Technical Report Documentation Page

1. Report No. SWUTC/05/167248-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Framework for Developing Integrated ITS Solutions to Improve Traffic Operations		5. Report Date June 2005 6. Performing Organization Code
7. Author(s) Zhong Wang and C. Michael Walton		8. Performing Organization Report No. Report 167248-1
9. Performing Organization Name and Address Center for Transportation Research University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 10727
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute Texas A&M University System College Station, TX 77843-3135		13. Type of Report and Period Covered Research Report September 2003 – August 2004 14. Sponsoring Agency Code
15. Supplementary Notes Supported by general revenues from the State of Texas		

16. Abstract

The overall objective of this study is to assist transportation agencies in developing appropriate ITS strategies to improve traffic operations. This report summarizes the effort in applying innovative methods for ITS planning and ITS evaluation. First, the authors present a study using FHWA ITS Planning Process Version 2.1 to develop appropriate ITS strategies to accommodate local needs. A case study was performed in Austin, Texas to illustrate the whole procedure. The results indicate that by incorporating the National ITS Architecture and IDAS, the FHWA ITS Planning Process could be more applicable to the regional ITS planning. Next, a multicriteria decision analysis method is presented for ITS alternative comparison and selection. The multicriteria approach developed in this study can be applied to identify the best ITS alternative among several candidates. An iterative ELECTRE-I procedure was employed to compare various ITS alternatives and identify the best one. With a case study in Austin, TX, the approach was illustrated and its applicability was proven. Finally, recommendations for further research activities are given at the end of the report.

17. Key Words ITS Evaluation, ITS Planning, Decision Analysis, Multicriteria Approach, National ITS Architecture, IDAS, ELECTRE-I,		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 63	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

A FRAMEWORK FOR DEVELOPING INTEGRATED ITS SOLUTIONS TO IMPROVE TRAFFIC OPERATIONS

by

Zhong Wang

and

C. Michael Walton

Research Report SWUTC/05/167248-1

Southwest Regional University Transportation Center
Center for Transportation Research
University of Texas at Austin
Austin, Texas 78712

June 2005

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGMENTS

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University of Transportation Centers Program to the Southwest Region University Transportation Center which is funded 50% with general revenue funds from the State of Texas. The authors express appreciation to the Texas Department of Transportation (TxDOT) and the Capital Area Metropolitan Planning Organization (CAMPO) of Austin for supplying data used in this study.

ABSTRACT

The overall objective of this study is to assist transportation agencies in developing appropriate ITS strategies to improve traffic operations. This report summarizes the effort in applying innovative methods for ITS planning and ITS evaluation. First, the authors present a study using FHWA ITS Planning Process Version 2.1 to develop appropriate ITS strategies to accommodate local needs. A case study was performed in Austin, Texas to illustrate the whole procedure. The results indicate that by incorporating the National ITS Architecture and IDAS, the FHWA ITS Planning Process could be more applicable to the regional ITS planning. Next, a multicriteria decision analysis method is presented for ITS alternative comparison and selection. The multicriteria approach developed in this study can be applied to identify the best ITS alternative among several candidates. An iterative ELECTRE-I procedure was employed to compare various ITS alternatives and identify the best one. With a case study in Austin, TX, the approach was illustrated and its applicability was proven. Finally, recommendations for further research activities are given at the end of the report.

EXECUTIVE SUMMARY

After the passing of Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, Intelligent Transportation Systems (ITS) has been supported by federal and state governments to solve today's surface transportation problems. Since transportation investments are greatly affected by budget limit and a complex political environment, the evaluation and planning of ITS become very important for transportation agencies and decision makers. Innovative ITS benefits evaluation and planning methods are being called for by the federal and state governments. The methods to assist decision makers in identifying the good ITS strategies for local transportation improvement would be very beneficial given this situation. With the intention of enhancing ITS evaluation and planning, this report summarizes the one-year effort in developing valuable methods for regional ITS planning and alternative comparison.

The overall objective of this study is to assist transportation agencies in planning appropriate ITS strategies based on local needs. Based on a one year effort, this report intended to answer the following specific questions:

- What should be the procedure for developing appropriate ITS strategies to meet local needs?
- Given the defined problems and goals and constraints, how can decision makers identify the best ITS strategies?
- When ITS applications are planned, what actions can be taken to provide the greatest likelihood of success?

