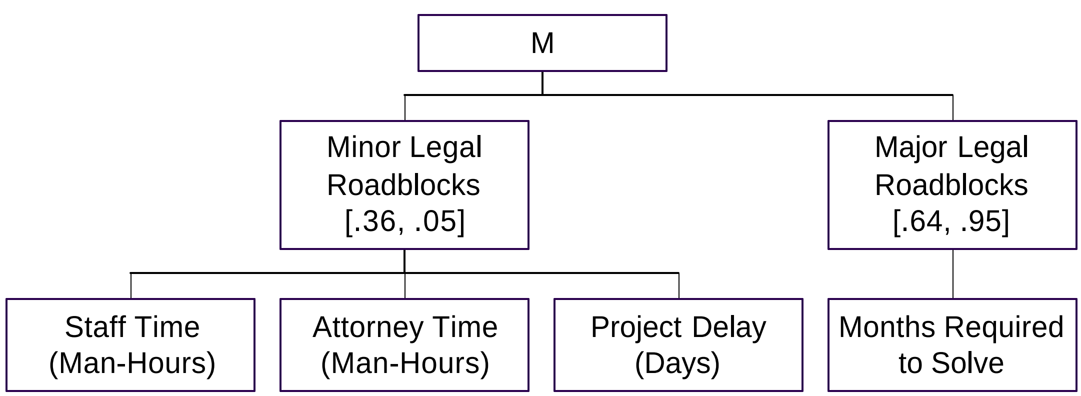

Figure 5.30. Legal Issues (Macaluso/Chechini)

factor between the group forum and individual administrator. The next section presents all of the results from the administrators' point-of-view while the following section provides a greater detailed investigation of the differences between the different decision-maker hierarchies.

5.4 Integrated Results

This section looks at the actual evaluation results using the administrator preferences. As in the previous chapter, the reported values are negative because all of the value functions are cost functions. The presentation of the results follows the procedure outlined in the previous chapter; however, this chapter uses a total of four different base hierarchies. The "A" hierarchies utilize the uniform weighting approach for all preference comparisons outside the administrators' expertise. In the aforementioned approach, the decision-makers give each leaf or branch equal weight. The "B" hierarchies rely on an expert to make these preference comparisons for the administrators. Both of the original hierarchies, that of Richard Macaluso (individual) and of the combined group, have an "A" and a "B" hierarchy. For all four of these hierarchies, this dissertation examines three different scenarios. These include the base case, alternate data set scenario, and the special event only scenario. Three of the scenarios from chapter four are not used. The emphasized institutional scenario and the altered interest rate are not selected because their effect on all hierarchies should be relatively similar; however, the previously mentioned scenarios can be expected to exhibit different behaviors depending on the hierarchy. The final scenario that proposes the elimination of the user benefits branch does not require evaluation because management goals always under perform with respect to user benefits. This occurs because these hierarchies use Richard Macaluso's value function for the floating car leaf, but John Thai's value function for the intersection delay leaf. In this case, John Thai's value function dominates those of Mr. Macaluso. Thus, the blending of two decision-maker value functions provides some interesting results.

5.4.1 *Richard Macaluso: Hierarchy A*

This hierarchy used Richard Macaluso's preference weights in conjunction with uniform weighting for all branches that were not suited for administrator definition.

5.4.1.1 Base Case

This base case looks at the same branches as the base case in chapter four. Tables 5.1 through 5.4 display some selected "before" and "after" comparisons for this scenario. Each of these tables gives the results for a single weighting scheme. Table 5.5 provides each branch's percentage contribution to overall value.

The user benefits and management goal branches remain identical across all four weighting schemes because their weights are identical and uniform for all of the approaches. The similarities in weights between weighting schemes at the leaf level lead to extremely stable results across the schemes. The change in overall value from the "before" and "after" case only varies between -19.5% (ratio and 100-point) and -17.7% (AHP-pairwise), which seems extremely stable compared to the other approaches. Furthermore, Mr. Macaluso tends to show little variability in his weights that enable them to remain in the same region. For each preference structure, reliability remains identical while network performance shows little change.

Table 5.1. Base Case Results with Ratio Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-35,360,023	-42,263,208	-19.5
Institutional Issues	-288,460	-331,134	-14.8
Administrative Issues	0	-17,357	-
System Operations Issues	7	-2,567	-367.7
System Maintainability	-13,771	-22,211	-61.3
Technical Issues	0	-300	-
Legal Issues	0	0	-
Implementation issues	0	-946	-
Operator Acceptance	0	-9,940	-
System Costs	-851,616	-940,096	-10.4
Technical Performance	-35,071,563	-41,932,074	-19.6
Reliability	-10,577,746	-13,410,974	-26.8
Network Performance	-42,029,598	-48,876,236	-16.3
User Benefits	-152,195,055	-176,902,820	-16.2
Special Event	-126,200,268	-155,347,205	-23.1
Ingress	-86,498,317	-47,963,458	+44.5
Egress	-18,693,186	-22,456,856	-20.1
Peak	-147,209,033	-240,274,097	-63.2
No-Event	-127,348,406	-139,354,717	-9.4
Off-Peak	-56,039,576	-62,226,363	-11.0
Peak	-198,657,235	-216,483,071	-9.0
Management Goals	-1,913,473	-2,310,047	-20.7
Special Event	-2,692,934	-3,516,069	-30.6
Ingress	-2,891,668	-3,885,513	-34.4
Egress	-877,492	-867,863	+1.1
Peak	-1,616,709	-2,278,762	-41.0
No-Event	-2,090,934	-2,260,106	-8.1
Off-Peak	-1,021,414	-956,782	+6.3
Peak	-3,160,453	-3,563,431	-12.8
Integration Performance	0	-610,900	-

Table 5.2. Base Case Results with 100-Point Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-40,683,333	-48,632,138	-19.5
Institutional Issues	-197,635	-227,981	-15.4
Administrative Issues	0	-7,443	-
System Operations Issues	9	-4,137	-460.7
System Maintainability	-16,567	-26,219	-58.3
Technical Issues	0	-244	-
Legal Issues	0	0	-
Implementation issues	0	-1,296	-
Operator Acceptance	0	-11,660	-
System Costs	-642,227	-708,935	-10.4
Technical Performance	-40,485,697	-48,404,158	-19.6
Reliability	-11,623,885	-14,737,319	-26.8
Network Performance	-46,212,825	-53,739,487	-16.3
User Benefits	-152,129,204	-176,821,153	-16.2
Special Event	-126,200,268	-155,347,205	-23.1
Ingress	-86,498,317	-47,963,458	+44.5
Egress	-18,693,186	-22,456,856	-20.1
Peak	-147,209,033	-240,274,097	-63.2
No-Event	-127,348,406	-139,354,717	-9.4
Off-Peak	-56,039,576	-62,226,363	-11.0
Peak	-198,657,235	-216,483,071	-9.0
Management Goals	-1,913,547	-2,310,470	-20.7
Special Event	-2,692,934	-3,516,069	-30.6
Ingress	-2,891,668	-3,885,513	-34.4
Egress	-877,492	-867,863	+1.1
Peak	-1,616,709	-2,278,762	-41.0
No-Event	-2,090,934	-2,260,106	-8.1
Off-Peak	-1,021,414	-956,782	+6.3
Peak	-3,160,453	-3,563,431	-12.8
Integration Performance	0	-671,990	-

Table 5.3. Base Case Results with Regular AHP Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-62,701,986	-74,419,609	-18.7
Institutional Issues	-80,553	-94,017	-16.7
Administrative Issues	0	-8,064	-
System Operations Issues	12	-2,700	-226.0
System Maintainability	-23,553	-30,775	-30.7
Technical Issues	0	-413	-
Legal Issues	0	0	-
Implementation issues	0	-915	-
Operator Acceptance	0	-13,609	-
System Costs	-459,778	-507,627	-10.4
Technical Performance	-62,621,432	-74,325,591	-18.7
Reliability	-9,560,166	-12,120,838	-26.8
Network Performance	-65,585,553	-76,241,807	-16.2
User Benefits	-211,290,561	-245,584,935	-16.2
Special Event	-126,200,268	-155,347,205	-23.1
Ingress	-86,498,317	-47,963,458	+44.5
Egress	-18,693,186	-22,456,856	-20.1
Peak	-147,209,033	-240,274,097	-63.2
No-Event	-127,348,406	-139,354,717	-9.4
Off-Peak	-56,039,576	-62,226,363	-11.0
Peak	-198,657,235	-216,483,071	-9.0
Management Goals	-797,311	-962,696	-20.7
Special Event	-2,692,934	-3,516,069	-30.6
Ingress	-2,891,668	-3,885,513	-34.4
Egress	-877,492	-867,863	+1.1
Peak	-1,616,709	-2,278,762	-41.0
No-Event	-2,090,934	-2,260,106	-8.1
Off-Peak	-1,021,414	-956,782	+6.3
Peak	-3,160,453	-3,563,431	-12.8
Integration Performance	0	-828,605	-

Table 5.4. Base Case Results with Pairwise AHP Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-80,545,966	-94,816,324	-17.7
Institutional Issues	-106,467	-123,248	-15.8
Administrative Issues	0	-6,398	-
System Operations Issues	7	-2,774	-397.3
System Maintainability	-18,502	-29,313	-58.4
Technical Issues	0	-508	-
Legal Issues	0	0	-
Implementation issues	0	-1,588	-
Operator Acceptance	0	-8,161	
System Costs	-513,840	-567,500	-10.4
Technical Performance	-80,439,499	-94,693,076	-17.7
Reliability	-10,793,607	-13,684,653	-26.8
Network Performance	-89,755,767	-104,349,251	-16.3
User Benefits	-190,161,505	-221,026,442	-16.2
Special Event	-126,200,268	-155,347,205	-23.1
Ingress	-86,498,317	-47,963,458	+44.5
Egress	-18,693,186	-22,456,856	-20.1
Peak	-147,209,033	-240,274,097	-63.2
No-Event	-127,348,406	-139,354,717	-9.4
Off-Peak	-56,039,576	-62,226,363	-11.0
Peak	-198,657,235	-216,483,071	-9.0
Management Goals	-1,195,967	-1,444,044	-20.7
Special Event	-2,692,934	-3,516,069	-30.6
Ingress	-2,891,668	-3,885,513	-34.4
Egress	-877,492	-867,863	+1.1
Peak	-1,616,709	-2,278,762	-41.0
No-Event	-2,090,934	-2,260,106	-8.1
Off-Peak	-1,021,414	-956,782	+6.3
Peak	-3,160,453	-3,563,431	-12.8
Integration Performance	0	-332,440	-

Table 5.5. Percentage Impact on Overall Value: The Base Case

Branch	Ratio Weights	100 Point Weights	AHP Regular	AHP Pairwise
Institutional Issues	0.78	0.47	0.13	0.13
Administrative Issues	0.01	0.01	0.00	0.00
System Operations Issues	0.00	0.00	0.00	0.00
System Maintainability	0.02	0.02	0.01	0.01
Technical Issues	0.00	0.00	0.00	0.00
Legal Issues	0.00	0.00	0.00	0.00
Implementation issues	0.00	0.00	0.00	0.00
Operator Acceptance	0.01	0.01	0.00	0.00
System Costs	0.74	0.44	0.11	0.08
Technical Performance	99.22	99.53	99.87	99.87
Reliability	21.16	21.21	13.57	11.55
Network Performance	77.10	77.35	85.37	88.04
User Benefits	76.10	76.35	85.04	87.47
Special Event	40.14	40.25	44.83	46.11
Ingress	6.20	6.21	6.92	7.12
Egress	2.90	2.91	3.24	3.33
Peak	31.04	31.13	34.67	35.66
No-Event	35.97	36.11	40.21	41.36
Off-Peak	8.03	8.06	8.98	9.24
Peak	27.94	28.04	31.24	32.13
Management Goals	0.99	1.00	0.33	0.57
Special Event	0.61	0.61	0.20	0.35
Ingress	0.33	0.34	0.11	0.19
Egress	0.08	0.08	0.03	0.04
Peak	0.20	0.20	0.07	0.11
No-Event	0.39	0.39	0.13	0.22
Off-Peak	0.08	0.08	0.03	0.05
Peak	0.31	0.31	0.10	0.18
Integration Performance	0.96	0.97	0.93	0.28

The overwhelming dominance of the technical performance branch provides further stability to this set of results. For all of the schemes, institutional issues fails to account for even one percent of the final overall value and for two schemes they fail to count for more than 0.2%. All of the variation in overall value comes from the different weights in the technical performance branch because the overall percentage change never varies more than a tenth of a percent from that of technical performance. In the two instances when reliability and network performance are equally weighted, the system seems to exhibit its worst performance from "before" to "after". The scheme that prefers network performance most strongly to its brethren exhibits the best performance. Using an outsider's value function in conjunction with the decision-maker's establishes a dominant situation for the outsider's value function when his value at identical attribute level greatly exceeds the typical values used by the primary decision-maker. In this case, John Thai determines all of the value functions associated with reliability and the user benefit value functions are determined by a small sample of users. These two branches dominate the entire evaluation by contributing between 98.2% and 99.6% of the final overall value. This does not seem appropriate, and a solution to this problem may require additional research as well as extensive discussions with the decision-makers. While the system fails to perform well under this hierarchy in the base case, many factors contribute to the observed difficulties.

5.4.1.2 Alternate Data Set

This and the subsequent section focus on comparing two scenarios to the base case. Detailed results for these scenarios are not presented because they show little information of import. All of the key findings for this scenario can be identified from its percentage changes between the "before" and "after" cases at the overall and branch level. Table 5.6 compares the results for this scenario to the base case over the branches affected by utilizing the alternate data set.

Table 5.6. Base Case vs. Alternate Data Case

Branch	Base Case	Alternate Data Case
Overall: Ratio Weights	-19.5	+0.9
Technical Performance	-19.6	+1.0
Network Performance	-16.3	+9.5
User Benefits: Special Event	-23.1	+28.7
Management Goals: Special Event	-30.6	+7.7
Overall: 100-Point Weights	-19.5	+0.9
Technical Performance	-19.6	+1.0
Network Performance	-16.3	+9.5
User Benefits: Special Event	-23.1	+28.7
Management Goals: Special Event	-30.6	+7.7
Overall: AHP-Regular Weights	-18.7	+3.8
Technical Performance	-18.7	+3.8
Network Performance	-16.2	+9.5
User Benefits: Special Event	-23.1	+28.7
Management Goals: Special Event	-30.6	+7.7
Overall: AHP-Pairwise Weights	-17.7	+5.3
Technical Performance	-17.7	+5.3
Network Performance	-16.3	+9.5
User Benefits: Special Event	-23.1	+28.7
Management Goals: Special Event	-30.6	+7.7

As previously discussed in section 4.4, some of the "after" data is adversely affected by an accident on I-5. The base case results indicate that the overall worth of the system decreases as a result of the SCOOT implementation. However, the branch of the hierarchy that is most affected by the accident, the special event-peak for user benefits, contributes somewhere between thirty-one (31) and thirty-six (36) percent of the overall system worth. Thus, an improvement for this branch can improve the apparent results of the evaluation.

This scenario shows overwhelming success where the percentage change in overall value improves from the –19.5% to –17.7% range to the 0.9% (ratio and 100-point) to 5.3% (AHP-pairwise) range. The identical weights that are found in the lower branches of these four weighting schemes mean that the schemes show identical improvements (any differences are attributed to rounding errors) in three of the branches of concern. Network performance improves from –16.3% to 9.5%. Furthermore, the special event branch attached to user benefits improves from –23.1% to 28.7% while the special event branch attached to management goals improves from –30.6% to 7.7%. These improvements fuel the improvements observed in the higher branches. Under this scenario, the system shows that the installation of the new system bears merit.

5.4.1.3 <u>Special Event Only</u>

The next scenario isolates the special event case and follows the same procedure as that found in section 4.5.4. Since the special events' network performance results are inferior to the no-event results; the system is expected to show worse performance. However, this scenario is still included so that its results can be compared to those found in chapter four. Table 5.7

compares the percentage change between the "before" and "after" cases in the base scenario to the change in this scenario.

Table 5.7. Base Case vs. Special Event Only Scenario

Branch	Base Case	Special Event Only
Overall: Ratio Weights	-19.5	-25.0
Institutional Issues	-14.8	-14.6
Technical Performance	-19.6	-25.1
Network Performance	-16.3	-23.2
User Benefits	-16.2	-23.1
Management Goals	-20.7	-30.6
Overall: 100-Point Weights	-19.5	-25.0
Institutional Issues	-15.4	-15.2
Technical Performance	-19.6	-25.1
Network Performance	-16.3	-23.2
User Benefits	-16.2	-23.1
Management Goals	-20.7	-30.6
Overall: AHP-Regular Weights	-18.7	-24.7
Institutional Issues	-16.7	-16.6
Technical Performance	-18.7	-24.7
Network Performance	-16.2	-23.1
User Benefits	-16.2	-23.1
Management Goals	-20.7	-30.6
Overall: AHP-Pairwise Weights	-17.7	-23.9
Institutional Issues	-15.8	-15.5
Technical Performance	-17.7	-23.9
Network Performance	-16.3	-23.1
User Benefits	-16.2	-23.1
Management Goals	-20.7	-30.6

As expected, this scenario continues to degrade where the percentage change in overall value shrinks from the –19.5% to –17.7% range to the –25.0% (ratio and 100-point) to –23.9% (AHP-pairwise) range. In all instances, institutional issues demonstrate a small improvement from 0.1 to 0.3 percent; however, this fails to offset the steep decline observed in network performance. The identical weights that are found in the lower branches of these four weighting schemes mean that the schemes show identical declines (any differences are attributed to rounding errors) in three of the branches of concern. Network Performance reduces from –16.3% to –23.2%. Furthermore, the user benefits shrink from –16.1% to –23.1% while the management goals degrade from -20.7% to –30.3%. These declines fuel the shrinking performance that is observed in the higher branches. Under this scenario, the system proves to be virtually useless for special event only operations.

5.4.2 *Richard Macaluso: Hierarchy B*

This hierarchy used Richard Macaluso's preference weights in conjunction with John Thai's preference weights for all branches that fell outside Mr. Macaluso's expertise.

5.4.2.1 Base Case

This base case looks at the same branches as the base case in chapter four. Tables 5.8 through 5.11 display some selected "before" and "after" comparisons for this scenario. Each of these tables gives the results for a single weighting scheme. Table 5.12 provides each branch's percentage contribution to overall value.

Table 5.8. Base Case Results with Ratio Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-35,729,019	-41,137,398	-15.1
Institutional Issues	-288,460	-331,134	-14.8
Administrative Issues	0	-17,357	-
System Operations Issues	7	-2,552	-365.6
System Maintainability	-13,771	-22,211	-61.3
Technical Issues	0	-300	-
Legal Issues	0	0	-
Implementation issues	0	-946	-
Operator Acceptance	0	-9 940	-
System Costs	-851,616	-940,096	-10.4
Technical Performance	-35,440,559	-40,806,263	-15.1
Reliability	-8,551,330	-10,853,378	-26.9
Network Performance	-44,609,508	-49,745,117	-11.5
User Benefits	-161,255,170	-179,611,745	-11.4
Special Event	-133,625,543	-151,103,745	-13.1
Ingress	-95,321,884	-53,304,572	+44.1
Egress	-23,431,966	-27,775,872	-18.5
Peak	-103,955,388	-170,759,131	-64.3
No-Event	-135,133,075	-148,249,164	-9.7
Off-Peak	-28,806,855	-31,499,988	-9.3
Peak	-309,025,832	-339,122,921	-9.7
Management Goals	-2,313,025	-2,787,017	-20.5
Special Event	-3,865,840	-4,855,604	-25.6
Ingress	-3,602,266	-4,747,826	-31.8
Egress	-1,135,730	-1,043,897	+8.1
Peak	-1,060,764	-1,491,683	-40.6
No-Event	-1,916,721	-2,111,938	-10.2
Off-Peak	-710,111	-641,040	+9.7
Peak	-5,040,054	-5,694,774	-13.0
Integration Performance	0	-610,900	-

Table 5.9. Base Case Results with 100-Point Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-38,760,494	-43,657,356	-12.6
Institutional Issues	-197,635	-227,981	-15.4
Administrative Issues	0	-7,443	-
System Operations Issues	9	-4,137	-460.7
System Maintainability	-16,567	-26,219	-58.3
Technical Issues	0	-244	-
Legal Issues	0	0	-
Implementation issues	0	-1,296	-
Operator Acceptance	0	-11,660	-
System Costs	-642,227	-708,935	-10.4
Technical Performance	-38,562,859	-43,429,375	-12.6
Reliability	-7,131,931	-9,022,089	-26.5
Network Performance	-47,957,867	-52,347,876	-9.2
User Benefits	-157,239,584	-171,576,109	-9.1
Special Event	-130,386,036	-139,722,380	-7.2
Ingress	-98,525,341	-49,019,310	+49.2
Egress	-27,739,406	-31,538,514	-13.7
Peak	-93,045,313	-152,312,809	-63.7
No-Event	-131,679,937	-146,237,801	-11.1
Off-Peak	-34,764,258	-37,750,193	-8.6
Peak	-294,435,583	-327,844,310	-11.3
Management Goals	-2,619,974	-2,916,813	-11.3
Special Event	-4,679,581	-5,263,997	-12.5
Ingress	-4,014,180	-5,057,077	-26.0
Egress	-1,679,715	-1,231,029	+26.7
Peak	-545,546	-730,557	-33.9
No-Event	-1,870,354	-2,028,034	-8.4
Off-Peak	-947,004	-706,348	+25.4
Peak	-6,534,410	-7,405,789	-13.3
Integration Performance	0	-671,990	-

Table 5.10. Base Case Results with Regular AHP Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-55,031,003	-58,726,025	-6.7
Institutional Issues	-80,553	-94,017	-16.7
Administrative Issues	0	-8,064	-
System Operations Issues	12	-2,700	-226.0
System Maintainability	-23,553	-30,775	-30.7
Technical Issues	0	-413	-
Legal Issues	0	0	-
Implementation issues	0	-915	-
Operator Acceptance	0	-13,609	-
System Costs	-459,778	-507,627	-10.4
Technical Performance	-54,950,450	-58,632,008	-6.7
Reliability	-6,832,966	-8,636,476	-26.4
Network Performance	-59,107,574	-60,893,868	-3.0
User Benefits	-190,242,606	-195,876,146	-3.0
Special Event	-165,631,793	-164,968,060	+0.4
Ingress	-102,912,760	-53,387,101	+48.1
Egress	-29,372,113	-33,315,153	-13.4
Peak	-66,473,279	-111,259,418	-67.4
No-Event	-62,659,334	-70,083,315	-11.8
Off-Peak	-19,567,709	-21,177,896	-8.2
Peak	-356,388,293	-399,321,995	-12.0
Management Goals	-897,044	-1,039,949	-15.9
Special Event	-4,029,392	-4,712,739	-17.0
Ingress	-2,249,705	-3,269,016	-45.3
Egress	-2,142,902	-1,752,777	+18.2
Peak	-442,663	-633,495	-43.1
No-Event	-1,352,871	-1,526,955	-12.9
Off-Peak	-308,872	-251,812	+18.5
Peak	-7,808,355	-8,909,920	-14.1
Integration Performance	0	-828,065	-

Table 5.11. Base Case Results with Pairwise AHP Weights

Branch	Before Value	After Value	Pct. Change

OVERALL	-65,441,559	-69,970,967	-6.9
Institutional Issues	-106,467	-123,248	-15.8
Administrative Issues	0	-6,398	-
System Operations Issues	7	-2,774	-397.3
System Maintainability	-18,502	-29,313	-58.4
Technical Issues	0	-508	-
Legal Issues	0	0	-
Implementation issues	0	-1,588	-
Operator Acceptance	0	-8,161	-
System Costs	-513,840	-567,500	-10.4
Technical Performance	-65,335,092	-69,847,719	-6.9
Reliability	-8,098,674	-10,231,259	-26.3
Network Performance	-73,570,191	-76,745,950	-4.3
User Benefits	-155,403,733	-161,870,972	-4.2
Special Event	-132,021,096	-131,898,251	+0.1
Ingress	-80,040,659	-41,705,764	+47.9
Egress	-35,583,303	-40,621,961	-14.2
Peak	-49,402,408	-82,545,089	-67.1
No-Event	-75,183,881	-83,929,712	-11.6
Off-Peak	-19,601,711	-21,205,211	-8.2
Peak	-356,317,696	-398,443,351	-11.8
Management Goals	-1,446,420	-1,749,835	-21.0
Special Event	-4,455,295	-5,507,161	-23.6
Ingress	-2,724,109	-3,995,530	-46.7
Egress	-2,125,756	-1,902,507	+10.5
Peak	-496,489	-710,556	-43.1
No-Event	-1,330,386	-1,492,180	-12.2
Off-Peak	-404,150	-332,536	+17.7
Peak	-7,578,166	-8,620,541	-13.8
Integration Performance	0	-332,440	-

Table 5.12. Percentage Impact on Overall Value: The Base Case

Branch	Ratio Weights	100 Point Weights	AHP Regular	AHP Pairwise

Institutional Issues	0.80	0.52	0.16	0.18
Administrative Issues	0.01	0.01	0.00	0.00
System Operations Issues	0.00	0.00	0.00	0.00
System Maintainability	0.02	0.02	0.01	0.01
Technical Issues	0.00	0.00	0.00	0.00
Legal Issues	0.00	0.00	0.00	0.00
Implementation issues	0.00	0.00	0.00	0.00
Operator Acceptance	0.01	0.01	0.00	0.00
System Costs	0.76	0.49	0.14	0.16
Technical Performance	99.20	99.48	99.84	99.82
Reliability	17.59	14.47	12.26	11.70
Network Performance	80.62	83.93	86.41	87.75
User Benefits	79.38	82.53	85.95	86.81
Special Event	40.07	40.33	60.33	53.05
Ingress	8.48	8.49	16.27	13.42
Egress	4.42	5.46	10.15	13.07
Peak	27.17	26.38	33.90	26.56
No-Event	39.31	42.21	25.63	33.76
Off-Peak	3.34	4.36	1.29	1.71
Peak	35.97	37.85	24.34	32.05
Management Goals	1.23	1.40	0.46	0.94
Special Event	0.86	1.01	0.35	0.74
Ingress	0.56	0.73	0.20	0.45
Egress	0.12	0.18	0.11	0.21
Peak	0.18	0.11	0.04	0.08
No-Event	0.37	0.39	0.11	0.20
Off-Peak	0.04	0.03	0.00	0.01
Peak	0.34	0.36	0.11	0.19
Integration Performance	0.99	1.08	1.18	0.38

By incorporating the varied weights in the lower portion of the hierarchy, these final results display more fluctuation than the type "A" hierarchy. The change in overall value from the "before" and "after" case varies between –15.1% (ratio) to -6.7% (AHP-regular). The large change in the overall values proves that all layers of the hierarchy exert influence on the final evaluation outcome. Although each level of the hierarchy merits importance, much like hierarchy “A” institutional issues fails to exert much influence on the final overall value. Reliability and user performance continues to dominate the evaluation by accounting for 97.2 to 99.5 percent of the overall value. Reliability remains stable across weighting schemes with all changes remaining within 0.6%, but user benefits and network performance exhibit wider swings from –11.5% (ratio) to –3.0% (AHP-regular).

Another portion of the results that seems contradictory refers to the management goals and user benefits corresponding to ingress, egress, and off-peak. User benefits are higher under ingress but management goals decline. Similarly, during egress and off-peak management goals improve when user benefits worsen. This bizarre result occurs because intersection delay dominates the management goal’s branch while the user benefits are more evenly distributed within the leaf. The contradicting results make deciding on the best operating conditions difficult. Even though user benefits appear worthy of receiving first priority, this may not prove true because the users may have received too much preference. In reality, the split between user benefits and management goals may be closer to an even division of overall contribution. If this proves to be the case then determining the proper operating conditions would be impossible. Once again, the base case indicates that the system fails to improve conditions between the “before” and “after” cases. Certainly this shows a very significant benefit from the new approach, which is identifying certain built-in contradictions in the structure of worth of a project, some that would not be readily apparent, but would merit careful examination during evaluation.

5.4.2.2 Alternate Data Set

As previously discussed in section 4.4, some of the "after" data is adversely effected by an accident on I-5. However, one of the branches of the hierarchy most effected by the accident, the special event-peak for user benefits, contributes somewhere between twenty-six (26) and thirty-four (34) percent of the overall system worth. Thus, an improvement for this branch can improve the apparent results of the evaluation. Table 5.13 focuses on the branches effected by utilizing the alternate data set.

In this scenario, the system improves dramatically on the system value compared to the base case. As in the base case, these final values display noticeable variation where the overall percentage change in values between "before" and "after" ranged from 2.3% (ratio) and 13.6% (AHP-regular). All of the branches of concern, technical performance, network performance, user benefits' special event, and management goals' special event, demonstrate at a minimum a fifteen point improvement compared to the base case. This alternate scenario proves that while the new system may not be able to handle volumes that would force most traffic control systems to fail, it can handle most special event operations quite effectively.

Table 5.13. Base Case vs. Alternate Data Case

Branch	Base Case	Alternate Data Case
Overall: Ratio Weights	-15.1	+2.3
Technical Performance	-15.1	+2.4
Network Performance	-11.5	+9.4
User Benefits: Special Event	-13.1	+28.9
Management Goals: Special Event	-25.6	+11.2
Overall: 100-Point Weights	-12.6	+4.2
Technical Performance	-12.6	+4.3
Network Performance	-9.2	+10.3
User Benefits: Special Event	-7.2	+31.9
Management Goals: Special Event	-11.3	+20.2
Overall: AHP-Regular Weights	-6.7	+13.6
Technical Performance	-6.7	+13.6
Network Performance	-3.0	+19.7
User Benefits: Special Event	+0.4	+31.7
Management Goals: Special Event	-15.9	+12.9
Overall: AHP-Pairwise Weights	-6.9	+9.1
Technical Performance	-6.9	+9.2
Network Performance	-4.3	+13.5
User Benefits: Special Event	+0.1	+28.0
Management Goals: Special Event	-23.6	+8.4

5.4.2.3 Special Event Only

The next scenario isolates the special event case. Since the special events' network performance results are superior to the no-event results (note that one of the weighting schemes exhibits inferior performance), a case may be made for implementing the system for only special events. This scenario follows the typical procedure for establishing the new hypothetical hierarchy. This section focuses exclusively on the percentage change between the "before" and "after" cases for this scenario and the base case and displays these results in Table 5.14.

As expected, this scenario returns mixed benefits depending on the weighting approach. In the ratio scheme, the percentage change moves from –15.1% in the base case to –17.2% in this scenario. Meanwhile, the other weighting styles return modest improvements to overall value ranging from one percentage point for the 100-point approach to three percentage points for AHP-pairwise. For the AHP-regular scheme, the system shows an increase in value for network performance, which indicates that traffic conditions likely improved. However, these gains are too slight to offset the other costs associated with implementing, operating, and maintaining the system. The downtime due to each loop detector failure continues to make a major impact on the final project valuation because its effect on reliability is the most difficult factor for network performance to overcome. The value attainment on management goals continues to be sub-par under special event condition, and the values continue to degrade with respect to the base case. This decline varies from about one percentage point for 100-point and AHP-regular up to over five percentage points for ratio. This deficiency manifests itself because this hierarchy allows intersections with poor delay results to dominate the resulting values. Institutional issues seem to exert little if any impact on the final overall weights. This special event scenario continues to demonstrate that the system looks viable for special event operations.

Table 5.14. Base Case vs. Special Event Only Scenario

Branch	Base Case	Special Event Only
Overall: Ratio Weights	-15.1	-17.2
Institutional Issues	-14.8	-14.6
Technical Performance	-15.1	-17.2
Network Performance	-11.5	-13.3
User Benefits	-11.4	-13.1
Management Goals	-20.5	-25.6
Overall: 100-Point Weights	-12.6	-11.6
Institutional Issues	-15.4	-15.2
Technical Performance	-12.6	-11.6
Network Performance	-9.2	-7.3
User Benefits	-9.1	-7.2
Management Goals	-11.3	-12.5
Overall: AHP-Regular Weights	-6.7	-4.3
Institutional Issues	-16.7	-16.6
Technical Performance	-6.7	-4.2
Network Performance	-3.0	+0.3
User Benefits	-3.0	+0.4
Management Goals	-15.9	-17.0
Overall: AHP-Pairwise Weights	-6.9	-3.9
Institutional Issues	-15.8	-15.5
Technical Performance	-6.9	-3.8
Network Performance	-4.3	-0.2
User Benefits	-4.2	+0.1
Management Goals	-21.0	-23.6

5.4.3 *Group: Hierarchy A*

This hierarchy uses Richard Macaluso and Frank Cechini's group forum preference weights in conjunction with uniform weighting for all branches that are not suited for administrator definition. As opposed to all of the previous hierarchies, this hierarchy only uses two weighting schemes, namely ratio and 100-point.

5.4.3.1 Base Case

This base case looks at the same branches as the base case in chapter four. Tables 5.15 and 5.16 display some selected "before" and "after" comparisons for this scenario. Each of these tables give the results for a single weighting scheme. Table 5.17 provides each branch's percentage contribution to overall value.

The user benefits and management goal branches remain identical across both weighting schemes because their weights are identical and uniform for both approaches. The similarities in weights between weighting schemes at the leaf level lead to extremely stable results across the two schemes. The change in overall value from the "before" and "after" case only vary between -19.0% (ratio) and -18.1% (100-point) which seems extremely stable compared to the other hierarchies. The group forum tends to have a little greater variability in their preference structure between schemes than Mr. Macaluso exhibits in his individual hierarchy. Reliability and network performance remain identical under the ratio and 100-point weighting approach. The overwhelming dominance of the technical performance branch provides further stability to this set of results. For the ratio weights, institutional issues account for 0.8% of the final overall value and for 100-point weights they account for 0.15%. All of the variation in overall

Table 5.15. Base Case Results with Ratio Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-34,486,910	-41,024,073	-19.0
Institutional Issues	-285,608	-328,934	-15.2
Administrative Issues	0	-13,834	-
System Operations Issues	11	-2,894	-264.1
System Maintainability	-13,698	-20,366	-48.7
Technical Issues	0	-253	-
Legal Issues	0	0	-
Implementation issues	0	-1,070	-
Operator Acceptance	0	-9.070	-
System Costs	-700,332	-774,849	-10.6
Technical Performance	-34.201,303	-40,695,138	-19.0
Reliability	-9,424,409	-11,948,718	-26.8
Network Performance	-47,577,762	-55,332,221	-16.3
User Benefits	-143,372,153	-166,647,584	-16.2
Special Event	-126,200,268	-155,347,205	-23.1
Ingress	-86,498,317	-47,963,458	+44.5
Egress	-18,693,186	-22,456,856	-20.1
Peak	-147,209,033	-240,274,097	-63.2
No-Event	-127,348,406	-139,354,717	-9.4
Off-Peak	-56,039,576	-62,226,363	-11.0
Peak	-198,657,235	-216,483,071	-9.0
Management Goals	-2,079,862	-2,510,920	-20.7
Special Event	-2,694,442	-3,516,837	-30.5
Ingress	-2,892,539	-3,883,992	-34.3
Egress	-878,107	-868,639	+1.1
Peak	-1,618,327	-2,281,043	-41.0
No-Event	-2,089,240	-2,258,280	-8.1
Off-Peak	-1,020,878	-956,510	+6.3
Peak	-3,157,603	-3,560,059	-12.7
Integration Performance	0	-544,291	-

Table 5.16. Base Case Results with 100-Point Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-55,602,924	-65,690,389	-18.1
Institutional Issues	-81,059	-95,804	-18.2
Administrative Issues	0	-9,004	-
System Operations Issues	22	-2,796	-126.1
System Maintainability	-6,431	-9,136	-42.1
Technical Issues	0	-107	-
Legal Issues	0	0	-
Implementation issues	0	-2,673	-
Operator Acceptance	0	-3,411	-
System Costs	-263,789	-292,221	-10.8
Technical Performance	-55,521,865	-65,594,584	-18.1
Reliability	-7,749,257	-9,824,879	-26.8
Network Performance	-71,567,693	-83,209,679	-16.3
User Benefits	-177,484,071	-206,291,345	-16.2
Special Event	-126,200,268	-155,347,205	-23.1
Ingress	-86,498,317	-47,963,458	+44.5
Egress	-18,693,186	-22,456,856	-20.1
Peak	-147,209,033	-240,274,097	-63.2
No-Event	-127,348,406	-139,354,717	-9.4
Off-Peak	-56,039,576	-62,226,363	-11.0
Peak	-198,657,235	-216,483,071	-9.0
Management Goals	-1,435,160	-1,732,853	-20.7
Special Event	-2,692,934	-3,516,069	-30.6
Ingress	-2,891,668	-3,885,513	-34.4
Egress	-877,492	-867,863	+1.1
Peak	-1,616,709	-2,278,762	-41.0
No-Event	-2,090,934	-2,260,106	-8.1
Off-Peak	-1,021,414	-956,782	+6.3
Peak	-3,160,453	-3,563,431	-12.8
Integration Performance	0	671,990	-

Table 5.17. Percentage Impact on Overall Value: The Base Case

Branch	Ratio Weights	100 Point Weights
Institutional Issues	0.80	0.15
Administrative Issues	0.01	0.00
System Operations Issues	0.00	0.00
System Maintainability	0.02	0.00
Technical Issues	0.00	0.00
Legal Issues	0.00	0.00
Implementation issues	0.00	0.00
Operator Acceptance	0.01	0.00
System Costs	0.76	0.13
Technical Performance	99.20	99.85
Reliability	17.48	10.47
Network Performance	80.93	88.67
User Benefits	79.73	87.93
Special Event	42.05	46.35
Ingress	6.49	7.16
Egress	3.04	3.35
Peak	32.52	35.85
No-Event	37.68	41.58
Off-Peak	8.41	9.28
Peak	29.27	32.30
Management Goals	1.20	0.74
Special Event	0.73	0.45
Ingress	0.40	0.25
Egress	0.09	0.06
Peak	0.24	0.15
No-Event	0.47	0.29
Off-Peak	0.10	0.06
Peak	0.37	0.23
Integration Performance	0.80	0.72

value comes from the different weights in the technical performance branch because the overall percentage change remains identical to technical performance. As network performance increases in preference or importance, the overall system and technical performance improves slightly. The dominance of individual branches and attributes continue to haunt this hierarchy as a few attributes control the entire outcome of the evaluation. Thus, a few troublesome areas determine the final overall values. Conversely, a few improvements to these dominant features can create overwhelming changes in the evaluation results.

5.4.3.2 Alternate Data Set

This section attempts to ascertain the effects of the I-5 accident that this dissertation previously discussed in section 4.4. Although the system fails to improve in the base case, this research expects the elimination of all data effected by the accident will improve the overall results. A single hierarchy branch which remains highly effected by the accident, the special event-peak for user benefits, contributes somewhere between thirty-two (32) and thirty-six (36) percent of the overall system worth. Thus, an improvement for this branch can affect a major improvement to the evaluation results. Table 5.18 focuses on all of the branches effected by utilizing the alternate data set.

The lower branches of this hierarchy remain identical for both of the weighting approaches as in the base case. In particular, network performance, user benefits, and management goals all improve dramatically but their values are identical for both schemes. In this scenario, the overall value continues to be almost entirely based on technical performance because the variation between the two remains no larger than 0.1%. Overall performance enjoys tremendous improvements from the base case to the current scenario; ratio weight percentage change improves from –19.0% to +2.4% while 100-point percentage change jumps from –18.1% to +5.1%. This scenario shows that the system proves to be successful with the elimination of the data effected by the accident.

Table 5.18. Base Case vs. Alternate Data Case

Branch	Base Case	Alternate Data Case
Overall: Ratio Weights	-19.0	+2.4
Technical Performance	-19.0	+2.5
Network Performance	-16.3	+9.5
User Benefits: Special Event	-23.1	+28.7
Management Goals: Special Event	-20.7	+7.7
Overall: 100-Point Weights	-18.1	+5.1
Technical Performance	-18.1	+5.1
Network Performance	-16.3	+9.5
User Benefits: Special Event	-23.1	+28.7
Management Goals: Special Event	-30.6	+7.7

5.4.3.3 Special Event Only

The next scenario isolates the special event case. Although the special events' network performance results are inferior to the no-event results, this scenario is included for completeness and comparison to the other hierarchies. This is accomplished using the same procedure as that outlined in chapter four. Table 5.19 compares the percentage change between the "before" and "after" cases in the base scenario to the change in this scenario. This hierarchy continues to show no variation between schemes for management goals, user benefits or network performance. In particular, management goals reduces from –20.7% to –30.6% while user benefits and network performance shrink by 6.9 percentage points. As expected, the overall percentage change between the "before" and "after" cases degrades for the ratio scheme from –19.0% to –24.7% and the 100-point approach –18.1% to –24.4%. For this scenario, institutional issues show a small improvement of either 0.2 to 0.1 percentage points for ratio and 100-point weighting approaches. This improvement is unable to affect any impact on the final outcome. The overall value of the system decreases when operated under special event only conditions.

Table 5.19. Base Case vs. Special Event Only Scenario

Branch	Base Case	Special Event Only
Overall: Ratio Weights	-19.0	-24.7
Institutional Issues	-15.2	-15.0
Technical Performance	-19.0	-24.8
Network Performance	-16.3	-23.2
User Benefits	-16.2	-23.1
Management Goals	-20.7	-30.6
Overall: 100-Point Weights	-18.1	-24.4
Institutional Issues	-18.2	-18.1
Technical Performance	-18.1	-24.4
Network Performance	-16.3	-23.2
User Benefits	-16.2	-23.1
Management Goals	-20.7	-30.6

5.4.4 *Group: Hierarchy B*

This hierarchy uses the group forum preference weights that Richard Macaluso and Frank Cechini settled on together. A local expert who understands all of the pertinent issues defines the portion of the hierarchy inappropriate for administrator definition.

5.4.4.1 Base Case

This base case looks at the same branches as the base case in chapter four. Tables 5.20 and 5.21 display some selected “before” and “after” comparisons for this scenario. These two tables give the results for a single weighting scheme. Table 5.22 provides each branch’s percentage contribution to overall value.

As opposed to hierarchy “A”, this hierarchy shows variance between the two schemes at all levels. This variability is increased because the group forum preference weights fluctuate more widely than Richard Macaluso’s individual preferences. The change in overall value from the “before” and “after” case varies between -14.5% (ratio) and –11.0% (100-point). The overwhelming dominance of the technical performance branch continues to drive the evaluation’s results. For the two schemes, institutional issues account for just over 0.8 percent in the ratio approach and not even 0.2 percent in the 100-point approach. While institutional issues still fail to play any role in the overall value, its performance varies from -18.2% (100-point) to –15.2% (ratio). All of the variation in overall value comes from the different weights in the technical performance branch because the overall performance remains identical to technical performance. As the weight on network performance increases, the system’s worth improves. Using an outsider’s value function in conjunction with the decision-maker’s establishes a dominant situation for the outsider’s value function when his value at identical attribute levels greatly exceeds the typical values that are used by the primary decision-maker. The external expert determines the reliability value functions while a small sample of users identifies the user benefit value functions. These two branches dominates the entire evaluation by contributing between 98.3% and 99.1% of the final overall value.

Table 5.20. Base Case Results with Ratio Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-35,163,938	-40,259,423	-14.5
Institutional Issues	-285,608	-328,934	-15.2
Administrative Issues	0	-13,834	-
System Operations Issues	11	-2,894	-264.1
System Maintainability	-13,698	-20,366	-48.7
Technical Issues	0	-253	-
Legal Issues	0	0	-
Implementation issues	0	-1,070	-
Operator Acceptance	0	-9,070	-
System Costs	-700,332	-774,849	-10.6
Technical Performance	-34,878,330	-39,930,489	-14.5
Reliability	-7,618,942	-9,669,986	-26.9
Network Performance	-50,511,608	-56,336,535	-11.5
User Benefits	-151,907,045	-169,199,470	-11.4
Special Event	-133,625,543	-151,103,745	-13.1
Ingress	-95,321,884	-53,304,572	+44.1
Egress	-23,431,966	-27,775,872	-18.5
Peak	-103,955,388	-170,759,131	-64.3
No-Event	-135,133,075	-148,249,164	-9.7
Off-Peak	-28,806,855	-31,499,988	-9.3
Peak	-309,025,832	-339,122,921	-9.7
Management Goals	-2,514,157	-3,029,366	-20.5
Special Event	-3,865,840	-4,855,604	-25.6
Ingress	-3,602,266	-4,747,826	-31.8
Egress	-1,135,730	-1,043,897	+8.1
Peak	-1,060,764	-1,491,683	-40.6
No-Event	-1,916,721	-2,111,938	-10.2
Off-Peak	-710,111	-641,040	+9.7
Peak	-5,040,054	-5,694,774	-13.0
Integration Performance	0	-544,291	-

Table 5.21. Base Case Results with 100-Point Weights

Branch	Before Value	After Value	Pct. Change
OVERALL	-55,324,419	-61,437,236	-11.0
Institutional Issues	-81,059	-95,804	-18.2
Administrative Issues	0	-9,004	-
System Operations Issues	22	-2,796	-128.1
System Maintainability	-6,431	-9,136	-42.1
Technical Issues	0	-107	-
Legal Issues	0	0	-
Implementation issues	0	-2,673	-
Operator Acceptance	0	-3,411	-
System Costs	-263,789	-292,221	-10.8
Technical Performance	-55,243,360	-61,341,432	-11.0
Reliability	-4,754,620	-6,014,732	-26.5
Network Performance	-74,164,465	-80,943,895	-9.1
User Benefits	-183,446,181	-200,172,127	-9.1
Special Event	-130,386,036	-139,722,380	-7.2
Ingress	-98,525,341	-49,019,310	+49.2
Egress	-27,739,406	-31,538,514	-13.7
Peak	-93,045,313	-152,312,809	-63.7
No-Event	-131,679,937	-146,237,801	-11.1
Off-Peak	-34,764,258	-37,750,193	-8.6
Peak	-294,435,583	-327,844,310	-11.3
Management Goals	-1,964,980	-2,187,609	-11.3
Special Event	-4,679,581	-5,263,997	-12.5
Ingress	-4,014,180	-5,057,077	-26.0
Egress	-1,679,715	-1,231,029	+26.7
Peak	-545,546	-730,557	-33.9
No-Event	-1,870,354	-2,028,034	-8.4
Off-Peak	-947,004	-706,348	+25.4
Peak	-6,534,410	-7,405,789	-13.3
Integration Performance	0	-671,990	-

Table 5.22. Percentage Impact on Overall Value: The Base Case

Branch	Ratio Weights	100 Point Weights
Institutional Issues	0.82	0.16
Administrative Issues	0.01	0.00
System Operations Issues	0.00	0.00
System Maintainability	0.02	0.00
Technical Issues	0.00	0.00
Legal Issues	0.00	0.00
Implementation issues	0.00	0.00
Operator Acceptance	0.01	0.00
System Costs	0.77	0.14
Technical Performance	99.18	99.84
Reliability	14.41	6.85
Network Performance	83.96	92.23
User Benefits	82.48	91.23
Special Event	41.64	44.58
Ingress	8.81	9.38
Egress	4.59	6.04
Peak	28.23	29.16
No-Event	40.85	46.65
Off-Peak	3.47	4.82
Peak	37.38	41.84
Management Goals	1.48	1.00
Special Event	1.03	0.72
Ingress	0.67	0.52
Egress	0.15	0.13
Peak	0.21	0.08
No-Event	0.45	0.28
Off-Peak	0.05	0.02
Peak	0.40	0.25
Integration Performance	0.82	0.77

This does not seem appropriate, and a solution to this problem may require additional research as well as extensive discussions with the decision-makers. User benefits drive the network performance results. In fact, network performance remains within a 0.1 percentage point of user benefits for both schemes. This "B" hierarchy behaves similarly to the hierarchy described in section 5.4.2 with respect to the user benefits and management goals because they have the same weights in both. Management goals fluctuate widely between the two weighting approaches from –20.5% (ratio) to –11.3% (100-point) while the special event branch shows a similar relation. While the system fails to perform well under this hierarchy in the base case, many factors contribute to the observed difficulties.