To answer these questions, the report begins by presenting the motivating factors for the applications of ITS and the current issues in ITS planning. Chapter 2 presents a study of using FHWA ITS Planning Process Version 2.1 to develop appropriate ITS strategies to accommodate local needs. The National ITS Architecture is employed to screen the appropriate ITS strategies. The IDAS program is then employed to evaluate those strategies. Following the FHWA ITS planning framework, appropriate ITS strategies for regional goals are identified and evaluated.

A case study was performed to illustrate the whole procedure. The results indicate that by incorporating the National ITS Architecture and IDAS, the FHWA ITS Planning Process is more applicable to the regional ITS planning. The proposed procedure would be valuable for decision-makings on ITS investments and deployments. Chapter 3 proposes a multicriteria decision analysis method for ITS alternative comparison and selection. The multicriteria approach developed in this study is applied to identify the best ITS alternative among several candidates. The ITS Deployment Analysis System (IDAS) is employed to assist the benefits evaluation of different ITS alternatives. An iterative ELECTRE-I procedure is then employed to compare these ITS alternatives and identify the best ITS alternative. With a case study in Austin, TX, the approach is demonstrated and its value is proved. The final chapter gives a summary of the study and further recommendations for the future effort.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

After the passing of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, Intelligent Transportation Systems (ITS) have been supported by federal and state governments to solve today's surface transportation problems. Since transportation investments are greatly affected by budget limit and a complex political environment, the evaluation and planning of ITS become very important for transportation agencies and decision makers. The methods to assist decision makers in identifying good ITS strategies for transportation improvement would be very beneficial. Innovative ITS benefits evaluation and planning methods are being called for by federal and state governments. With the intention of enhancing ITS evaluation and planning, this report summarizes the one-year effort in developing valuable methods for regional ITS planning and alternative comparison.

1.1 WHAT ARE INTELLEGENT TRANSPORTATION SYSTEMS?

ITS are varieties of technological advances implemented to improve the interfaces between drivers, vehicles, and roads. There are different versions of ITS definition. One of them defines ITS as "an application of current and evolving technology to transportation systems and the careful integration of system functions to provide more efficient and effective solutions to multimodal transportation problems" (Stockton et al. 1998).

Advanced ITS technologies include sensor and control technologies, information processing and management, telecommunications, electronic technologies, navigation technologies, and other advanced technologies. The operations of these technologies can satisfy various requirements of the travelers in the transportation system and make transportation systems more efficient, safer, more reliable, and more environmentally friendly.

1.2 WHY APPLY ITS?

The transportation system affects people's daily lives from mobility to accessibility, to safety, and to environmental quality. Although the United States maintains one of the best transportation systems in the world, American drivers are still experiencing increasing congestion and delay due to the continued growth of travel demand.

The original impetus for ITS applications was increasing public concern about congestion, accidents, delays, safety, and travel costs. All the problems could eventually be associated with one cause: the current transportation system capacity cannot meet the increasing travel demand. It is well known that for meeting the increasing travel demand, there are two basic measures: one is to expand the transportation system by adding new capacity, the other is to increase the system throughput by improving the efficiency of current infrastructures.

With limited funding and a complex political environment, it is almost impossible to solve current surface transportation problems by adding more capacity only. The reason is simple: the expansion of transportation system capacity may never catch up with the rapid increase of travel demand. Given this situation, improving the efficiency of current transportation systems with ITS becomes more and more important for transportation agencies in the federal, state, and local levels. One such option that can address the dilemma includes the use of ITS technologies.

In 1991, ISTEA was passed by the United States Congress. Since then, the applications of ITS and relevant research have flourished. Many states, especially those that received ITS model deployment initiative (MDI) funding from the federal government, have developed functional and integrated metropolitan transportation management systems in the 1990s (ITS America 2005). To promote the research and application of ITS, ITS America has established a National ITS Program Plan (ITS America 2002).