5.4.4.2 Alternate Data Set

Although the base case results indicate that the overall worth decreases "after" SCOOT, it appears that the accident described in section 4.4 negatively effected these results. Additionally, the "after" system seems to deteriorate over time with respect to the existing system. However, the special event peak user benefits branch, which is highly effected by the accident, contributes somewhere between twenty-eight (28) and thirty (30) percent of the overall system worth. Thus, an improvement may improve the apparent evaluation results. Table 5.23 focuses on the effected branches by utilizing the alternate data set, including the management goals special event peak.

This scenario shows tremendous improvement over the base case and proves that this hierarchy is successful after reducing the data set. The overall worth percentage change increases from values of –14.5% (ratio) and –11.0% (100-point) to +3.6% (ratio) and +7.2% (100-point). Both of the special event branches enjoy increases of between thirty-two (32) and forty-two (42) percentage points. These improvements translate into gains of approximately twenty percentage points to the new levels of +9.4% (ratio) and +10.3% (100-point). Technical performance continues to drive this scenario not only demonstrating that the system may prove useful but identifying the potential to make significant changes to the values by changes to the data.

Table 5.23. Base Case vs. Alternate Data Case

Branch	Base Case	Alternate Data Case
Overall: Ratio Weights	-14.5	+3.6
Technical Performance	-14.5	+3.7
Network Performance	-11.5	+9.4
User Benefits: Special Event	-13.1	+28.9
Management Goals: Special Event	-25.6	+11.2
Overall: 100-Point Weights	-11.0	+7.2
Technical Performance	-11.0	+7.2
Network Performance	-9.1	+10.3
User Benefits: Special Event	-7.2	+31.9
Management Goals: Special Event	-12.5	+20.2

5.4.4.3 Special Event Only

This scenario deals with a case where regular operations are not undertaken. The procedure for identifying this hierarchy follows the same procedure as that outlined in section 4.5.4. Table 5.24 compares the percentage change between the "before" and "after" cases in the base scenario to the change in this scenario. This scenario offers mixed results where one of the weighting options improves, -11.0% to –9.6% (100-point), and the other degrades, -14.5% to -16.5% (ratio). In both cases, institutional issues enjoy a modest gain of 0.1 or 0.2 percent, and this scenario's values are –18.1% (100-point) and –15.0% (ratio). Conversely, management goals show a decrease in value change of over one percentage point to –13.1% (ratio) and –12.5% (100-point). Technical performance remains identical to the overall results. Similarly, network performance remains essentially equivalent to user benefits. In this scenario, network performance either increases (-9.6%, 100-point) or decreases (-13.1%, ratio) about two percentage points depending on the time periods of emphasis in the user benefits special event branch. The mixed results reinforce the difficulties associated with the determination of the proper operating conditions.

Table 5.24. Base Case vs. Special Event Only Scenario

Branch	Base Case	Special Event Only
Overall: Ratio Weights	-14.5	-16.5
Institutional Issues	-15.2	-15.0
Technical Performance	-14.5	16.5
Network Performance	-11.5	-13.3
User Benefits	-11.4	-13.1
Management Goals	-20.5	-25.6
Overall: 100-Point Weights	-11.0	-9.6
Institutional Issues	-18.2	-18.1
Technical Performance	-11.0	-9.6
Network Performance	-9.1	-7.2
User Benefits	-9.1	-7.2
Management Goals	-11.3	-12.5

5.5 Comparison to Chapter Four

This section attempts to identify the differences between the four hierarchies that are identified in this chapter and the one that is detailed in chapter four. When direct comparisons between the primary hierarchy and the four administrator hierarchies are made, they result in some unusual findings. Furthermore, the differences between the preferences of the primary decision-maker and the administrator become less clear because they share many but not all of the value functions. The differences between the weights and value functions within these hierarchies generate dramatically different results; however, the key branches of impact tend to remain similar across all four of the schemes.

While most of the value functions remain the same for all hierarchies, three dominant attributes use an alternative value function for all of the administrator hierarchies. These value functions that one administrator, Richard Macaluso, determined individually included the two value functions for floating car network performance, and project management. In John Thai's hierarchy, these three value functions proved to be dominant either within their leaf or within the entire hierarchy. The alternative value functions proved to be about a tenth the magnitude of the original value functions. This causes the importance of these particular branches, specifically management goals and administrative issues, to decrease dramatically in importance. This makes a direct comparison of the differences between just the decision-makers' weighting schemes impossible.

The comparison of the results and findings from the five hierarchies that are described in chapters four and five permit extensive analysis of the alternative points-of-view. As a necessity for this comparison, the results are presented as the percentage change between the "before" and “after” cases. The analysis looks at the same branches as the dissertation previously discussed for all of the base cases. Tables 5.25 through 5.28 present the overall results and aforementioned branches by weighting scheme for all of the appropriate hierarchies. Further investigation accounted for the impact of each of the aforementioned branches on the overall value. Tables 5.29 through 5.32 outline the percentage of the overall value that each branch contributes by weighting scheme for all appropriate hierarchies. All of the discussion in this section looks at a single weighting scheme at a time and ignores comparisons between the approaches while the next section analyzes all of the overall results at the same time and compares the different weighting schemes with one another. The combination of both of these analyses provides a wealth of information about the results.

Table 5.28 focuses on the results using the ratio weighting scheme. As expected, both of the type “A” and both of the type “B” hierarchies’ results look very similar to one another. The most dramatic differences are noticed when comparing the dissimilar hierarchies: John Thai, type “A”, and type “B”. The type “A” hierarchies show the poorest overall results with Richard Macaluso’s individual hierarchy looking the worst at a –19.5% change in value while John Thai’s hierarchy exhibits the best performance at a -7.8% change. The swing in results among the hierarchies arises from the differences in their network performance. While the results from many branches that attached to user benefits remain almost identical, the difference in preferences makes the special event branch much worse for the type ”A” hierarchies, -23.1%, as opposed to the others, -13.1%. The management goals branch varies dramatically across the hierarchies, but the final results for all of the administrator hierarchies are remarkably similar. Some major

Table 5.25. Comparison of all Base Case Results with Ratio Weights

Branch	John Thai	Macaluso-A	Macaluso-B	Group-A	Group-B
OVERALL	-7.8	-19.5	-15.1	-19.0	-14.5
Institutional Issues	-25.1	-14.8	-14.8	-15.2	-15.2
Administrative Issues	-	-	-	-	-
System Operations Issues	-3,618.3	-367.7	-365.6	-264.1	-264.1
System Maintainability	-66.7	-61.3	-61.3	-48.7	-48.7
Technical Issues	-	-	-	-	-
Legal Issues	-	-	-	-	-
Implementation issues	-	-	-	-	-
Operator Acceptance	-	-	-	-	-
System Costs	-11.4	-10.4	-10.4	-10.6	-10.6
Technical Performance	-7.5	-19.6	-15.1	-19.0	-14.5
Reliability	-27.8	-26.8	-26.9	-26.8	-26.9
Network Performance	-1.8	-16.3	-11.5	-16.3	-11.5
User Benefits	-11.4	-16.2	-11.4	-16.2	-11.4
Special Event	-13.1	-23.1	-13.1	-23.1	-13.1
Ingress	+44.1	+44.5	+44.1	+44.5	+44.1
Egress	-18.5	-20.1	-18.5	-20.1	-18.5
Peak	-64.3	-63.2	-64.3	-63.2	-64.3
No-Event	-9.7	-9.4	-9.7	-9.4	-9.7
Off-Peak	-9.3	-11.0	-9.3	-11.0	-9.3
Peak	-9.7	-9.0	-9.7	-9.0	-9.7
Management Goals	+17.2	-20.7	-20.5	-20.7	-20.5
Special Event	+24.6	-30.6	-25.6	-30.5	-25.6
Ingress	+64.1	-34.4	-31.8	-34.3	-31.8
Egress	-18.4	+1.1	+8.1	+1.1	+8.1
Peak	-85.8	-41.0	-40.6	-41.0	-40.6
No-Event	-15.9	-8.1	-10.2	-8.1	-10.2
Off-Peak	-6.1	+6.3	+9.7	+6.3	+9.7
Peak	-17.4	-12.8	-13.0	-12.7	-13.0
Integration Performance	-	-	-	-	-

Table 5.26. Comparison of all Base Case Results with 100-Point Weights

Branch	John Thai	Macaluso-A	Macaluso-B	Group-A	Group-B
OVERALL	-3.1	-19.5	-12.6	-18.1	-11.0
Institutional Issues	-33.9	-15.4	-15.4	-18.2	-18.2
Administrative Issues	-	-	-	-	-
System Operations Issues	-2,693.0	-460.7	-460.7	-126.1	-128.1
System Maintainability	-53.1	-58.3	-58.3	-42.1	-42.1
Technical Issues	-	-	-	-	-
Legal Issues	-	-	-	-	-
Implementation issues	-	-	-	-	-
Operator Acceptance	-	-	-	-	-
System Costs	-11.5	-10.4	-10.4	-10.8	-10.8
Technical Performance	-2.8	-19.6	-12.6	-18.1	-11.0
Reliability	-27.4	-26.8	-26.5	-26.8	-26.5
Network Performance	+2.7	-16.3	-9.2	-16.3	-9.1
User Benefits	-9.1	-16.2	-9.1	-16.2	-9.1
Special Event	-7.2	-23.1	-7.2	-23.1	-7.2
Ingress	+49.2	+44.5	+49.2	+44.5	+49.2
Egress	-13.7	-20.1	-13.7	-20.1	-13.7
Peak	-63.7	-63.2	-63.7	-63.2	-63.7
No-Event	-11.1	-9.4	-11.1	-9.4	-11.1
Off-Peak	-8.6	-11.0	-8.6	-11.0	-8.6
Peak	-11.3	-9.0	-11.3	-9.0	-11.3
Management Goals	+36.5	-20.7	-11.3	-20.7	-11.3
Special Event	+44.3	-30.6	-12.5	-30.6	-12.5
Ingress	+76.4	-34.4	-26.0	-34.4	-26.0
Egress	-3.1	+1.1	+26.7	+1.1	+26.7
Peak	-68.4	-41.0	-33.9	-41.0	-33.9
No-Event	-18.2	-8.1	-8.4	-8.1	-8.4
Off-Peak	-3.2	+6.3	+25.4	+6.3	+25.4
Peak	-20.6	-12.8	-13.3	-12.8	-13.3
Integration Performance	-	-	-	-	-

Table 5.27. Comparison of all Base Case Results with Regular AHP Weights

Branch	John Thai	Macaluso-A	Macaluso-B
OVERALL	-10.4	-18.7	-6.7
Institutional Issues	-21.4	-16.7	-16.7
Administrative Issues	-	-	-
System Operations Issues	-5,375.8	-226.0	-226.0
System Maintainability	-61.8	-30.7	-30.7
Technical Issues	-	-	-
Legal Issues	-	-	-
Implementation issues	-	-	-
Operator Acceptance	-	-	-
System Costs	-10.5	-10.4	-10.4
Technical Performance	-10.1	-18.7	-6.7
Reliability	-27.2	-26.8	-26.4
Network Performance	+1.0	-16.2	-3.0
User Benefits	-3.0	-16.2	-3.0
Special Event	+0.4	-23.1	+0.4
Ingress	+48.1	+44.5	+48.1
Egress	-13.4	-20.1	-13.4
Peak	-67.4	-63.2	-67.4
No-Event	-11.8	-9.4	-11.8
Off-Peak	-8.2	-11.0	-8.2
Peak	-12.0	-9.0	-12.0
Management Goals	+18.0	-20.7	-15.9
Special Event	+24.7	-30.6	-17.0
Ingress	+65.1	-34.4	-45.3
Egress	-4.9	+1.1	+18.2
Peak	-93.8	-41.0	-43.1
No-Event	-21.6	-8.1	-12.9
Off-Peak	-4.9	+6.3	+18.5
Peak	-22.3	-12.8	-14.1
Integration Performance	-	-	-

Table 5.28. Comparison of all Base Case Results with Pairwise-AHP Weights

Branch	John Thai	Macaluso-A	Macaluso-B
OVERALL	-13.6	-17.7	-6.9
Institutional Issues	-30.3	-15.8	-15.8
Administrative Issues	-	-	-
System Operations Issues	-3,353.8	-397.3	-397.3
System Maintainability	-47.3	-58.4	-58.4
Technical Issues	-	-	-
Legal Issues	-	-	-
Implementation issues	-	-	-
Operator Acceptance	-		-
System Costs	-10.5	-10.4	-10.4
Technical Performance	-13.5	-17.7	-6.9
Reliability	-27.2	-26.8	-26.3
Network Performance	+1.2	-16.3	-4.3
User Benefits	-4.2	-16.2	-4.2
Special Event	+0.1	-23.1	+0.1
Ingress	+47.9	+44.5	+47.9
Egress	-14.2	-20.1	-14.2
Peak	-67.1	-63.2	-67.1
No-Event	-11.6	-9.4	-11.6
Off-Peak	-8.2	-11.0	-8.2
Peak	-11.8	-9.0	-11.8
Management Goals	+19.5	-20.7	-21.0
Special Event	+25.2	-30.6	-23.6
Ingress	+64.5	-34.4	-46.7
Egress	-8.7	+1.1	+10.5
Peak	-93.8	-41.0	-43.1
No-Event	-20.9	-8.1	-12.2
Off-Peak	-5.9	+6.3	+17.7
Peak	-21.8	-12.8	-13.8
Integration Performance	-	-	-

Table 5.29. Comparing the Percentage Impact on Overall Value: The Base Case

with Ratio Weights

Branch	John Thai	Macaluso-A	Macaluso-B	Group-A	Group-B
Institutional Issues	2.31	0.78	0.80	0.80	0.82
Administrative Issues	.17	0.01	0.01	0.01	0.01
System Operations Issues	.05	0.00	0.00	0.00	0.00
System Maintainability	.06	0.02	0.02	0.02	0.02
Technical Issues	.00	0.00	0.00	0.00	0.00
Legal Issues	.00	0.00	0.00	0.00	0.00
Implementation issues	.00	0.00	0.00	0.00	0.00
Operator Acceptance	.02	0.01	0.01	0.01	0.01
System Costs	2.02	0.74	0.76	0.76	0.77
Technical Performance	97.69	99.22	99.20	99.20	99.18
Reliability	15.88	21.16	17.59	17.48	14.41
Network Performance	79.83	77.10	80.62	80.93	83.96
User Benefits	57.98	76.10	79.38	79.93	82.48
Special Event	29.27	40.14	40.07	42.05	41.64
Ingress	6.20	6.20	8.48	6.49	8.81
Egress	3.23	2.90	4.42	3.04	4.59
Peak	19.85	31.04	27.17	32.52	28.23
No-Event	28.72	35.97	39.31	37.68	40.85
Off-Peak	2.44	8.03	3.34	8.41	3.47
Peak	26.28	27.94	35.97	29.27	37.38
Management Goals	21.85	0.99	1.23	1.20	1.48
Special Event	16.26	0.61	0.86	0.73	1.03
Ingress	5.35	0.33	0.56	0.40	0.67
Egress	2.67	0.08	0.12	0.09	0.15
Peak	8.24	0.20	0.18	0.24	0.21
No-Event	5.59	0.39	0.37	0.47	0.45
Off-Peak	.67	0.08	0.04	0.10	0.05
Peak	4.92	0.31	0.34	0.37	0.40
Integration Performance	1.98	0.96	0.99	0.80	0.82

Table 5.30. Comparing the Percentage Impact on Overall Value: The Base Case with 100-Point Weights

Branch	John Thai	Macaluso-A	Macaluso-B	Group-A	Group-B
Institutional Issues	1.45	0.47	0.52	0.15	0.16
Administrative Issues	.18	0.01	0.01	0.00	0.00
System Operations Issues	.03	0.00	0.00	0.00	0.00
System Maintainability	.04	0.02	0.02	0.00	0.00
Technical Issues	.00	0.00	0.00	0.00	0.00
Legal Issues	.00	0.00	0.00	0.00	0.00
Implementation issues	.00	0.00	0.00	0.00	0.00
Operator Acceptance	.02	0.01	0.01	0.00	0.00
System Costs	1.18	0.44	0.49	0.13	0.14
Technical Performance	98.55	99.53	99.48	99.85	99.84
Reliability	16.20	21.21	14.47	10.47	6.85
Network Performance	80.94	77.35	83.93	88.67	92.23
User Benefits	67.24	76.35	82.53	87.93	91.23
Special Event	32.85	40.25	40.33	46.35	44.58
Ingress	6.92	6.21	8.49	7.16	9.38
Egress	4.45	2.91	5.46	3.35	6.04
Peak	21.49	31.13	26.38	35.85	29.16
No-Event	34.38	36.11	42.21	41.58	46.65
Off-Peak	3.55	8.06	4.36	9.28	4.82
Peak	30.83	28.04	37.85	32.30	41.84
Management Goals	13.70	1.00	1.40	0.74	1.00
Special Event	10.51	0.61	1.01	0.45	0.72
Ingress	4.75	0.34	0.73	0.25	0.52
Egress	2.39	0.08	0.18	0.06	0.13
Peak	3.38	0.20	0.11	0.15	0.08
No-Event	3.19	0.39	0.39	0.29	0.28
Off-Peak	.38	0.08	0.03	0.06	0.02
Peak	2.80	0.31	0.36	0.23	0.25
Integration Performance	1.42	0.97	1.08	0.72	0.77

Table 5.31. Comparing the Percentage Impact on Overall Value: The Base Case with Regular AHP Weights

Branch	John Thai	Macaluso-A	Macaluso-B
Institutional Issues	3.06	0.13	0.16
Administrative Issues	.17	0.00	0.00
System Operations Issues	.05	0.00	0.00
System Maintainability	.07	0.01	0.01
Technical Issues	.00	0.00	0.00
Legal Issues	.00	0.00	0.00
Implementation issues	.00	0.00	0.00
Operator Acceptance	.04	0.00	0.00
System Costs	2.74	0.11	0.14
Technical Performance	96.94	99.87	99.84
Reliability	34.63	13.57	12.26
Network Performance	60.22	85.37	86.41
User Benefits	50.69	85.04	85.95
Special Event	35.58	44.83	60.33
Ingress	9.60	6.92	16.27
Egress	5.99	3.24	10.15
Peak	20.00	34.67	33.90
No-Event	15.11	40.21	25.63
Off-Peak	.76	8.98	1.29
Peak	14.35	31.24	24.34
Management Goals	9.53	0.33	0.46
Special Event	7.47	0.20	0.35
Ingress	2.05	0.11	0.20
Egress	2.88	0.03	0.11
Peak	2.54	0.07	0.04
No-Event	2.06	0.13	0.11
Off-Peak	.07	0.03	0.00
Peak	1.99	0.10	0.11
Integration Performance	2.09	0.93	1.18

Table 5.32. Comparing the Percentage Impact on Overall Value: The Base Case with Pairwise-AHP Weights

Branch	John Thai	Macaluso-A	Macaluso-B
Institutional Issues	1.32	0.13	0.18
Administrative Issues	.15	0.00	0.00
System Operations Issues	.02	0.00	0.00
System Maintainability	.05	0.01	0.01
Technical Issues	.00	0.00	0.00
Legal Issues	.00	0.00	0.00
Implementation issues	.00	0.00	0.00
Operator Acceptance	.02	0.00	0.00
System Costs	1.09	0.08	0.16
Technical Performance	98.68	99.87	99.82
Reliability	31.02	11.55	11.70
Network Performance	61.84	88.04	87.75
User Benefits	50.46	87.47	86.81
Special Event	30.84	46.11	53.05
Ingress	7.80	7.12	13.42
Egress	7.60	3.33	13.07
Peak	15.44	35.66	26.56
No-Event	19.62	41.36	33.76
Off-Peak	.99	9.24	1.71
Peak	18.63	32.13	32.05
Management Goals	11.38	0.57	0.94
Special Event	9.26	0.35	0.74
Ingress	2.70	0.19	0.45
Egress	3.47	0.04	0.21
Peak	3.09	0.11	0.08
No-Event	2.12	0.22	0.20
Off-Peak	.10	0.05	0.01
Peak	2.02	0.18	0.19
Integration Performance	5.82	0.28	0.38

differences develop where John Thai's hierarchy notes improvements overall for management goals as well as special events and ingress, and the administrator hierarchies note improvements in egress and off-peak. Also of interest is the observation that John Thai's special event peak results and no-event results are noticeably worse than those observed for the administrator hierarchies. For all of the hierarchies, the user benefit impacts are split relatively equally between the special event and no-event case while management goal impacts emphasize the special event branch. The primary observations about the percentage impacts of each of the branches note that most of the administrator hierarchies make similar impacts at the highest level, but differ in the lower levels. The institutional issues for John Thai's hierarchy accounts for more of the overall value than the others because he emphasizes one of the dominant attributes, system costs, to a greater extent than the other decision-makers. Furthermore, his value function for project management allows administrative issues to make a modest contribution as well. This addition in particular makes the institutional issues results much worse for his hierarchy, -25.1%, as opposed to the administrator hierarchies, about –15%. Other than the branches that extensively use Richard Macaluso's value functions, the lower levels of the hierarchies look remarkably similar; however, varied preferences allow very different final results to develop.

The other weighting schemes display relationships similar to the ratio scheme; however, a few interesting insights and results still emerge. In the 100-point approach, John Thai's network performance branch shows improvement because the management goals exhibit a tremendous increase in value. Using the same scheme, the two type "A" and two type "B" hierarchies remain near one another in percentage change in overall value, but they are not as close as the changes found in the first weighting approach. The impact of institutional issues decreases for all of the hierarchies under the 100-point scheme. Surprisingly when using either AHP weighting scheme, Richard Macaluso's type "B" hierarchy shows better results than John Thai's hierarchy while the type "A" hierarchy shows the poorest results. This occurs in spite of an improvement in network performance for the John Thai hierarchies because he places little importance on network performance while it ranks as Mr. Macaluso's highest priority in the technical performance branch. The type "A" hierarchies fare poorly because they have poor network performance results. The user benefit impacts for John Thai's hierarchy and Mr. Macaluso's type "B" hierarchy are not evenly split for the AHP weighting approaches because special events are highly preferred. Interestingly, integration performance has a dramatic impact on John Thai's hierarchy when using the pairwise AHP weighting scheme and it accounts for almost six percent of the overall value. For the other three weighting approaches, it accounts for about two percent of the overall value. The observed trends remain relatively consistent across all weighting schemes and hierarchies.

The results that are presented in chapter four seem to be a better representation of the system while those found in chapter five seem to have numerous difficulties associated with them. The interaction of the value function and preference weights seems fairly clear; however, a consistent, accurate valuing of the attributes remains critical. The observed behaviors continue across the various scenarios that this research investigates.

5.6 Findings

As previously discussed, user benefits completely dominate all four hierarchies, and reliability carry the remainder of the load. The dominance of these two branches is so complete that all of the rest of the branches could have been dropped from the evaluation without making an impact on the overall value. The weights combined with the large values that are generated by the user benefit value functions establish the dominance of the aforementioned branches. Within the overwhelmed institutional issues branch, system costs remains the only branch of any interest. The dominance of intersection delay within the management goals branch creates numerous interesting results. The dominance is much more pronounced in the administrator hierarchies than the single City of Anaheim decision-maker. Furthermore, the user benefits branch dominates the entire network performance branch where management goals have little impact.

Although the previous section look at the base case in extreme detail for all of the hierarchies and weighting schemes, Table 5.33 allows for a closer investigation of the overall values for all of the frequently discussed scenarios: base case, alternate data set and special event only. Looking at all of the weighting schemes, all of the hierarchies appear to return reductions in overall system value for the base case while all of the alternate data set scenarios (except one) enjoy increases in overall value. The identified preferences play a large role in determining whether the special event scenario reduces or increases the overall system value when compared to the base case. Thus, the type "A" hierarchies fare poorly for the special event scenario while the type "B" and John Thai hierarchies enjoy improvements. John Thai's 100-point weighting approach seems to possess the best results because its initial decline is the smallest of all, and its value actually increases in the two scenarios that this table lists. Mr. Macaluso's type "A" hierarchy under both the ratio and 100-point weighting schemes shows the worst results. Most of the differences that are observed in each hierarchy's results arise simply from the different weights attributed to each objective.

Table 5.33. Percentage Change in Overall Value for Three Scenarios and all Hierarchies

Scenario(Weighting Style)	J.Thai	Macaluso-A	Macaluso-B	Group-A	Group-B
Base(ratio)	-7.8	-19.5	-15.1	-19.0	-14.5
Base(100-Point)	-3.1	-19.5	-12.6	-18.1	-11.0
Base(AHP-Regular)	-10.4	-18.7	-6.7	-	-
Base(AHP-pairwise)	-13.6	-17.7	-6.9	-	-
Alternate Data(ratio)	+9.7	+0.9	+2.3	+2.4	+3.6
Alternate Data(100-Point)	+11.8	+0.9	+4.2	+5.1	+7.2
Alternate Data(AHP-Regular)	+3.9	+3.8	+13.6	-	-
Alternate Data(AHP-pairwise)	-1.4	+5.3	+9.1	-	-
Special Event(ratio)	-4.0	-25.0	-17.2	-24.7	-16.5
Special Event (100-Point)	+2.5	-25.0	-11.6	-24.4	-9.6
Special Event(AHP-Regular)	-8.2	-24.7	-4.3	-	-
Special Event(AHP-pairwise)	-11.4	-23.9	-3.9	-	-

While the weights play a large role in determining the results, the value functions form the foundation for the entire evaluation. Based on the unusual results that are observed in this chapter, the mixing of value functions that are generated by different individuals may not be appropriate. In fact, a certain sum of money may have one value for a given individual but a different value for another. If this characteristic exists, then value functions must not be mixed within a hierarchy unless the value functions require different experts to assess them.. The latter case should be the exception rather than the rule; therefore, the hierarchical organization should consider these assessment issues.

The group dynamics observed when attempting to assess a value function reinforces the hypothesis of different values for different individuals. While group assessment of value functions seems to end in complete failure, it works very well for the preference weights. Furthermore, like-minded people may be able to determine a value function in a group setting, but those without a common bond will unlikely generate any usable value functions that they will support. Throughout the group-determined preferences, the group that is used in this research interacted well and quickly resolved all discrepancies. The group-assessed preferences did not take any more time than the individually assessed preferences because the group worked together on a regular basis and communicated easily. Therefore, the composition of a group for any portion of the decision-maker interview must be considered carefully.

The results from the administrator hierarchies and the procedure required to generate them provide valuable insight into the evaluation technique and the requirements for its effective use. The technique seems to be effective under group decision-making schemes; however, the administrators' lack of knowledge about the lower levels of the hierarchy has a tremendous impact on the final evaluation results. The organization of the hierarchy and desired data must be considered carefully because decision-makers may not be able to adequately assess preferences for these. If administrative decision-makers lack the knowledge to assess the lower levels of the hierarchy, they must decide on their course of action carefully.

CHAPTER 6
AN INSTITUTIONAL PERSPECTIVE ON THE ANAHEIM FOT

Achieving the FOT objective of adaptive arterial traffic control necessitates the identification, evaluation, and resolution of a wide variety of institutional barriers to successful project completion. While both federal and state policy are firmly supportive of the rapid deployment of new technologies in Advanced Transportation Management Systems, the actual implementation involves the integration of diverse technologies from a variety of competing vendors in local environments with little if any experience with such technologies. This suggests that a variety of learning curves must be traced, as the players deal with the technical issues, and necessarily, the institutional issues, of implementation. The focus of the assessment is to identify under what structure ATMS strategies can be deployed so that their effectiveness is neither reduced nor confounded by limitations posed by institutional issues. The scope of potential institutional issues is necessarily quite wide.

The arterial traffic control systems planned for implementation, 1.5GC and SCOOT, respectively represent a partial automation of existing UTCS (Urban Traffic Control System) control and the separate installation of an adaptive traffic control system as an independent control option. Since 1.5GC maintains the existing control system and algorithms, the key evaluation issue involves an assessment of the man-in-the-loop operational format more so than a direct assessment of technical feasibility. Similarly, SCOOT has been installed and evaluated in numerous locations throughout the world, thus, the key evaluation issues involve the limited implementation of SCOOT as an option of Anaheim Traffic Management Center operations, the development of operational policies for SCOOT operation, and the resultant operational effectiveness for defined scenarios (particularly for special events).

6.1 Project Background

The City of Anaheim has achieved an impressive track record in the application of advanced technologies to address their pressing transportation problems. Over the past decade, the City has planned and actively pursued participation and funding from county, state, and federal agencies to leverage local funds for the installation of increasing sophisticated elements of a comprehensive traffic management system. The fact that the technologies associated with the Anaheim FOT project were identified years before the FOT program began exemplifies the pro-active perspective that characterizes the City. JHK and Associates (1992) identified many institutional factors which have contributed and continue to contribute to this perspective including (a) incremental implementation, (b) agency participation, staffing, and commitment, (c) agency flexibility, (d) interagency cooperation, (e) accepting some risk to gain opportunities, and (f) leveraging local funds.

Over the last four decades, the City of Anaheim (and the rest of Orange County) has experienced tremendous growth, far exceeding the City's initial expectations (JHK, 1992). Since the opening of Disneyland, the impact of special activity generators has begun to dominate traffic planning for the City. Together with Edison Field at Anaheim, the Anaheim Convention Center, and the Arrowhead Pond at Anaheim, the City has a core of four major special generators at the heart of a dense employment/residential area in the midst of heavily utilized regional freeway corridors. In 1986, a strategic planning process "identified transportation management solutions for the reduction of traffic congestion throughout the area as the top priority" (JHK, 1992). The City adopted an underlying philosophy of applying advanced but proven techniques of surveillance, control, and integrated response to address local, event-based, and regional traffic demands in the City.

6.2 Anaheim FOT Technologies

Anaheim's integrated transportation management system was evolving toward adaptive control since the City's TMC was first established. With significant international success, but only limited domestic application, SCOOT was considered an ideal candidate for traffic control. The City was particularly interested in effective control for the varying traffic demands associated with the many special events occurring within the city. The City envisioned an intermediate step between their first generation (1.0GC) UTCS control system and plans for second generation control (2.0GC) with SCOOT. This link was 1.5GC, planned as, effectively, a man-in-the-loop control system which would automatically generate and evaluate alternative signal timing plans. VTDS also evolved from the variable traffic patterns observed in the city and the need to insure an uninterrupted flow of field data to the control system during construction and other activities that deactivate conventional in-pavement loop detectors. Video traffic detection systems existed but were sufficiently expensive to preclude their widespread application in the city. When a low-cost alternative was presented, it became the third technology in the FOT proposal.

6.2.1 *SCOOT Adaptive Control*

Adaptive control continuously assesses and adjusts signal timing because the traffic conditions fluctuate on a regular basis. SCOOT (Siemens, 1996) alters traffic signal timings according to current traffic demand by application of an on-line traffic model. The City planned to implement a SCOOT system in parallel with the existing UTCS using existing infrastructure at the intersections near the four major special event locations in Anaheim. Due to construction, the City eliminated intersections adjacent to Disneyland and the Convention Center from the project.

6.2.2 *1.5 Generation Control*

In a first generation system, the engineer could collect the data for the optimization software from the traffic control system; however, the system failed to provide a technique for directly importing the data into the model. A 1.5GC System bridges the gap between the field and the analysis. In addition to collecting real-time data from the traffic control system, 1.5GC analyzes the performance of the current control system. As part of the FOT, the City installed an updated version of 1.5GC based on an earlier unsuccessful version installed in the TMC (JHK, 1996). The City anticipated that the new version would be a useful traffic analysis tool and planned to use it to (a) evaluate current time-of-day plans, (b) evaluate special event traffic conditions, (c) monitor system trends and volumes, and (d) eventually replace TMC staff utilized for smaller events.

6.2.3 *Video Traffic Detection System (VTDS)*

Odetics' VTDS provides surveillance and control capabilities. At a cost significantly below VTDS alternatives, Odetics believed that their system could achieve widespread deployment. Theoretically, VTDS can provide area-wide surveillance and control for entire regions. Odetics designed their system as a single board product so that it can be plugged directly into the existing signal controllers. This design makes VTDS compatible with existing equipment and simplifies maintenance. The FOT tested the VTDS under varying weather and traffic conditions at a major City intersection. Although Odetics originally expected their VTDS to provide traffic counts in addition to presence detection, the final system implemented functioned in the presence mode only. Please refer to MacCarley (1998) for more information.

6.3 Interviews With Key Participants

Achieving the FOT objective of adaptive arterial traffic control necessitates the identification, evaluation, and resolution of a wide variety of institutional barriers to successful project completion. While both federal and state policy are firmly supportive of the rapid deployment of new technologies in Advanced Transportation Management Systems, the actual deployment involves the integration of diverse technologies from a variety of independent vendors in local environments with limited if any experience with such technologies. This suggests that a variety of learning curves must be traced, as the players deal with the technical issues, and necessarily, the institutional issues, of deployment. The focus of the assessment is to identify under what structure can advanced transportation management strategies be deployed so that effectiveness is neither reduced nor confounded by limitations posed by institutional issues. The associated evaluation plan for this FOT was consistent with Federal guidelines for the FOT program (USDOT, 1993). Further details on the material covered in all of the subsequent sections are found in another source (McNally *et. al*., 1998).

6.3.1 *Goals and Objectives*

These questions served to elicit opinions on the evolution of the Anaheim FOT in terms of overall project goals and objectives, defined both locally and relative to the national ITS program. Most respondents believed that the Anaheim FOT held an important role in the national FOT program because it considered adaptive control, specifically SCOOT, using existing infrastructure. Over half of the interviewees stated that SCOOT performance within an existing infrastructure was the primary FOT goal while several others mentioned SCOOT performance during normal and/or special event conditions. Other goals related to SCOOT included the institutional issues related to SCOOT implementation, familiarity with SCOOT for domestic practitioners, SCOOT transferability, and SCOOT algorithm performance. Overwhelmingly, the interviewees believed that the FOT was meeting these goals.

About a third of the respondents discussed the Video Traffic Detection System (VTDS), but few of them agreed on specific VTDS goals. Related issues raised included the potential plan for VTDS to work with adaptive control (this was not attempted), the ability of the VTDS to provide volume counts or simply presence detection (the final VTDS product evaluated performed presence detection only), and the potential role of VTDS to maintain detection in construction zones (the City currently uses it in this role). One third of the respondents also discussed the planned implementation of 1.5 Generation Control (a functional implementation was not achieved). Related issues raised included the use of 1.5GC and SCOOT to minimize staff time required for traffic operations. Operational goals were not fully achieved during the period of evaluation, but the City remains committed to long-term operations.

6.3.2 *Implementation and Operations*

These questions addressed the implementation process and operations, and considered project scheduling and deliverables, implementation costs, operation and maintenance policies, and technology issues. Project management, the contracting process, and SCOOT technical issues surfaced as cross-cutting issues that were identified throughout the project.

Overall, most agencies indicated that they maintained their schedules; where schedule delays were identified, respondents most often attributed these delays to contracting problems. Seventy-five percent of the respondents indicated that their firm or agency failed to anticipate all of the implementation costs. Some participants' costs exceeded expectations when the project experienced a major yearlong delay, a delay that increased personnel costs. Some unexpected equipment costs were encountered. Consultants spent more time than anticipated in the TMC assuming the City's role as liaison with the SCOOT provider, partially due to the departure of the City's Principal Traffic Engineer and Project Manager, a position which was not filled for eight months. It is possible that the presence of the Principal Traffic Engineer and continuity in the project management position could have precluded unanticipated costs that were delay or staffing induced.

6.3.3 *FOT Control Technologies*

Respondents identified technical problems for the control technologies implemented. Siemens stated that their inability to allow SCOOT to set offsets on anything other than the sync phases might have adverse effects on SCOOT's performance. Additionally, Siemens felt that the location of the loop detectors might be problematic and that the City's older inductive loops were not typical of those experienced in British applications (note that the existing detector system was defined in the RFP as the system that would be utilized in the FOT). Siemens was also forced to deactivate SCOOT's ability to up/download SCOOT parameters due to preclude compatibility problems. Also, the British to American translation forced SCOOT into using higher minimal cycle lengths than desirable. The 1.5GC control system also received significant attention from many respondents. The original 1.5GC implementation project began in 1992 prior to the City's FOT proposal. That version was not successfully implemented but the City hoped that the continued development of the system would both provide validated baseline signal timing plans and a means for data collection in evaluating SCOOT; it was thus continued as a component of the FOT. Respondents suggested that, although the new version was operational, it failed as a practical tool (due to data requirements, dependence on system detectors, and excessive computational time). By April 1998, the TMC ceased 1.5GC operations.

6.3.4 *Maintenance Policy*

Respondents were also queried as to what changes in maintenance policy were expected; seventy-five of them expected the City to change its existing policies. These respondents focused on the need for not only more training on multiple systems but also on developing a new maintenance policy that reflected the requirements of maintaining the increasingly complex system. The SCOOT system required certain changes, such as the need for additional personnel and a higher priority on maintaining SCOOT detectors and communications. While half of the respondents believed that the partners adequately planned for the operations, maintenance, and training needs of the new system, all of the City TMC staff believed that the project failed to plan adequately. City staff emphasized the underestimation of training needs, the overestimation of operators' ability to switch to a new system and the maintenance needed to meet SCOOT's requirements.

6.3.5 *Cross-Cutting Issues*

Three cross-cutting institutional issues surface upon review of participant interviews: project management, the contractual process, and technical limitations.

6.3.5.1 Project Management

All partners emphasized that a breakdown in project management in the interval between the SCOOT contract award and contract signing was a critical and potentially fatal stumbling block. The SCOOT component of the project would not have been completed without the third and final contract extension. This delay also resulted in a reduction in the implementation time allotted to the Siemens/Eagle team and the City for readying field equipment. In November 1996, the City's Principal Traffic Engineer and FOT Project Manager left the City of Anaheim and, while FOT management responsibilities were quickly reassigned internally, a replacement for the open engineering position was not named for eight months. The new Project Manager needed to champion the cause of the project to obtain the final contract extension. It is quite possible had the required extension not fit entirely within the Caltrans fiscal year then it may not have granted the extension and the project would have ended. It is unclear what financial implication this would have had on the partners but SCOOT would not have been implemented. The change in project management included a change in management style from a more passive, less responsive approach to a proactive approach; after the changeover, the project moved through its revised schedule in a timely manner.

6.3.5.2 Contractual Matters

During the course of the project, Caltrans executed three contract amendments; each time, Caltrans executed no-cost extensions for the project. The State contract amendment process had been recently changed, with the new process requiring amendments to pass through two additional levels of internal bureaucracy. The difficulties associated with this amendment process introduced considerable problems for the FOT. The City's Traffic and Transportation Manager attributed a significant portion of the delay to a breakdown in communication between the traffic engineering department and the City Attorney's office. The Manger had frequently encountered problems with the City Attorney's office, but these problems were readily solved when directly addressed. The changeover in project management coinciding with the threat of project termination due to contractual delays pushed the City to quickly resolve these issues.

6.3.5.3 Technical Concerns

Technical concerns were identified with SCOOT implementation, including operator acceptance, training, and SCOOT operational problems. After the original SCOOT training, few of the TMC staff members felt comfortable with SCOOT operations. The staff members wanted to see training include more hands-on practice and feedback as well as an increase in the depth of the training course. Other training problems included City staff schedules that precluded continuous attendance and differences in U.K. traffic control style and terminology. One staff member participated in a second training session after some experience with SCOOT had been gained and strongly believed that this second training session was much more useful, also recommending less time between follow-up sessions. The eight-hour time difference between Siemens' office and the City of Anaheim also limited communication between the two. The TMC staff remained divided over many issues surrounding SCOOT operations and performance. The SCOOT system installed also had incomplete graphics which made operation more difficult (note that this issue was a problem with the City's TMC and not with SCOOT).

6.4 Synthesis of Results

The institutional assessment was defined in terms of five primary phases (or goals). Each of the technologies implemented, 1.5GC, SCOOT, and VTDS, are considered in each phase. General research hypotheses were developed for each phase; however, the nature of this evaluation task was primarily qualitative, thus conventional quantitative techniques were not utilized. Although the institutional evaluation proceeded in parallel with the technical evaluation, the former is process-centered versus the effectiveness orientation of the technical evaluation. The results of the two primary evaluation approaches, the systematic "fly-on-the-wall" review of the FOT in terms of institutional catalysts and constraints and the comprehensive interviews of key project participants, are synthesized with historical and other empirical evidence to provide a general assessment of institutional catalysts and barriers associated with the Anaheim FOT. Summaries are presented for each of five evaluation goals, each incorporating information from all sources.

6.4.1 *Goal 1: Establish Baseline Institutional Status*

The first phase involves an historical assessment of the institutional environment in which both current traffic operation systems and planned enhancements have developed.

Objective 1.1 Prepare an Institutional Assessment of Prior Related Work in the Study Area

The City has an extensive track record in advanced technologies and methodologies for traffic control, including the FHWA Demonstration program establishing the integrated traffic management system. The City has capitalized on institutional strengths while monitoring potential institutional limitations. The City's track record, and that of the partners in general, strongly suggested that the Partners were eminently qualified to proceed, and that all initial parties were cognizant of potential institutional problems. The only open issue, from both institutional and technical perspectives, was the yet to be defined interaction with the SCOOT vender and the subsequent performance of that system in a sub-standard implementation (the few prior domestic SCOOT implementations involved full detectorization). The City and the system manager were experienced with the 1.5GC system, so few implementation problems were anticipated.

Objective 1.2 Identify and Assess the Constraints Present in FOT Proposal Development

The City's plans for adaptive control were established prior to the FOT RFP. Various funding mechanisms had been sought to implement each of the technologies; the FOT program provided an ideal program to greatly enhance local matching funds for system development. The project offered much beyond a basic performance testing of SCOOT. The proposal addressed the use of both SCOOT and 1.5GC in parallel to the existing UTCS system, providing an arena for assessing technical performance and institutional issues in deployment. Implementing SCOOT in an American city with a conventional distribution of system detectors and evaluating its resultant efficacy was a prime objective. Consultant suggestions to add limited detectorization were not implemented to adhere to this original goal. Sponsors considered neither 1.5GC nor the VTDS as important as SCOOT, but the City was able to successfully incorporate these technologies into the proposal. The City and major transportation agencies in Orange County signed a Memorandum of Understanding that provided the foundation that resolved many potential institutional problems. Here again the City's track record assisted. In summary, many potential constraints in developing the proposal were not present because of the City's prior experience and effectively resolved these issues prior to the start of the project.

Objective 1.3 Develop a Baseline Status of Current and Planned Technologies

The City's vintage timing plans could inflate the performance improvement of either of the control technologies. Given the experience of the City's system manager, integration of 1.5GC and SCOOT into the existing control system was expected to proceed without major problems. Problems, which were foreseen, included the limited prior success with 1.5GC, extensive use of part-time TMC operators who had limited experience, and Siemens' limited domestic experience.

Objective 1.4 Develop a Baseline Status of the Current Transportation Infrastructure

There was some concern with inter-departmental communications between traffic operations and public works. Construction plans were not raised in a timely manner; when raised, little information was available. Status of the control system timing plans was indeterminate; only informal field plan assessment was completed for unspecified intersections at unspecified times in the preceding years. FETSIM documentation was not available from the City. The existing system would require that improved communications be established and loops made operational for proper operations. The proposed network had several potential problems which could led to inconsistencies in SCOOT implementation. There were no known compatibility issues with existing system controllers.

6.4.2 *Goal 2: Assess Institutional Issues in System Implementation*

The FOT proposed the field implementation of capabilities that may be considered as compatible (1.5GC) and incompatible (SCOOT) with the existing control system, from the perspective of a readily integratable system. The process required considerable cooperation and coordination between all parties. Specific areas include interactions between (a) the City and the Partners, (b) the City and its system manager (JHK, now Transcore), and (c) currently deployed and proposed technologies and their operators. Of equal importance are interactions within the agencies that manage special events systems within the study area.

Objective 2.1 Assess Coordination Between the City and the System Provider

Once contractual matters were resolved, a high level of coordination existed between the City and system vendors (Siemens for SCOOT, Odetics for VTDS, and JHK for 1.5GC). Significant problems did exist prior to approval of the SCOOT contract (due to differences in US and UK attorney terminology, licensing disagreements, and whether there was sufficient time to complete the project) and some communication problems existed after implementation (due to the time difference between Anaheim and the UK and the lack of TMC international calling privileges).

Objective 2.2 Assess Coordination between the City and the System Manager

JHK, the City's system manager, clearly had played and continued to play a significant role in defining the proposal, selecting the SCOOT provider, and coordinating systems implementation. They provided much needed expertise while the staff vacancy existing during SCOOT implementation. They were not, however, experienced with SCOOT and therefore could not anticipate many of the subsequent problems. They were also unsuccessful in implementing the 1.5GC system, nor did it appear that the City was aware of the devolving nature of 1.5GC capabilities until late in the project.

Objective 2.3 Assess the Impacts of Inter-agency Cooperation on Systems Implementation

There appeared to be a high level of inter-agency cooperation between all FOT partners. The problems that arose were attributed to management, contractual, and technical issues. There was also a high level of cooperation with the Evaluation Team monitoring negotiations, contracting, planning and design, and implementation of proposed technologies.

Objective 2.4 Assess Impact of Implementing a New Technology into an Existing Control System

The primary implications involved operator acceptance and impacts on other functions. While there were some technical issues in system integration, these were resolved. TMC operators did not appear enthused relative to SCOOT, due to a variety of factors including resistance to change, limited training, lack of an operation policy, and current work loads.

Maintaining the enhanced system was also seen to be a significant future problem, not just with respect to the added TMC hardware and software, but due to greater dependence on field instrumentation. Testing a sub-standard SCOOT implementation sounded good on paper, but the degree to which it was substandard was not fully recognized until after system activation. It was also unclear what role 1.5GC would play. Initial plans to evaluate it as a SCOOT and UTCS alternative were dropped when its lack of functionality became apparent.

Objective 2.5 Assess Overall FOT Project Administration

On a local level, project management was a critical institutional impediment. The project manager for the City of Anaheim changed at the beginning of project development and again at the beginning of the SCOOT implementation process. Some responsibility for legal delays must rest upon the project manager. The third project manger was quite successful in resolving contractual matters, re-establishing accountability, and pushing action items to bring the project in on time. The FOT Evaluation Oversight Charter was an initial stumbling block from the perspective of the Evaluators who concluded that such a document presented limitations on an unbiased evaluation. On the Federal and State level, the laissez-faire approach of project monitors was a limitation. Oversight was particularly lacking when critical decisions had to be made (relative to 1.5GC status, SCOOT legal issues, network problems, project schedule).

Objective 2.6 Assess Staffing and Personnel Issues in the City

SCOOT training was limited and there was a noticeable lack of continuity in City attendance. There was some concern regarding staff qualifications for multiple operating systems. Local knowledge of the baseline system was weak, despite the presence of the TMC. Staff dependency on the system manager, especially with respect to 1.5GC, may have limited them in gaining relative experience. Such limitations, however, may also be indicative of insufficient staffing. Some institutional issues (legal, construction) appeared beyond the control of the traffic group, and it was uncertain what the Public Works Director's role was in dealing with City legal staff and City Council.

Objective 2.7 Technology Issues

Several technical issues were not anticipated. Neither the existing field communication system nor the City's CSC T-1 traffic controllers could provide full functionality for SCOOT. This is attributed to lack of domestic experience for the SCOOT provider. The VTDS system provided presence detection only, despite plans to provide full traffic counts. The VTDS was considered as still in development during the early part of the FOT. Similarly, the planned functionality of 1.5GC was never realized, despite years of on-going planning and development. Several operational problems in SCOOT resulted in part of the field test data being discarded since SCOOT had effectively shut down during data collection.

Objective 2.8 Legal & Liability Issues

Contractual issues in SCOOT licensing threatened deployment. Intervention of the City's new project manager and support of all project participants effectively accelerated resolution of these issues and a contract was in place in time to complete the implementation.

6.4.3 *Goal 3: Assess Institutional Issues in System Operations*

The development of operational policies for the arterial network was not formalized prior to system start-up. It was anticipated that the effectiveness of these policies with respect to common institutional issues (such as personnel, liability, risk management, maintenance, etc.) as well as to preliminary operational problems would result in a dynamically developing set of policies for each independent technology, as well as for the system as a whole. It is possible that institutional barriers associated with each independent component preempted a system optimal operational policy with respect to technical efficiency. New experiences from mixing new with existing technologies in a complex institutional environment were expected to precipitate new reactions and new institutional policies.

Objective 3.1 Assess the Evolution of Operational Policies Relative to Institutional Issues

Many issues addressed in system implementation contribute to potential issues in system operations. Unfortunately, there was no real shakedown period preceding evaluation and only limited experience with SCOOT since, therefore, it is not possible to draw formal conclusions. More critically, only a draft operation policy currently exists. This is particularly limited with respect to special event operations, one of the major reasons for testing SCOOT. SCOOT training is still considered inadequate, despite a second session several months after system startup. The lack of knowledge and training complicates system utilization. It is recommended that the City review task assignments and operational policies in the TMC. Finally, system displays do not provide TMC personnel with enough information while SCOOT is running.

Objective 3.2 Assess the Impacts of Inter-agency Cooperation on Systems Operations

There were limited operational problems impacting performance of local freeways. Lack of advance detectors on off-ramps leading to SCOOT controlled intersections initially caused spillback onto the freeway. Nevertheless, the high level of coordination between these agencies quickly identified and resolved the problem.

Objective 3.3 Assess the Impacts of Risk Management on System Operations

Risk management is a primary consideration in any municipal activity, and of particular importance in traffic operations due to obvious safety concerns. The combination of improved flow and safety through advanced traffic management with a large portion of the financial burden from other agencies makes projects such as this favorable despite potential risks. The lack of a formal policy and commitment to SCOOT precludes formal conclusions at this time.

6.4.4 *Goal 4: Assess Project Transferability*

Recommendations relative to project transferability necessarily require full consideration of all project components, which are judged primarily by the ultimate indicators of success defined by measures of performance. Given technical feasibility of the various technologies and acceptable performance, the potential for success now becomes primarily defined by institutional concerns. Ultimate success in transferring these technologies is, of course, equally dependent on the transportation and institutional environment into which the transfer will be attempted. Only a relevant assessment of potential barriers (or catalysts) to success is made.

Objective 4.1 Identify Institutional Barriers and Catalysts with Respect to Project Transferability

The track record of Anaheim in related areas and the associated experience of City staff, as well as the overall climate toward advanced technologies in the City, County, and State may limit transferability to areas where these conditions do not exist. Anaheim is not a conventional U.S. city, it has the presence of not only the above factors but the presence of the four major activity generators in the City. Institutional factors, which may well be difficult barriers in most cities, have been resolved in Anaheim well before the FOT was proposed. Barriers which were identified were judged as dynamic and difficult to project or address, such as turnover in key technical positions at critical stages of the project, and unprecedented legal issues.

Objective 4.2 Review Prior Institutional Assessments in Anaheim

In a sense, the FOT itself is a test of transferability of an existing control system (SCOOT) to an implementation site for which the technology was not initially designed. Although SCOOT has been installed in a rather limited number of domestic locations, the

Anaheim application is unique in its implementation in an area defined by traffic characteristics resulting from a high frequency of special events. Furthermore, in Anaheim SCOOT resides in parallel with an existing UTCS control system and utilizes only existing system detectors. As such, the evaluation of system performance may not be directly comparable to other sites.

6.4.5 *Goal 5: Assess of Project Maintainability*

An acceptable level of system performance defines a successful implementation only if such performance can be maintained. It is necessary to evaluate project maintainability; primarily, this involves maintenance of the physical system, continuity in administrative structure and policy, and suitable funding.

Objective 5.1 Identify and Assess TMC and Field Hardware and Software Maintainability issues

The City experienced difficulties preparing the infrastructure for the FOT. All major work required for the project was delayed until the City and Siemens approved their contract; therefore, the maintenance staff worked under the same reduced schedules that affected Siemens and Eagle. With the City's Principal Traffic Engineer position being vacant during SCOOT implementation, poor communications existed between field operations and TMC staff. This lack of communication exacerbated the maintenance staff's problems. The field operations staff found it impossible to meet some of Siemens' infrastructure expectations (given the vintage of field hardware such as 15-20 year-old cables). In response, Siemens reduced their communication expectations because the City's system seemed incapable of attaining them.

Objective 5.2 Assess Feasibility of Maintaining an FOT System in Routine Operations

Critical factors were identified, primarily through the interview process, which suggest that there are unresolved issues in maintaining the system. The first such issue is, of course, whether SCOOT should be maintained. Preliminary technical assessment indicates only marginal improvement in key performance measures. If maintained, direct observation and the interview process strongly suggest that additional and perhaps on-going SCOOT training is required. A key maintenance issue is the status of system detectors. The City's inductive loops apparently were not regularly maintained prior to the project; the cost of maintaining these loops which are critical for SCOOT while only advisory to UTCS would be significant. The required communication infrastructure is expected to also require a greater maintenance effort, and the source of these funds has not been identified. City traffic management must develop projected budgets and maintenance policies prior to fully addressing this objective.

6.5 Summary and Conclusions

The administration of this project proved to be much more time consuming than anticipated, despite fairly extensive prior City experience with complex, multi-agency projects. This was due in part to a lack of precedence in developing legal agreements, and the necessary review and approval delays of city attorneys and councils. Initially scheduled to be completed within 12 months, the evaluation study was not completed until four years after project approval; table 6.1 presents a timeline of some of the critical events during the project. From a federal perspective, it was hoped that the FOTs would promote the development of ITS technology and provide a bridge between research and deployment. FHWA assigned responsibility for deployment to the states. In the early phases of the FOT program, FHWA field staff was not fully prepared to handle evaluation issues and only limited central monitoring of individual FOTs was attempted.

Anaheim had committed to both SCOOT and 1.5GC well in advance of applying for to the FOT program. The FOT project represented an opportunity for the City to obtain federal funds in support of their traffic control network. Several interview respondents suggested that 1.5GC was included in the FOT to provide additional funds to resolve its operational status. VTDS was brought into the project, in part, as an example of a public-private partnership, rather than as a necessary part of the package.

Table 6.1. Anaheim FOT Event Timeline

Year	Month	Event
1992	October	Initial FOT proposal submitted to FHWA
	December	Proposal accepted for FY 1993 Operational Test Program funding
1993	May	Memorandum of Understanding signed by Orange County participants
	June	Updated Project Work Plan submitted to FHWA
	July	Selection of PATH Evaluation Team
1994	March	Preliminary approval of evaluation contract; Caltrans pre-award audit
	October	Evaluation Team contracts approved as sub-contracts to PATH
	December	Final evaluation proposal submitted to PATH
1995	June	PATH partner agreements completed
		Contract amendment between Caltrans and Anaheim for a twelve month extension executed by City and forwarded to Caltrans for

		execution
	November	JHK stated that 1.5GC to be used to define new baseline signal plans
		JHK completed review of existing 1.5GC package
		SCOOT Vendor RFP advertised/distributed
		FHWA and BAH hold review meeting for FOT projects in ATMS
	December	SCOOT Vendor proposals due; SCOOT Vendor interviews
		JHK begins work on 1.5GC Modifications - design and development
		Siemens selected as the SCOOT Vendor

Table 6.1. Anaheim FOT Event Timeline (cont'd)

Year	Month	Event
1996	January	Evaluation Team's contract receives a one-year no cost extension
		Odetics submitted *Site Analysis Report* Draft
	February	Siemens performs a SCOOT demonstration
		Eagle, a US Siemens' subsidiary, to handle SCOOT/controller interface
		Caltrans contract with PATH extended
		Siemens to start in early March (20% of their budget may extend beyond June.) Caltrans considers whether to grant an extension.
	March	Odetics to begin VTDS installation
		Siemens contract is still in negotiations
	April	JHK completed installation of 1.5GC
		14 percent of SCOOT detectors currently operational in the City
	May	Anaheim begins in-house testing of 1.5GC; 1.5GC Training
		Caltrans sent amendment to Anaheim for a six month extension
		SCOOT contract goes to the City Attorney for final review
	July	1.5GC in-house testing completed
		JHK provided Anaheim with a revised version of the 1.5GC software

	September	Siemens contract unresolved; SCOOT FOT status is questionable
		VTDS is found to operate in presence mode only, cannot provide counts
		1.5GC requires 4-5 hours to process a 31 intersection network
	October	Siemens contract remains unresolved due to differences in US/UK legal terminology, licensing issues, and time remaining to complete contract
	November	Principal Traffic Engineer and FOT Project Manager leaves the City of Anaheim
	December	VTDS field data collection at Odetics facility and Official end of Odetics contract
		City Traffic and Transportation Manager becomes FOT Project Manager

Table 6.1. Anaheim FOT Event Timeline (cont'd)

Year	Month	Event
1997	January	The field evaluation tentatively set for October in the Arena and Stadium area; Disneyland & Convention Center dropped due to extensive reconstruction
		Siemens agreement signed on January 14. SCOOT work will be completed by June 27, 1997
		98% of the system loops are operational
		Eagle, Siemen's US subsidiary, assigned the SCOOT contract
	February	Siemens' SCOOT software operational; UK/US command translation remains
	March	JHK needs CSC firmware to continue the integration with UTCS
	April	New Katella and Douglas left-hand turn loops installed; all system loops are operational within the SCOOT area
	May	SCOOT firmware and equipment functional at three intersections; all SCOOT equipment has been installed
	June	Siemens works with City to resolve communication and detector problems
		Presentation of final VTDS evaluation results to partners/EOT
		SCOOT is running on all 18 intersections in the SCOOT network
	July	SCOOT Training
		JHK holds Softgraph training

	August	City of Anaheim in-house testing of SCOOT
	October	SCOOT evaluation field tests – Before Case
	November	SCOOT evaluation field tests – After Case
1998	January	FHWA/BAH complete review of *Task C Evaluation Report*
	February	Final *Task C Evaluation Report* submitted
	March	Official end of Evaluation Team contracts
	April	Preliminary presentation on *Task B Institutional Evaluation Report*
	May	Preliminary presentation on *Task A Technical Evaluation Report*
	June-July	Draft *Task A and Task B Final Reports* submitted for review
	December	*Evaluation Final Reports* submitted for review

There were institutional ramifications of implementing a new technology into an existing control system, although most of these issues were technically-based. Coordination between City and Siemens was significantly impacted by the vacancy in the Principal Traffic Engineer position. Despite assumption of responsibilities by other staff and partners, there was a decided lack of City experience and authority during the SCOOT implementation. Siemens dismissed the significance of implementing SCOOT without detectors in standard SCOOT locations but only because other factors represented a greater concern. SCOOT's inability to control the offsets except with the sync phase and field data communications (which were less reliable than Siemens had anticipated) represented the major areas of concern. A draft operating policy, which included full SCOOT usage except during special events, was implemented only at the end of the evaluation period, thus, no evaluation of operations under that policy was possible. Some difficulty was expected to be encountered in converting TMC operators to SCOOT primarily because these operators were comfortable with the existing system and policy. This provides further evidence that operator acceptance might represent a critical stumbling block and management commitment becomes critical.

Siemens guaranteed a successful SCOOT implementation within budget, even in the unique environment in Anaheim. To what degree advanced technologies which are not primarily off-the-shelf products can be similarly guaranteed in not certain. In the case of systems such as the FOT's VTDS and 1.5GC, products that are not widely deployed are essentially still in the research and development process and can encounter significant delays, cost overruns, changes in product specifications, and unsuccessful implementation. Potentially significant costs may compromise project maintainability; these costs include TMC and field hardware and software maintainability. The City will have to devote more time to training to continue to operate SCOOT effectively.

The technical assessment of SCOOT performance suggested that improvement occurred where it was most expected, but the degree of improvement was significantly less than expected. The City is committed to the continual use of SCOOT, although an operational policy is still evolving. Similar technical results could be drawn from the VTDS evaluation: the performance of the system tested was both limited and less than expected, although system cost was as proposed. The system provider has apparently replaced the product with an improved version, which has been adopted by the City for deployment in construction zones. The 1.5GC system did not successfully meet its goals of either off-line plan generation in approximate real time or the generation of baseline plans for SCOOT comparisons. Nevertheless, the concept appears sound and participants were still supportive of the technology.

Two broad conclusions can be drawn. First, the technologies implemented enjoyed limited success. Second, given these results, institutional and technical factors were identified which were critical in defining this performance. In this sense, the project was successful, although without more extensive observations under normal operating conditions, it would be premature to advise extended implementation in the City or elsewhere. Therefore, caution is expressed relative to potential success in transferring the technologies. It is also difficult to fully assess system maintainability issues, due to the field test orientation of the project and the limited observation of system operations. It is expected, however, that fairly significant increases in traffic management costs would be realized if SCOOT operations are expanded. This paper has summarized critical technical and institutional factors in system definition, implementation, and operations. The technical problems were judged as somewhat expected for a project of this scale. Institutional issues associated with project management and contractual matters were judged as unexpected and critical influences on the project. While they were ultimately resolved, their presence nearly terminated the project prior to final implementation.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions and Contributions

This research provides an innovative approach to evaluating implemented projects, with explicit inclusion of qualitative and quantitative attributes by incorporating decision theory concepts. The technique itself is a much more flexible approach than the commonly used cost-benefit analysis, though this work also ultimately develops a dollar value for the project. Furthermore, the new evaluation framework provides an approach for addressing a project with large institutional concerns as well as multiple stakeholders and conditions. This section discusses the conclusions derived from this research as well as its contributions to evaluation research. There were many discoveries and observations made during the development and application of the methods presented in the earlier chapters and the salient ones are summarized in this chapter.

From the theoretical perspective, the dissertation's first contribution is in recognizing and reiterating the fact, perhaps not unknown to some researchers, that evaluation of an implemented project can be done using decision theory approaches. It recognizes that the valuation process applied across alternatives in a decision problem is essentially the same process that needs to be applied when only one implemented alternative is evaluated. While doing this, this research bridges the gap between separate schemes in decision theory, namely Analytical Hierarchy Process (AHP) for weighting across alternatives and Multi-Attribute Value Functions (MAVF), two techniques which are used primarily in different kinds of problems, and are preferred by different groups of researchers. The newly developed framework recognizes that if all the attributes of the project are taken together, under various operating conditions and for various factors, then additive value functions would be theoretically fragile and practically impossible to develop. It thus groups these attributes at the bottom tier of the hierarchy with the groups being further grouped into factors in a hierarchical and logical manner.

The MAVF techniques are used for deriving the values at the bottom of this hierarchy and AHP and a few other weighting schemes are found applicable for finding the weights on the hierarchy branches. The weights thus theoretically become multipliers used to combine a set of additive value functions into a single value function through summation. It was not within the scope of this dissertation to determine many of the more detailed theoretical underpinnings of the decision theory scheme; however, it presents many theoretical possibilities for future research. The conclusions from the application are presented in the next section and contributions of the work are summarized in the following section.

7.1.1 *Conclusions from the Application*

The application of the evaluation technique to the Anaheim FOT evaluation revealed many interesting results, of the kind that a conventional cost-benefit analysis would not reveal. The primary interest of the funding agency was in finding whether a non-ideal SCOOT implementation would be worthwhile in a US network. The evaluation techniques were capable of providing some answers on this question. While the system initially seemed to decrease in value compared to the base case, the elimination of all data affected by the I-5 accident caused the system to enjoy an increase in value. The fact that SCOOT did not cause totally unacceptable performance, despite having non-ideal traffic detector placement (i.e., existing system's detectors where used as opposed to detectors at entries to links that SCOOT requires) was a qualitative initial conclusion that was proved correct after the application of the evaluation framework. A further important note was the less than optimal operating conditions for the network in the "after" case for two reasons. First, the SCOOT network had some intersections, included as requirements in the project though they would normally not be part of a single SCOOT network. Second, poor communications caused a portion of the SCOOT system to revert its operations to isolated SCOOT intersections. On answering these primary questions about the feasibility of SCOOT in US city networks with existing traffic control infrastructure, the application of the new framework can be considered successful.

As for the flexibility of the technique, several insights were found during the application. The management goals seemed to be capable of adequately assessing the importance and values of the network performance attributes. The different weighting schemes helped demonstrate that the overall results were greatly affected by changing the weights at different hierarchy levels. In some cases, certain objectives or portions of the system switched from a net gain to a loss based on the emphasis identified within a given approach. Most of the hierarchies indicated that the system operated better under special event conditions than no-event conditions; however, they disagreed as to the best time period within the special event operations, some hierarchies indicating good performance during ingress, some during egress. This evaluation should provide the City of Anaheim with a large amount of information to better understand their system.

Money served well as the universal scaling proxy (USP), but unfortunately each individual did not value a given quantity of money in the same manner. This caused difficulties when combining the value functions from two or more different decision-makers within a single hierarchy. This single factor had a tremendous effect on all of the administrator hierarchies. The USP seemed to fulfill its role in uniting the disparate value functions quite effectively; in fact, sometimes the decision-makers seemed to prefer direct monetary comparisons to those involving two attributes. Money served well as the USP because it was an easy reference point for the decision-makers.

This evaluation did an effective job capturing the institutional component of the system. For John Thai's hierarchy, the primary institutional components, administrative issues and system costs, matched the concerns uncovered as part of the institutional evaluation. Most of the institutional issues that seemed unimportant in the institutional evaluation had no impact on the overall system value. The evaluation technique translated all of the issues into quantitative values without too many difficulties, thus achieving one of the primary goals of this research, namely incorporating all factors into an overall quantitative worth. The institutional component of the evaluation seemed quite effective and comprehensive.

Some major concerns developed during this research. Although the evaluation identified the performance of the system at a point in time, the lifetime of the system must be considered when determining a value. Unfortunately, a large amount of data might be forecasted with no way of determining its accuracy. This would be a concern in any evaluation scheme, as the future is difficult to predict. The variation within the overall results seemed to be much higher than expected; therefore, the reliability of the decision-maker responses became critical. If the responses are unreliable, a successful system could appear to be evaluated as an unsuccessful system or vice a versa. The importance of this problem seemed obvious; however, solving this issue increased the time requirements for the decision-maker as well the analyst. Sections 7.2 and 7.3 discuss possible solutions to this problem. Finally, the ability of a single attribute to overwhelm all others seems troubling. The overall worth of a system should not be solely dependent on two or three attributes because the entire system should work in concert together to establish its value. While this seemed troubling, the research could not identify a proper course of action for solving this problem other than adjusting the preference weights or assuring that the appropriate ranges were covered in value function assessment. The adjustments to the preference weights might reduce the importance of a dominant attribute while increasing the importance of others while the possible range for an attribute should be thoroughly discussed during value function assessment. These concerns require further investigation.

Identifying appropriate decision-makers and developing user (network driver) value functions represents another difficulty. The problems associated with determining the value functions from a limited sample of people, which arise from their disparate opinions and struggles to comprehend the enumeration process, made this branch's inclusion in the hierarchy rather dubious. It is, however, felt that these should still be included in any hierarchy for a public-service system, the suggestion being that there should be more elaborate work to develop value functions for the users.

A few concerns exist regarding the decision-theory techniques that the evaluation scheme utilized. Goicoechea, Hansen, and Duckstein (1982) outlined a number of significant theoretical and practical difficulties associated with MAUF. These included the tedium of calculating the component utility functions and scaling constants, the lack of immediate feedback to the decision-maker of the implications of his preferences, and the absence of an efficient procedure to update the decision-maker's preferences and conduct sensitivity analysis. While a number of these problems remained, this technique was specifically developed to address many of them. The component value functions still must be calculated for each attribute; however, the calculation of the scaling constants had been simplified and reduced through the use of the various weighting schemes and universal scaling proxy. Furthermore, the universal scaling proxy allowed the analyst to provide some immediate feedback to the decision-makers, but not any feedback on the system's overall value. Finally, one needed to investigate the process of updating the preference structure in MAVF applications; however, this difficulty was diminished through the incorporation of the AHP and other weighting schemes as well as a hierarchical approach, which enabled fairly efficient updating and sensitivity analyses. These should be considered significant improvements to overcome certain well-known difficulties in applying MAVF, which were mostly procedural difficulties rather than theoretical deficiencies.

A significant criticism that exists whenever AHP is used, is the possibility of rank reversal while ranking alternatives. That is, if the analyst introduces new options or elements to the hierarchy, the preference order might not be preserved. This is especially so, if important elements of the hierarchy are omitted initially. This problem could potentially exist in applications of the new scheme, as well, if the factors considered are not sufficiently dissimilar. The only real solution to the problem is to be very careful in developing the hierarchy, so that all relevant elements of the evaluation hierarchy are included. This matches previously discussed requirements that focussed on maintaining hierarchical consistency. Identifying relevant issues in transportation evaluation is an area where transportation analysts have significant experience already; however, techniques for combining the qualitative and quantitative elements into a cohesive analysis scheme is not a current area of expertise for analysts now. Thus it is expected that the techniques presented in this research would be used in applications where the analyst has sufficient experience in identifying the elements of comprehensive hierarchies which avoids the rank-reversal problem.

7.1.2 *Contributions*

Several contributions are already discussed in the conclusion section above, but further comments are included in this section. This research makes many contributions that improve the state of the art in transportation evaluation. The research creates a new evaluation approach that incorporated decision-theory techniques, and effectively captured the institutional issues associated with the implementing, maintaining, and operating a system. This may perhaps be the first time that an evaluation technique integrated all of the various components into a single overall worth. Furthermore, the overall worth exists on a ratio scale that allows for an examination of the percentage change between alternative cases. Once again, this marks a departure from decision-theory that only required its values to be interval-scaled. The evaluation should help guide decision-makers so that they have a better idea of a technology's capability when they form operating policies. The hierarchical approach adopted by the author provides great flexibility and frames of reference for valuable comparisons. These comparisons allow the decision-makers to identify problem areas within the system. Furthermore, other agencies can examine transferability issues by examining the evaluation results and drawing inferences to the affects on the different components within the hierarchy for their system. Finally, the examination of hypothetical systems and levels of performance provides other agencies with a powerful planning tool when they try to determine which technologies to implement.

Institutional issues can have a tremendous impact on the outcome of a project; for example, a new technology that improves network performance by ten percent would be of little value if it is impossible to maintain and fails on a regular basis. This evaluation technique captures these effects very well by identifying some quantifiable measures for all of the institutional attributes. Most previous research ignores the institutional issues while focussing exclusively on performance and costs. This research arrives at the appropriate levels for these institutional attributes through an extensive institutional evaluation. This technique's ability to capture and quantify institutional issues broadens the evaluation's meaning.

Combining the distinct value functions together poses a problem because each value function only has meaning for the attributes that it represented. Thus, they can not be combined together without first establishing a common frame of reference. The universal scaling proxy that this research uses represents a unique solution to this problem. The concept of a universal scaling proxy requires that at least one attribute in each attribute-set to be linearly scaleable and preferentially comparable with the proxy. This new technique does not pose a constraint on the application, but rather directs the analyst towards more careful grouping of factors and attributes. The flexibility in the scheme extends to introducing levels in the hierarchy that comprise operational conditions.

The most important aspect of the technique presented is its flexibility to incorporate various dissimilar factors, objectives, and attributes into a simple, elegant and comprehensive scheme. The technique may not provide the most correct possible overall worth of any evaluation; however, this should be taken in the context of there being no such single value that can be considered the most correct due to the subjective nature of several of the attributes, and objectives involved. Furthermore, the actual determination of an overall system worth that incorporates all of the factors influencing the system did not exist in prior evaluations. However, the two techniques (AHP and MAVF) being combined here, to the author's knowledge for the first time, have both undergone several years of methodological scrutiny. There have been criticisms on these two techniques in decision-theory research, but they have both been accepted to a large extent by academicians and perhaps to a larger extent by practitioners.

7.2 Recommendations

This research develops some insights that serve to guide and improve future applications of this new evaluation approach. In general, the recommendations apply to one of two broad classes either improving its application procedures or strengthening its theoretical grounding. Both of these classes remain important and serve to improve the evaluation techniques because the decision-makers find the interview portion of the evaluation quite cumbersome and want to see it improved. After combining these initial recommendations with future research, the evaluation should continue to improve.

The hierarchical structure for the evaluation remains critical because unnecessary attributes weaken the impacts of the other attributes within their leaf. Additionally, the amount of work required of the decision-makers may be reduced if only critical or dominant attributes are included in the hierarchy. When a decision-maker lacks knowledge or information about a specific portion of the hierarchy, he or she may want to eliminate it to reduce the assessment and data collection requirements. While the problem seems to simplify by reducing the number of attributes, the technique's flexibility decreases because the eliminated attributes may play a major role for another agency or at a later time. The decision-maker should carefully consider which hierarchical approach best fits his or her needs.

While this research only briefly explores group decision-making, it still makes some critical discoveries. These discoveries must be improved, and further research must take place. The group forum for value assessment seems to not be very useful, even with just a handful of decision-makers, unless the participants share very common value-structure because the questioning approach fails to direct the decision-makers towards agreement. Agreement seems possible when the decision-makers' initial judgements remain close to one another, but the research observes that disparate opinions make consensus extremely difficult. On the other hand, the preference weights are much easier to assess in a group forum setting. The participants in this research's group forum quickly and easily arrive at a consensus on the appropriate hierarchical weights. In fact, they did not require any moderation or coaxing to settle on these weights. The participants in the forum had worked with each other frequently in the past, which strengthened their bond and decision-making ease. The group forum for preference weights seems completely appropriate while value function assessment seems more difficult.

As part of this research, some of the hierarchies use value functions from different decision-makers which causes some unusual results. The value structure for each of the decision-makers that enumerate the value functions differs dramatically; therefore, when combined, the value functions from one of the decision-makers dominate those created by the other. This did not seem to be appropriate and care must be taken in the future to not repeat this problem. All of the value functions within a given hierarchy need to be generated by a single decision-maker. The only exception to this case can occur when an attribute requires an expert to assess its value function. The mixing of value functions from different decision-maker seems to generate inappropriate results.

The importance of the preference weights effects on the outcome of the evaluation materializes during this research. Therefore, the decision-maker responses need to be reliable and repeatable. If the responses fail these criteria, the evaluation results can fluctuate wildly. Until the determination of the appropriate weighting style, the analyst must insure that a decision-maker can post reliable responses at a later date. If discrepancies exist, the decision-maker should resolve them with the analyst's assistance. Insuring the reliability of the decision-maker's responses remains critical for a successful evaluation outcome.

The decision-makers seem to prefer the two rating techniques with the 100-point approach being the favorite for an individual interview. The AHP approaches received very unfavorable responses from the decision-makers; therefore, future research needs to focus on the adoption of the rating techniques. One of the decision-makers does prefer AHP in the group setting, but overall still has no desire to use it again. The value function techniques require some simplification to make them more user-friendly, but the decision-makers appear satisfied with the actual results. One of the decision-makers believes that a clearly understandable example may increase understanding of the process and improve responses. Careful examination of all decision-maker recommendations and opinions can help improve the process for future applications.

Experience in dealing with all of the components of the evaluation makes it easier to apply in the future because each component, such as those in the FOT application, poses some peculiar problems. More experience with such applications can guide future applications of the technique. The recommendations set forth in this section should improve future applications of this research's new evaluation technique. Future applications of it should continue to improve the technique because further insights can be gleaned. In some cases, these recommendations identify points of concern that require closer investigation.

7.3 Future Work

This research proves that its techniques can suitably generate values for an evaluation. Its flexibility makes it applicable to many different evaluation topics and technologies. However, numerous concerns and possible improvements arose throughout the research. This section discusses the possible extensions and improvements to this evaluation technique.

During the decision-maker interview with John Thai, he frequently wanted to enumerate a minimum acceptable level for many of the attributes. This represents a key discovery that requires further investigation. While this investigation is beyond the scope of this dissertation, future research should look at many factors that relate to a minimum acceptable level. One factor is the technique for identifying the decision-makers' minimum acceptable level. Although these levels may be difficult to obtain and require considerable thought on the part of the decision-makers, the researcher can determine the percentage change from their minimal acceptable system and the evaluation results. In many cases, the minimal acceptable system may only differ slightly from the baseline system, but these values would provide decision-makers with another frame of reference. Research needs to look at different approaches for finding this quantity.

In conjunction with a minimum acceptable level or some goal level, a decision-maker's value function may consist of a piecewise function over all of the appropriate regions. For example, a decision-maker may attach a lot of value to obtaining a certain level, but no value for exceeding this goal. This topic requires extensive investigation because a technique for noticing this phenomenon must be determined. After identifying its existence, the number of ranges subject to different value functions has to be identified. Finally, an easily applied interview technique must integrate the determination of the break points as well as each unique value function. This topic must be investigated to determine its existence and available solution techniques.

As previously discussed, the various weighting schemes return very different results. Therefore, the consistency of a given scheme remains critical where a given decision-maker would provide nearly identical weights when questioned again after a short period of time. The consistency of the various schemes that this research uses is not investigated. Therefore, the existing schemes may or may not be consistent; if they fail to be consistent, an altogether new weighting scheme may require development. Furthermore, more detailed research may expand on the decision-maker preference research introduced in this dissertation. Finally, future research needs to look at the stability of preference structures and value functions over time. Do they change? If they change, in what ways and how fast? The stability of value functions can prove to make the evaluation technique very user friendly. The weighting schemes and value functions require future research to improve their performance.

A standardized approach for modifying a hierarchy needs development. In this research, numerous branches, leafs, and attributes make such a small impact on the final results that perhaps they should not have been included in the first place. An approach must be developed that identified a procedure for deciding on keeping or eliminating these seemingly insignificant components from the hierarchy. Furthermore, if a screening procedure can be developed to eliminate a component before collecting decision-maker data on it, then the entire process can be streamlined. The organizational effects of creating and modifying the hierarchy require future investigation.

Group decision making requires further investigation because the limited set of decision-makers in a group studied in this research can not readily identify the appropriate techniques for incorporating group decision-making issues into the evaluation. At this time, a group forum or benevolent dictator approach seems to be the only course of action for enumerating value functions because combining dissimilar value functions into a single function did not seem to be appropriate. Future research should look specifically at the group decision-making concerns associated with this evaluation technique.

The evaluation technique that this dissertation describes represents a step forward in the evaluation of large-scale civil engineering projects. While this section describes some potential areas for future research, the initial development proceeded smoothly and appeared to have a strong foundation. However, the research in this area should seek to continually improve these initial gains.

REFERENCES

Allen, W. G., Jr. and F. Di Cesare (1976), "Transit Service Evaluation: Preliminary Identification of Variables Characterizing Level of Service," *Transportation Research Record*, no. 606, 41-47.

Arrow, K. J. (1951), "Social Choice and Individual Values," *Cowles Commission Monograph 12*, Wiley, New York.

Beinat, E. (1997), *Value Functions for Environmental Management*, Kluwer Academic Publishers, Norwell, MA.

Beinat, E. (1992), *An Interactive Procedure to Assess Value Functions for Environmental Quality*, Research Report, R-92/16 Institute for Environmental Studies, Free University, Amsterdam.

Bishop, A. B., W. A. O'Neill and K. Ullah (1994), "Cost-Benefit Analysis of a Rural Advanced Traveler Information System," *Transportation Research Record*, no. 1450, 25-33.

Bodily, S. E. (1979), "A Delegation Process for Combining Individual Utility Functions," *Management Science*, 25 (10).

Bolczak, R. (1993), "Generic IVHS Operational Test Evaluation Guidelines," unpublished working paper MITRE, Washington, D.C.

Booz, Allen & Hamilton (1998), *Atlanta Navigator Case Study*. Final report prepared under project FHWA-RD-98-099 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

Brand, D. (1994), "Criteria and Methods for Evaluating Intelligent Transportation System Plans and Operational Tests," *Transportation Research Record*, 1453, 1-15.

Brock, H. W. (1980), "The Problem of Utility Weights in Group Preference Aggregation," *Operations Research*, 28 (1), 176-187.

Charnes, A. and W. W.Cooper (1961), *Management Models and Industrial Applications of Linear Programming*, Vol. 1, Wiley, New York.

Churchman, C. W. and R. L. Ackoff (1954), "An Approximate Measure of Value," *Journal of Operations Research*, 2, 172-187.

Cirillo, J. A. and F. M. Council (1986), “Highway Safety: Twenty Years Later,” Transportation Research Record, no. 1068, 90-95.

Cook, W. D. and L. M. Seiford (1978), "Priority Ranking and Consensus Formation," *Management Science,* 24 (16), 1721-1732.

Cook, W. D. and M. Kress (1985), "Ordinal Ranking with Intensity of Preference," *Management Science*, 31 (1), 26-32.

Debreu, G. (1960), "Topological Methods in Cardinal Utility Theory," In *Mathematical Methods in the Social Sciences*, K. J. Arrow, S. Karlin and P. Suppes, eds., Stanford University Press, Stanford.

De Neufville R. and R. L. Keeney (1973), “Multiattribute Preference Analysis for Transportation Systems Evaluation,” *Transportation Research*, 7 (1), 63-76.

Dyer, J. S. and R. K. Sarin (1979), "Measurable Multiattribute Value Functions," *Operations Research*, 27 (4), 810-822.

Edwards W., D. von Winterfeldt, and D. L. Moody (1988), "Simplicity in Decision Analysis: an Example and a Discussion," in Bell, D. E., H. Raiffa and A. Tversky (Eds.) *Decision Making: Descriptive, Normative, and Prescriptive Interactions*, Cambridge University Press, Cambridge, 443-464.

Evans, A. W. (1994), “Evaluating Public Transport and Road Safety Measures,” *Accident Analysis and Prevention*, 26 (4), pp. 411-428.

French, S. (1986), *Decision Theory: An Introduction to the Mathematics of Rationality*, John Wiley and Sons, New York.

Gillen, D., J. Li, J. Dahlgren, and E. Chang (1999), *Assessing the Benefits and Costs of ITS Projects: Volume 1 Methodology*, California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR-99-9.

Goicoechea A., D. R. Hansen and L. Duckstein (1982), *Multiobjective Decision Analysis with Engineering and Business Applications*, John Wiley and Sons, New York.

Gorman, W. M. (1968a), "The Structure of Utility Theory," *Review of Economic Studies*, 35, 367-390.

Gorman, W. M. (1968b), "Conditions for Additive Separability," *Econometrica*, 36, 605-609.

Haimes, Y. Y., W. A. Hall and H. T. Freedman (1975), *Multiobjective Optimization in Water Resources Systems: The Surrogate Worth Trade-off Method*, Elsevier, The Netherlands.

Hall, R., M. Miller and A. Khattak (1996), "Evaluating the Effectiveness of Integrated Traffic Corridors: Concept and Practice," *ITS Journal,* 3 (1), 49-67.

Harsanyi, J. C. (1955), "Cardinal Welfare, Individual Ethics, An Interpersonal Comparison of Utility," *J. Political Economy*, 63, 309-321.

Harsanyi, J. C. (1975), "Nonlinear Social Welfare Functions," *Theory and Decision*, 6, 311-332.

IBI (1995), *Capital Investment Socio-Economic Analysis*. Report for the Ministry of Transportation Ontario, Canada.

ITS America Safety and Human Factors Committee and the National Highway Traffic Safety Administration (1996*), Safety Evaluation of Intelligent Transportation Systems,* A Workshop on the Safety Evaluation of Intelligent Transportation Systems.

James, S., T. Rother, W. R. Stockton, S. Turner, S and C. M. Walton (1998), *ITS Benefits: Review of Evaluation Methods and Reported Benefits.* Report for the Federal Highway Administration and Texas Department of Transportation.

JHK & Associates (1992), *City of Anaheim Integrated Traffic Management Systems Demonstration Project - Implementation Report*. Report DOT-T-93-13. U.S. Department of Transportation, Washington, DC.

Keeney, R. L. (1976), "A Group Preference Axiomization with Cardinal Utility," *Management Science,* 23 (2), 140-145.

Keeney, R. L. and C. W. Kirkwood (1975), "Group Decision Making using Cardinal Social Welfare Functions," *Management Science,* 22 (4), 430-437.

Keeney, R.L. and H. Raiffa (1976), *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, John Wiley and Sons, New York.

Keeney, R. L. and A. Sicherman (1976), "An Interactive Computer Program for Assessing and Analyzing Preferences Concerning Multiple Objectives," *Behavioral Science*, 21, 173-182.

Kirkwood, C.W. (1972), "Decision Analysis Incorporating Preferences of Groups," *Technical Report 74*, Operations Research Center, MIT, Cambridge, Mass.

Krantz, D.H., R. D. Luce, P. Suppes, and A. Tversky (1971), *Foundations of Measurement*, Volume 1, Academic Press, New York.

Krzysztofowicz, R. (1979), "Group Utility Assessment Through a Nominal Interacting Process," unpublished working paper Dept. of Civil Engineering, MIT, Cambridge, Mass.

Leontif, W. (1947a), "Introduction to a Theory of the Internal Structure of Functional Relationships," *Econometrica*, 15, 361-373.

Leontif, W. (1947b), "A note on the Interrelation of Subsets of Independent Variables of Continuous Function with Continuous First Derivatives," *Bulletin of the American Mathematical Society*, 53, 343-350.

Levine, J. and S. E. Underwood (1996), "A Multiattribute Analysis of Goals for Intelligent Transportation System Planning," *Transportation Research-C*, 4 (2), 97-111.

Lu, J. J., M. J. Rechtorik and S. Yang (1997), “Automatic Vehicle Identification Technology Applications to Toll Collection Services,” *Transportation Research Record*, no. 1588, 18-25.

Luce, R.D. and J. W. Tukey (1964), "Simultaneous Conjoint Measurement: a New Type of Fundamental Measurement," *Journal of Mathematical Psychology*, 1, 1-27.

MacCarley, C. A. (1998), *Anaheim Advanced Traffic Control System Field Operational Test - Evaluation Task C: Video Traffic Detection System*. Final report prepared under project RTA-65V313 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR- 98-32).

McNally, M. G. *et al*. (1999), *Anaheim Advanced Traffic Control System Field Operational Test -Evaluation Task B: Institutional Issues*. Final report prepared under project RTA-65V313 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR-99-27).

Miller, G.A. (1956), "The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information." *Psychological Review*, 13, 81-97.

Mollaghasemi, M. and J. Pet-Edwards (1997), *Making Multiple-Objective Decisions*, IEEE Computer Society Press, Los Alamitos.

Moore, James E.,et al. (1999), *Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Introduction and Task A: Evaluation of SCOOT Performance*. Final report prepared under project RTA-65V313 for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (California PATH, University of California, Berkeley, Research Report UCB-ITS-PRR-99-26).

Nijkamp, P., P. Rietveld and H. Voogd (1990) *Multicriteria Evaluation in Physical Planning*, Elsevier, Amsterdam, Netherlands.

Papageorgiou, M.(ed.) (1991), *Concise Encyclopedia of Traffic and Transportation Systems*, Pergamon Press, Oxford.

Pardee, F. S. (1969), “Measurement and Evaluation of Transportation System Effectiveness,” *Rand Memorandum*, RM-5869-DOT.

Peat, Marwick, Mitchell & Co (1973), *New Systems Requirements Analysis Program, Transportation System Evaluation Indicators*.

Peeta, S. K. Poonuru, N. Richards, K. Sinha, and M. Sultan (1998), *Evaluation of the Impacts of ITS Technologies on the Borman Expressway Network*. Report for the Federal Highway Administration and Indiana Department of Transportation.

Pliskin, J.S. and C.H. Beck, Jr. (1976), "A Health Index for Patient Selection: A Value Function Approach with Application to Chronic Renal Failure Patients," *Management Science*, 22 (9): 1009-1021.

Pruzan, P. M. and J. T. R. Jackson (1963), "On the Development of Utility Spaces for Multi-Goal Systems," *Saertryk af Erhvervsøkonmisk Tidsskrift*, 4, 257-274.

Roy, B. (1974), “Critères Multiples et Modelisation des Preferences-L`Apport des Relations de Surclassement,” *Revue d`Econome Politique*, No. 1, 1974.

Roy, B. (1975), “Why Multicriteria Decision Aid May Not Fit in With the Assessment of a Unique Criteria,” in M. Zeleny (ed.), *Multiple Criteria Decision Making: Kyoto 1975*, Springer-Verlag, 280-283.

Saaty, T. L. (1977), "A Scaling Method for Priorities in Hierarchical Structures," *Journal of Mathematical Psychology*, 15 (3), 234-281.

Saaty, T. L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York.

Saaty, T. L. (1982), *Decision Making for Leaders*, Lifetime Learning, Belmont, California.

Saaty, T. L. (1994), "How to Make a Decision: The Analytic Hierarchy Process," *Interfaces*, 24 (6), 19-43.

Saaty, T.L. and L. G. Vargas (1982), *The Logic of Priorities: Applications in Business, Energy, Health, and Transportation*, Kluwer, Boston.

Sarin, R. K. (1990), "Conjoint Measurement: Theory and Methods," in C. Bana e Costa (ed.), *Readings in Multiple Criteria Decision Aid*, Springer, Berlin, 277-294.

Siemens Traffic Controls, Ltd. (1996), *SCOOT User Guide*.

Simon, H.A., *Administrative Behavior*, McMillan, New York, 1953.

Small, K. A. (1999), "Project Evaluation," *Essays in Transportation Economics and Policy*, 137-177.

Srinivasan, V. and A.D. Shocker (1973), "Linear Programming Techniques for Multidimensional Analysis of Preference," Psychometrika, 38 (3), 337-369.

Streff, FM, (1991), "Traffic Safety Evaluations: Design, Implementation, and Use," *UMTRI Research Review*, 21 (5).

Thrall, R. M., C. H. Coombs, and R. L. Davis (eds.), *Decision Processes*, John Wiley and Sons, New York, 1954.

Ting, H. M. (1971), "Aggregation of Attributes for Multiattributed Utility Assessment," *Technical Report No. 66, Operations Research Center, M.I.T.*, Cambridge.

Underwood, S. and S. Gehring (1994), "Framework for Evaluating Intelligent Vehicle-Highway Systems," *Transportation Research Record*, no. 1453, 16-22.

USDOT (1993), *Intelligent Vehicle Highway Systems Operational Test Evaluation Guidelines*. DOT Document HTV-20, prepared by the MITRE Corporation.

Vemuri, V. (1947), "Multi-Objective Optimization in Water Resources Systems," *Water Resources Research*, 10 (1), 44-48.

von Neumann, J. and O. Morgenstern (1947), *Theory of Games and Economic Behavior*, 2nd Ed., Princeton Univ. Press, Princeton.

von Winterfeldt, D. and W. Edwards (1986), *Decision Analysis and Behavioral research*,Cambridge University Press, Cambridge.

Yu, P.L. (1973), "A Class of Solutions for Group Decision Problems," *Management Science*, 19 (8), 936-946.

APPENDIX A INDIVIDUAL
DECISION-MAKER FOLLOW-UP QUESTIONNAIRE

Participant ______________________________ Date: ________
Interviewer ______________________________

Please rank the four weighting techniques:

1. Ease of understanding the technique.

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

2. Ease of selecting weights.

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

3. Suitability of final weights.

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

4. Overall desire to use in the future

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

5. Explain the reasons for your selections.

Please rate your experiences with the value function questions.

6. Ease of understanding the technique. worst 1 2 3 4 5 6 7 best

7. Ease of selecting the value function. worst 1 2 3 4 5 6 7 best

8. Suitability of final value functions. worst 1 2 3 4 5 6 7 best

9. Please explain the reasons for your selections

10. Applicability of comparing the attributes to money worst 1 2 3 4 5 6 7 best

11. Did you believe that one or more of the attributes were not comparable to money?

11a. Which ones?

12. Agreement with the overall grouping of the attributes. worst 1 2 3 4 5 6 7 best

13. Did you believe that some of the attributes were not grouped properly?

13a. Which ones?

Please rate your experiences with the overall technique.

14. Ease of understanding the technique. worst 1 2 3 4 5 6 7 best

15. Ease of the overall interview process worst 1 2 3 4 5 6 7 best

16. Suitability of final values. worst 1 2 3 4 5 6 7 best

17. Please explain the reasons for your selections.

18. Did this interview increase your understanding of the issues for this problem?
worst 1 2 3 4 5 6 7 best

19. How did it increase your understanding?

20. What was the best feature of this technique?

21. What was the worst feature?

and How would you change it?

APPENDIX B **GROUP**

DECISION-MAKER FOLLOW-UP QUESTIONNAIRE

Participant ______________________________ Date: ________

Interviewer ______________________________

Please rank the four weighting techniques:

1. Ease of selecting weights.

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

2. Suitability of final weights.

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

3. Group vs. Individual. Please identify your preference for finding weights.

	individual					group	
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

4. Overall desire to use in the future

	worst						best
a. Ratio approach	1	2	3	4	5	6	7
b. 100 point approach	1	2	3	4	5	6	7
c. Regular AHP	1	2	3	4	5	6	7
d. AHP - Pairwise Comparisons	1	2	3	4	5	6	7

5. Compare and contrast your experiences finding weights alone and in a group.

6. Explain the reasons for your selections.

Please rate your experiences with the value function questions.

7. Ease of selecting the value function. worst best
1 2 3 4 5 6 7

8. Suitability of final value functions. worst best
1 2 3 4 5 6 7

9. Please explain the reasons for your selections

10. Group vs. Individual. Please identify your preference for finding value functions.
individual group
1 2 3 4 5 6 7

11. Compare and contrast your experiences finding value functions alone and in a group.

Please rate your experiences with the overall technique.

12. Ease of the overall interview process worst best
1 2 3 4 5 6 7

13. Suitability of final values. worst best
1 2 3 4 5 6 7

14. Please explain the reasons for your selections.

15. Group vs. Individual. Please identify your overall preference.

individual					group	
1	2	3	4	5	6	7

16. Compare and contrast your experiences between the individual and group interviews.

17. Did this interview increase your understanding of the issues for this problem?

worst						best
1	2	3	4	5	6	7

18. How did it increase your understanding?

19. Did the individual or group interview have a greater impact on your understanding of the issues for this problem?

worst						best
1	2	3	4	5	6	7

20. What was the best feature of this technique?

21. What was the worst feature?

and How would you change it?

APPENDIX C TRAVEL TIME STUDY ROUTES

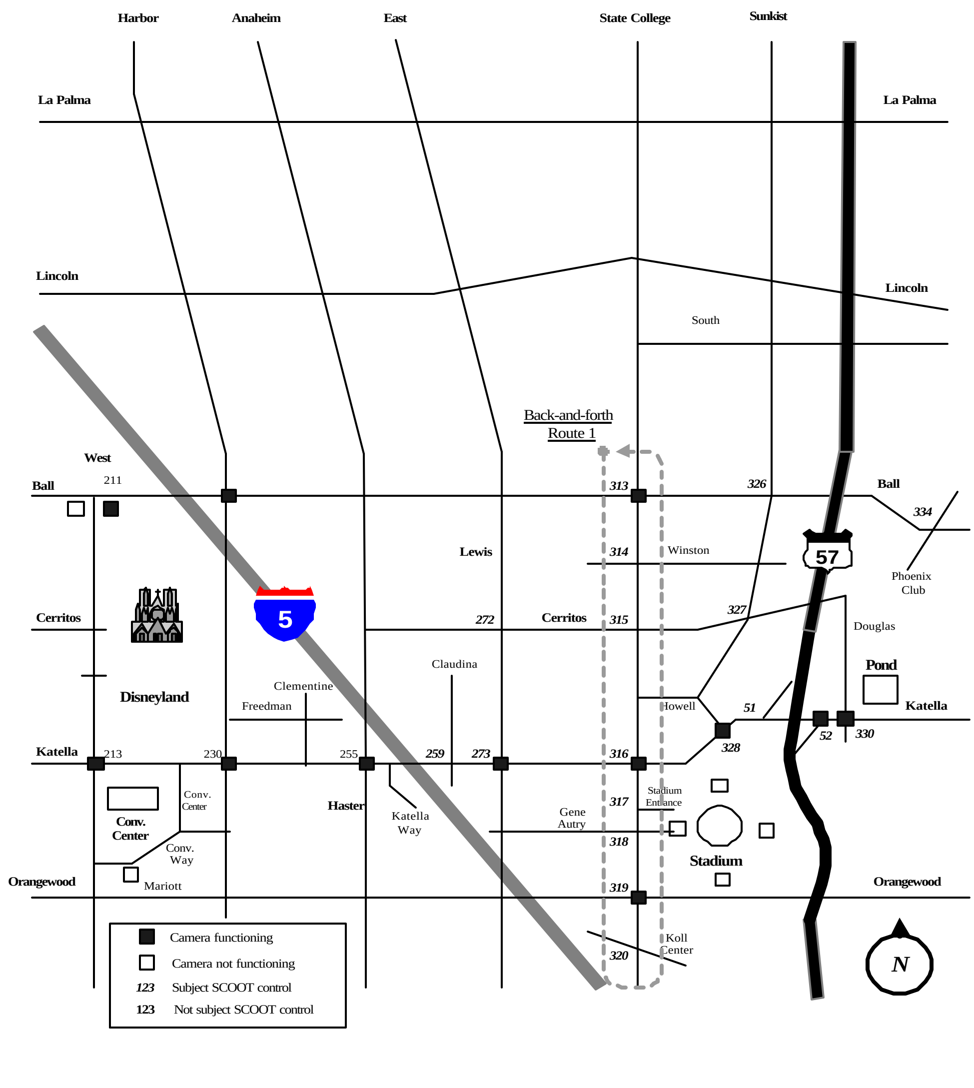

Figure C.1. Floating Car Route 1

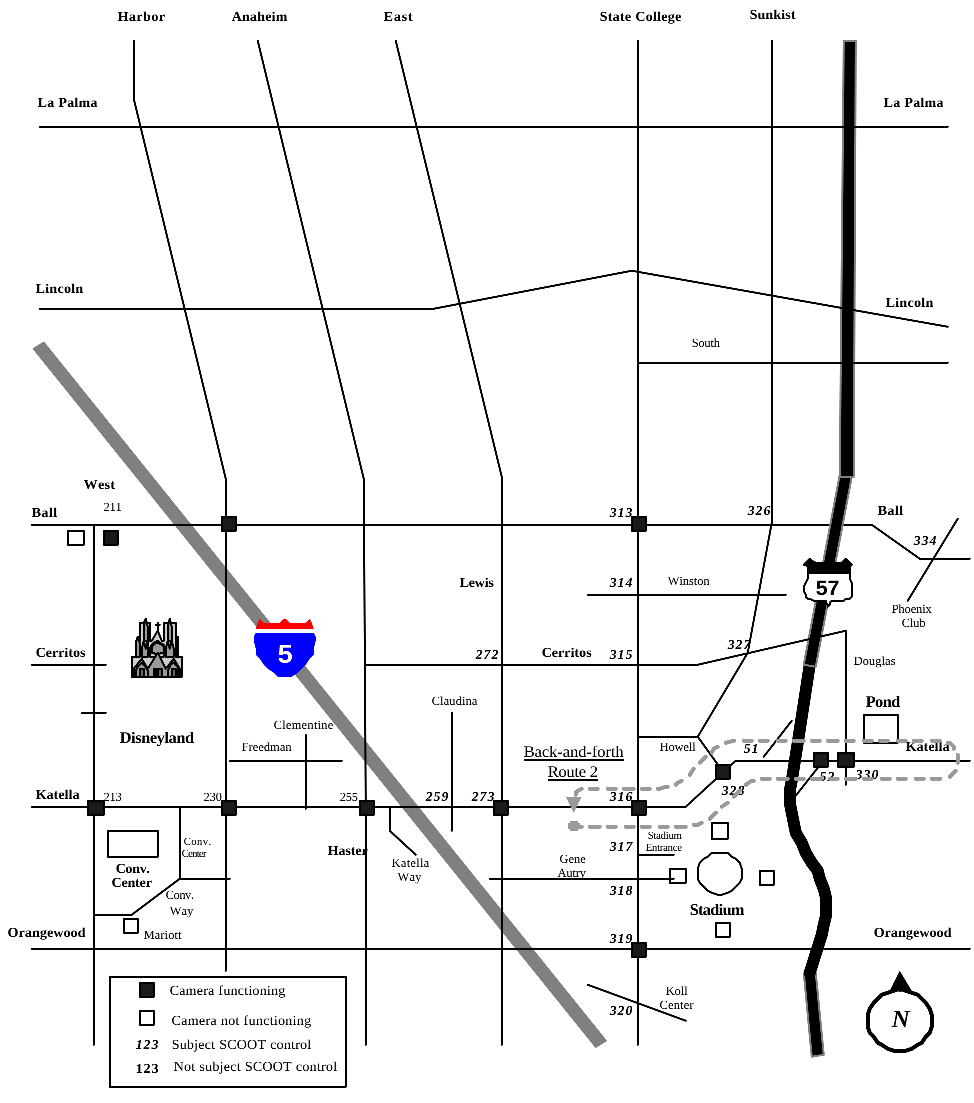

Figure C.2. Floating Car Route 2

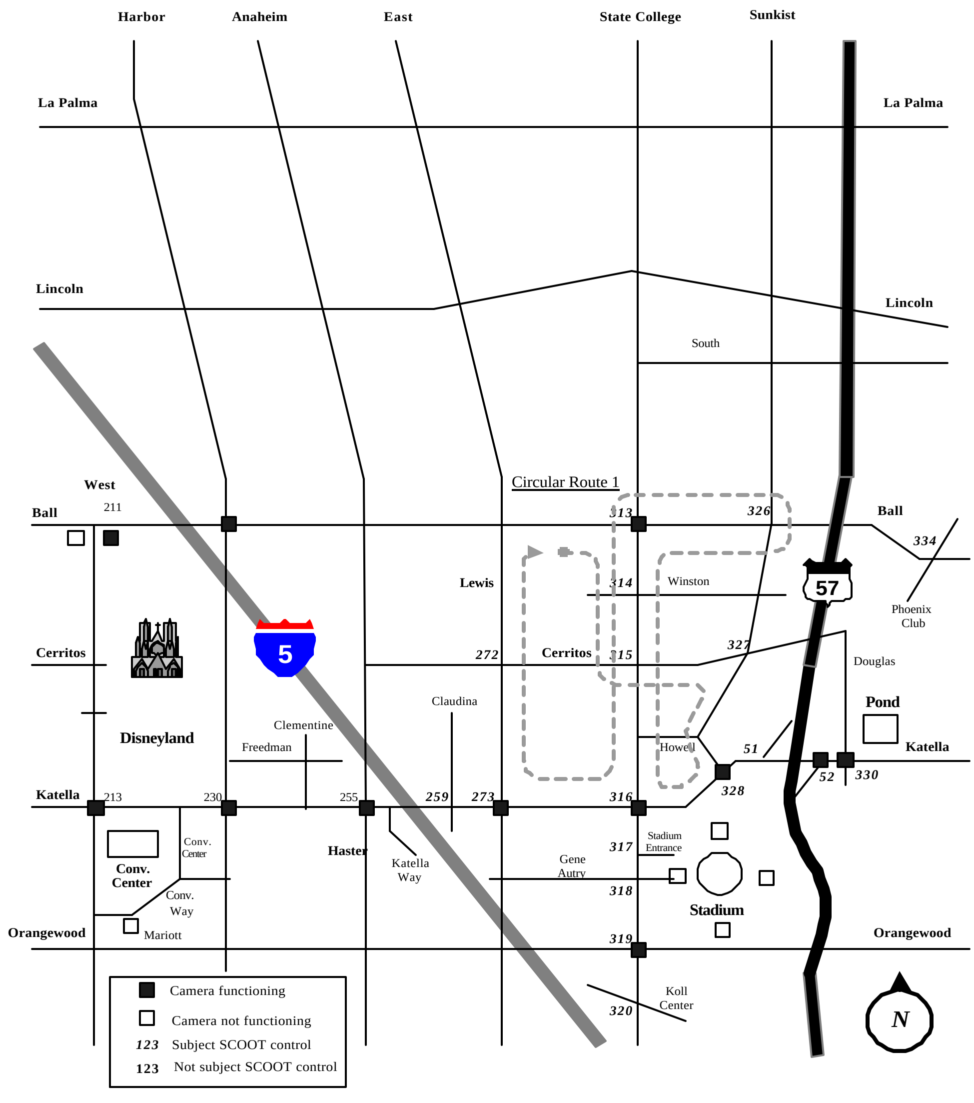

Figure C.3. Floating Car Route 3

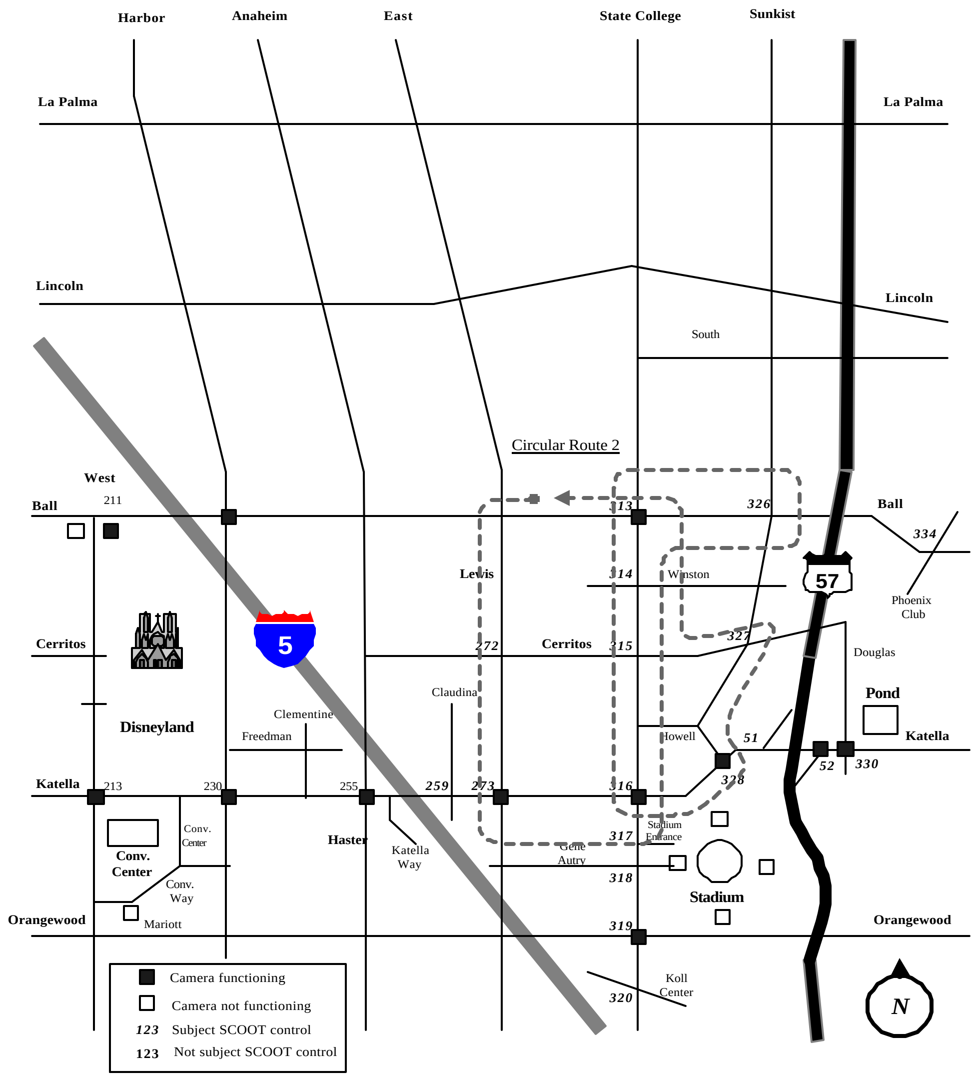

Figure C.4. Floating Car Route 4

APPENDIX D
INSTITUTIONAL INTERVIEW QUESTIONS AND FORMAT

Individual ________________________________ **Date: ________**

1. What is your role in the Anaheim FOT?

2. Query as to how long, formal responsibilities, predecessor, previous FOT roles, etc.

Programmatic Goals and Objectives

3. What is the importance of the Anaheim FOT in the national FOT or ITS programs?

4. Why was this FOT initially selected as part of the FOT program?

5. What are the key goals and objectives of the Anaheim FOT? **[query for details]**

6. Are/have these goals been met, and to what degree?

7. What, if any, potential national impacts would result from the successful (or unsuccessful) completion of the Anaheim FOT?

8. To what extent were you involved in the development of the FOT?

9. Have there been any changes in the FOT's goals/priorities?

10. How did your firm/agency/city become involved in this FOT project?
11. When was the final notice to proceed/funding given by the FHWA?

12. What role did the evaluation team charter play in the overall FOT?

13. To what degree is this FOT more "Research & Development" versus "Implementation and Operations"?

    ... was this perceived from the beginning?

Implementation:

1. Has your agency been fully maintaining your schedule and meeting deadlines?

   [**Query to what degree...]**

2. How useful did you find the schedule/project management for this FOT?

3. Do you believe the time invested in maintaining an up-dated schedule influenced your performance on this FOT?

4. To what degree have the other participants been meeting their deadlines?

5. Do other partners impact the implementation of your portions of the project?

   [**describe**]

6. Did you anticipate all of the implementation costs?

7. What potential problems do you foresee with the implementation of any of the technologies(SCOOT, VTDS, 1.5GC)?

8. What could change to expedite the contract process?

9. What changes in operational policies are anticipated with regard to SCOOT (and other technologies) ?

10. What changes in maintenance policies are anticipated with regard to the new technologies?

11. Do you believe that the current UTCS system and 1.5 GC will compliment SCOOT?

12. How will the substandard implementation of SCOOT with respect to detectorization impact its overall performance?

Funding:

1. What is the Source of Project Funding?
2. Was the budget sufficient to complete the project as planned?
3. What non-budgeted expenses were associated with this project?

4. What budget would be necessary to repeat the implementation process in a similar situation?

5. What one thing would you change if your budget could be increased by, say, 10%?

Working Relationships:

An Alternative Question: How did personnel issues contribute to the project's success/failure?

What were some of the key issues related to personnel concerns? What happened?

1. Relative to the FHWA as an Anaheim FOT Partner:

   a. Has your relationship with the FHWA affected your performance on the FOT?

   b. Has your relationship with the FHWA affected the FOT's overall success?

   c. What were FHWA's project responsibilities?

2. Relative to the City of Anaheim as an Anaheim FOT Partner:

   a. Has your relationship with the City affected your performance on the FOT?

   b. Has your relationship with the City affected the FOT's overall success?

   c. What were City's project responsibilities?

3. Relative to Caltrans as an Anaheim FOT Partner:

a. Has your relationship with Caltrans affected your performance on the FOT?

b. Has your relationship with Caltrans affected the FOT's overall success?

c. What were Caltrans's project responsibilities?

4. Relative to PATH (Robert Tam) as an Anaheim FOT Partner:

a. Has your relationship with PATH affected your performance on the FOT?

b. Has your relationship with PATH affected the FOT's overall success?

c. What were PATH's project responsibilities?

5. Relative to JHK (Transcore) as an Anaheim FOT Partner:

a. Has your relationship with JHK affected your performance on the FOT?

b. Has your relationship with JHK affected the FOT's overall success?

c. What were JHK's project responsibilities?

6. Relative to Seimens/Eagle as an Anaheim FOT Partner:

a. Has your relationship with Seimens affected your performance on the FOT?

b. Has your relationship with Seimens affected the FOT's overall success?

c. What were Seimens's project responsibilities?

7. Relative to the Evaluation Team (ET) as an Anaheim FOT Partner:

   a. Has your relationship with the ET affected your performance on the FOT?

   b. Has your relationship with the ET affected the FOT's overall success?

   c. What were the ET's project responsibilities?

Conclusions:

1. How did administrative issues contribute to the project's success/failure?

   What were some of the key issues related to administration concerns? What happened?

   Did project administration affect the project's implementation?

2. How did legal and liability issues contribute to the project's success/failure?

   What were some of the key issues related to legal and liability concerns? What happened?

3. How did legal/liability issues affect implementation?

   Would you change the approach to legal/liability issues if you had to implement the project again? Why?

   How did legal/liability issues change to accommodate the operational needs of the new technologies?

   Did you expect these changes? Why?

Would you expect similar changes if you had to implement the project again? Why?

4. How did the number and quality of personnel assigned to the project affect implementation?
   Would you change the composition or quantity of the personnel involved if you had to implement the project again? Why?

5. How did the combination of technologies assigned to the project affect implementation?

   Would you change the composition or quantity of the technologies involved if you had to implement the project again? Why?

6. Do you believe that you and the other partners adequately planned for the operations, maintenance and training needs related to the new system?

7. Would you recommend that your firm/agency/city participate in another FOT?

   [**query: Why or why not?**]

8. What benefits do you think the FOT will provide in the short-term?

   ... in the Long-term?

9. What level of overall performance does SCOOT need to obtain in order for you to continue to use the technology?

10. What level of overall performance does 1.5GC need to obtain in order for you to continue to use the technology?

11. What level of overall performance does VTDS need to obtain in order for you to continue to use the technology?

12. How critical is this FOT to the overall development of SCOOT ?

    a. in operational terms?
    b in financial terms?

APPENDIX E INDIVIDUAL USER VALUE FUNCTIONS

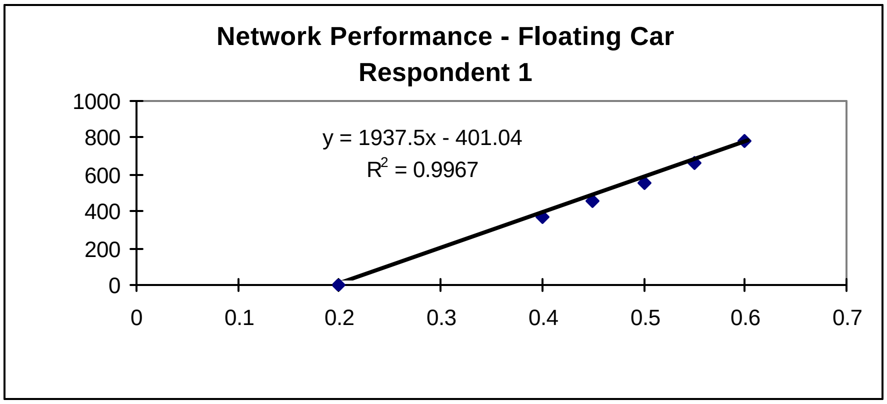

Figure E.1. Network Performance-Floating Car, Stop Time, Respondent 1 (User Defined)

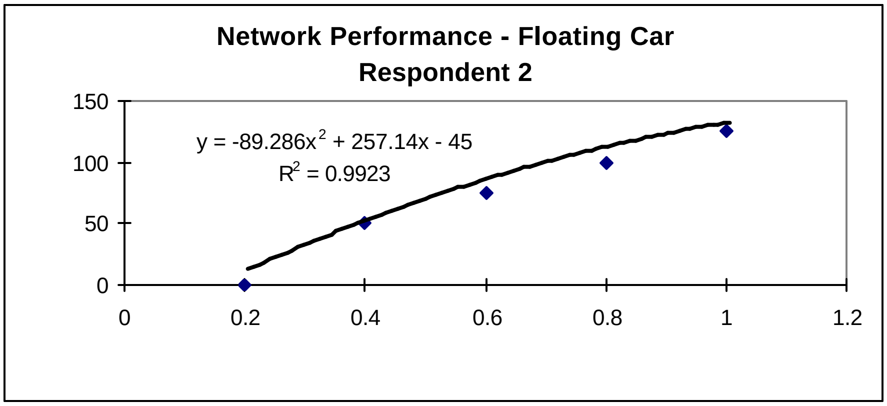

Figure E.2. Network Performance-Floating Car, Stop Time, Respondent 2 (User Defined)

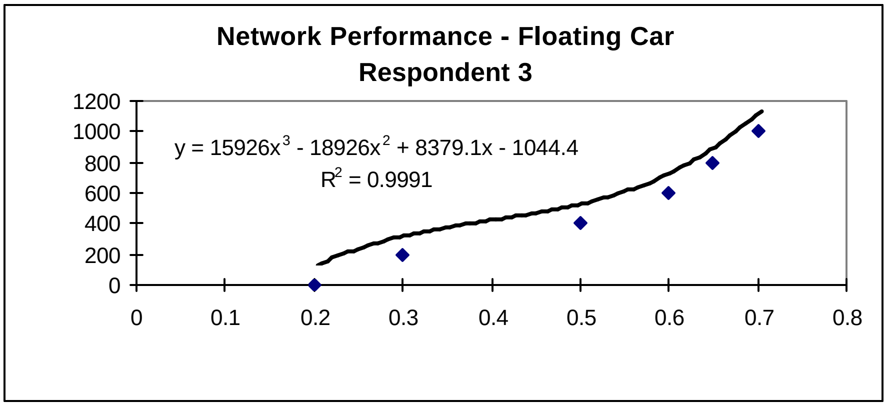

Figure E.3. Network Performance-Floating Car, Stop Time, Respondent 3 (User Defined)

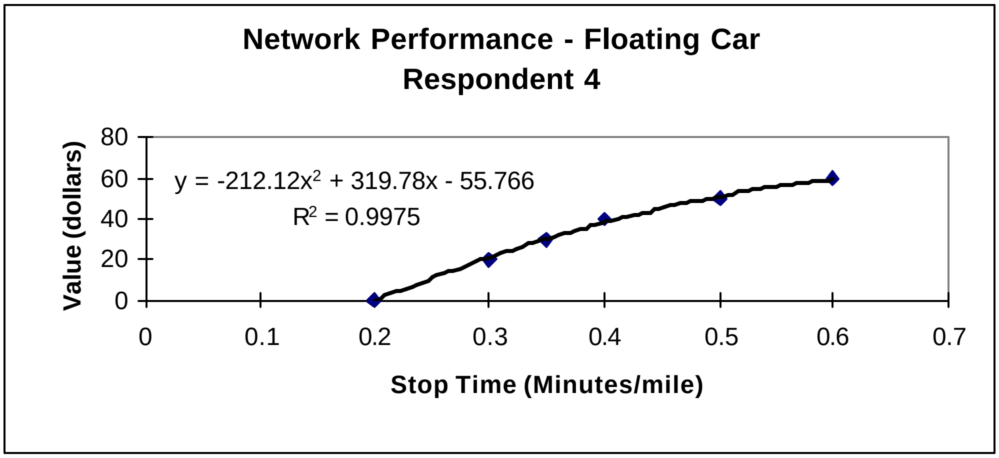

Figure E.4. Network Performance-Floating Car, Stop Time, Respondent 4 (User Defined)

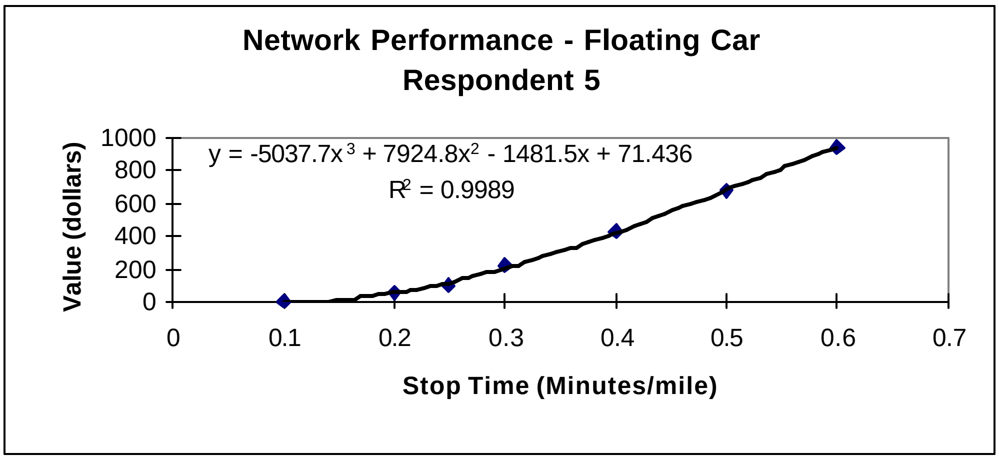

Figure E.5. Network Performance-Floating Car, Stop Time, Respondent 5 (User Defined)

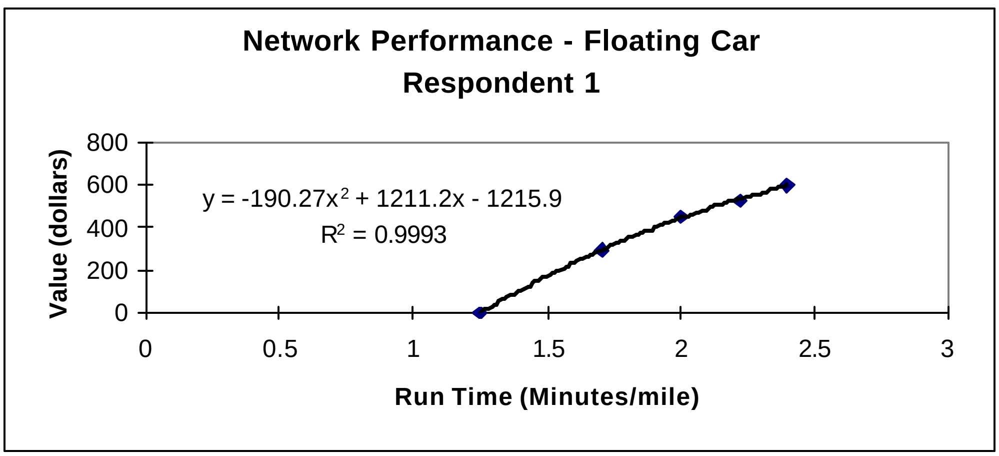

Figure E.6. Network Performance-Floating Car, Run Time, Respondent 1 (User Defined)

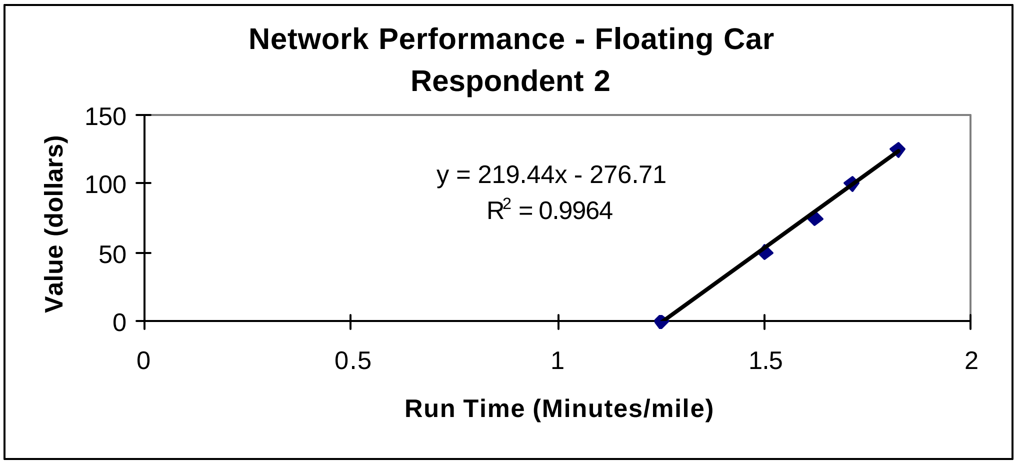

Figure E.7. Network Performance-Floating Car, Run Time, Respondent 2 (User Defined)

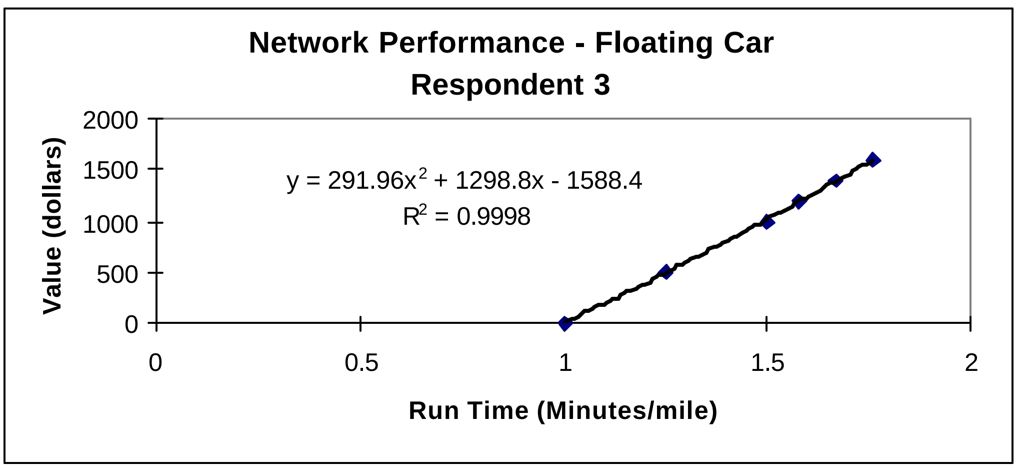

Figure E.8. Network Performance-Floating Car, Run Time, Respondent 3 (User Defined)

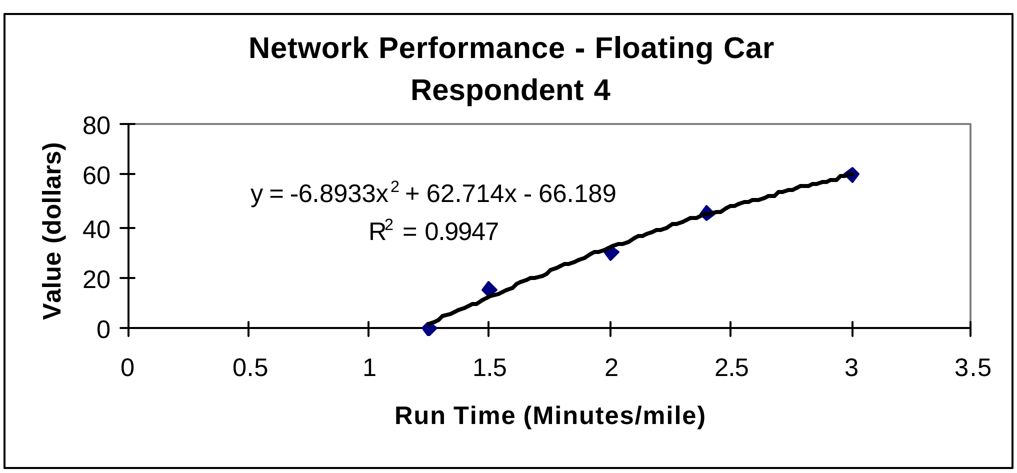

Figure E.9. Network Performance-Floating Car, Run Time, Respondent 4 (User Defined)

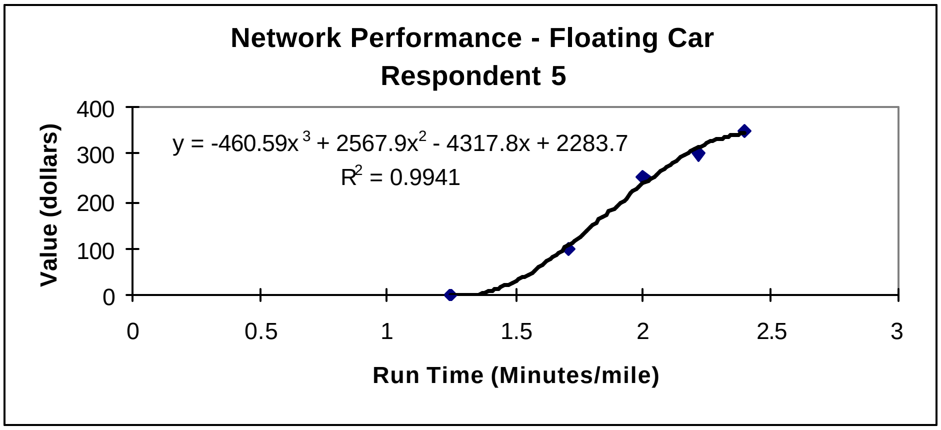

Figure E.10. Network Performance-Floating Car, Run Time, Respondent 5 (User Defined)

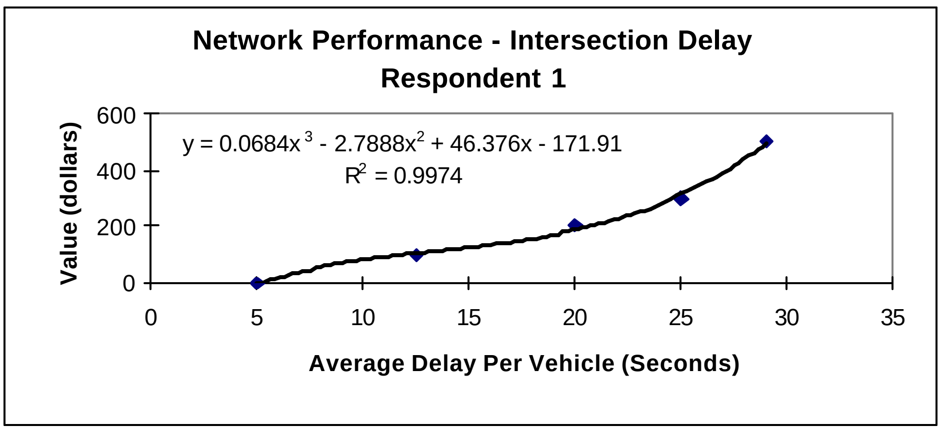

Figure E.11. Network Performance-Intersection Delay, Average Delay, Respondent 1 (User Defined)

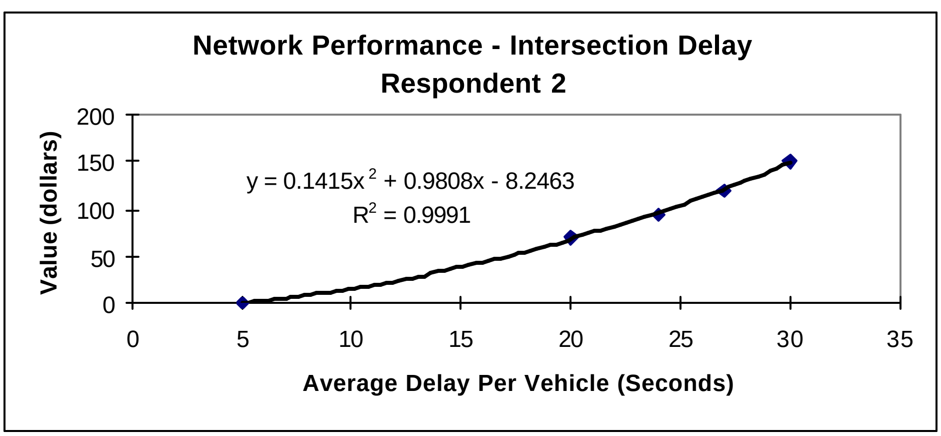

Figure E.12. Network Performance-Intersection Delay, Average Delay, Respondent 2 (User Defined)

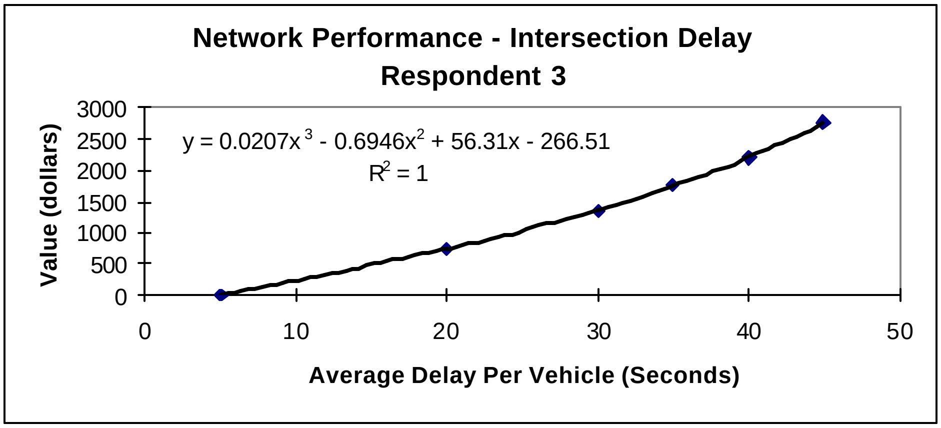

Figure E.13. Network Performance-Intersection Delay, Average Delay, Respondent 3 (User Defined)

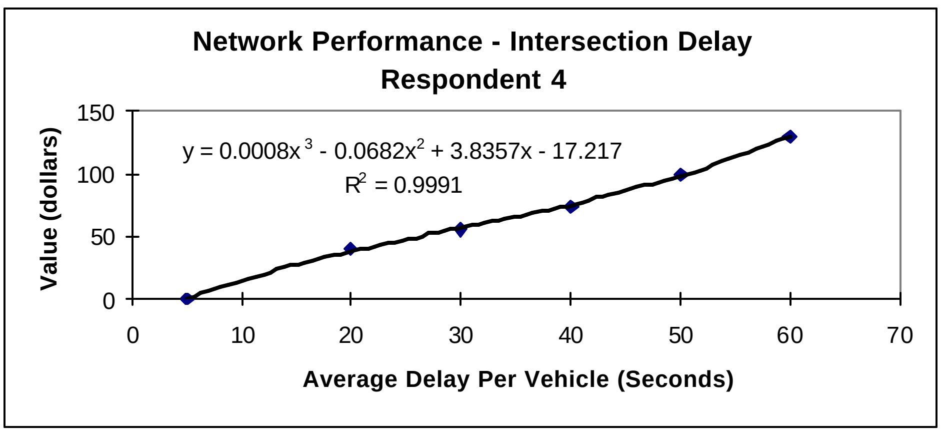

Figure E.14. Network Performance-Intersection Delay, Average Delay, Respondent 4 (User Defined)

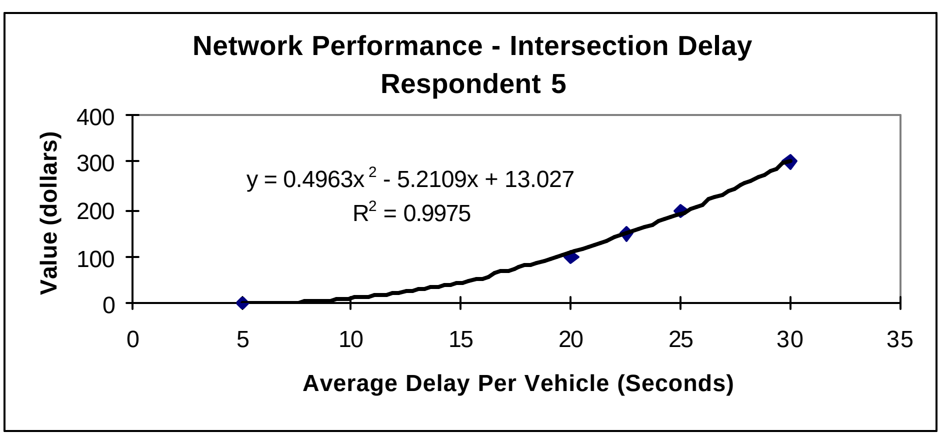

Figure E.15. Network Performance-Intersection Delay, Average Delay, Respondent 5 (User Defined)