In general, ITS applications are deliberately deployed to manage the traffic, to manage incidents, to collect and manage data, to provide information and guidance to travelers, to improve transit operations, and to manage commercial vehicle operations. The national ITS program and US Department of Transportation (USDOT) suggest six goals for ITS implementation:

1. Increase operational efficiency and capacity of transportation system
2. Enhance personal mobility, convenience, and comfort of the transportation system
3. Improve the safety of the nation’s transportation system
4. Reduce energy consumption and environmental costs
5. Enhance the present and future economic productivity of individuals, organizations, and the economy as a whole
6. Create an environment in which the development of ITS can flourish

1.3 THE BENEFITS OF ITS

The deployment of ITS applications could potentially improve transportation efficiency through:

1. Affecting users' route choice and the traffic flow along the specific links of the transportation network
2. Affecting the number of trips (vehicle or person) by mode and time-of-day along the specific links or road segments
3. Changing the travel cost for specific origin and destination (O-D) pairings

After a number of early-stage implementations and evaluations, ITS technologies have been widely recognized as one of the most promising approaches to address today's surface transportation problems. Some valuable studies have already been conducted to evaluate the cost-effectiveness of building new roads and improving transportation efficiency with ITS. According to an ITS benefits study (USDOT 1997) and a cost-effectiveness study of ITS versus new roads (McGurrin and Shank 1997), the ITS-based investment would "reduce the need for new roads while saving approximately 35% of the required investment in urban highways" based on a 20-year life-cycle cost analysis of fifty major urban areas in the United States.

According to the field test results, the Joint Program Office (JPO) of the Federal Highway Administration (FHWA) summarizes that ITS applications have shown their values in improving (Mitretek Systems Inc. 2001):

1. Mobility
2. Safety
3. Efficiency
4. Productivity
5. Energy and environment
6. Consumer satisfaction

These six aspects are also the measures suggested by the USDOT ITS Joint Program Office for ITS project evaluation.

1.4 PURPOSE OF THE STUDY

As the federal, state, and local governments promote the deployment of ITS components and technologies, the planning and evaluation of ITS become more and more important because the resources are limited and the reward must be maximized.

To provide guidance for ITS planning, the National ITS Architecture (USDOT 2003) was developed. It has been applied to develop a variety of regional ITS strategic plans and architectures. To assist in the evaluation and planning of ITS deployment, the nationwide field test results were synthesized and updated periodically (Mitretek Systems Inc. 2001). In addition, some computer programs were also developed to assist in ITS evaluation. These include the ITS Deployment Analysis System (IDAS) developed by Cambridge Systematics, DynaSmart-P, developed at the University of Texas at Austin and the University of Maryland, DynaMIT developed at The Massachusetts Institute of Technology, SCRITS, developed by Science Applications International Corporation (SAIC), Process for Regional Understanding and Evaluation of Integrated ITS Networks (PRUEVIIN), developed by Mitretek Systems Inc., etc. These programs have shown great values to researchers and practitioners.

However, with the National ITS Architecture and various evaluation tools available, there are still several issues that need to be addressed to develop appropriate ITS strategies targeting specified objectives in certain areas.

One important issue is to develop a regional ITS plan based on local needs with a clear understanding of potential benefits. Today, a regional ITS plan is usually developed by following the guidance of the National ITS Architecture. However, potential benefits of these ITS implementations in the planning area are usually not very clear. The unknown impact causes substantial difficulties to ITS planners and decision-makers for ITS implementations. In order to help ITS planners and decision makers make rational decisions on ITS investments, a method to develop appropriate ITS strategies based on local needs is necessary.

Another important issue is the ITS alternatives comparison. Transportation investments are generally affected by budget limit and a complex political environment (Khattak and Kanafani 1996) and so are ITS investments. To maximize the reward of an ITS investment, the best alternative that meets local needs must be identified for implementation. The traditional method for alternative comparison is benefit/cost analysis. Benefit/cost analysis is widely used in engineering decision making because it is simple and straightforward. However, the decision makers may not see an alternative's operational performance from the benefit/cost ratio. The alternative with the highest benefit/cost ratio might not meet the local objectives and needs. Thus, innovative methods need to be developed to address this issue. With a thorough literature review, it was found that few studies were performed to assist decision making in ITS alternative comparison. Another characteristic of decision making in ITS implementation is that decision-makers usually have to analyze and judge the ITS alternatives based on limited information and data. In order to address this issue, an appropriate procedure for ITS alternative comparison will be developed in this study.

In summary, the objectives of this study include:

1. Develop a method to identify appropriate ITS strategies to accommodate local needs
2. Develop a method for ITS alternative comparison

1.5 ORGANIZATION OF THE REPORT

This report is the summary of the study to assist transportation agencies in planning and evaluating ITS strategies. There are two major sections in this report. First, in Chapter 2, the authors present a study of using FHWA ITS planning processes to develop appropriate ITS strategies to meet local needs. A case study in Austin, Texas was performed to illustrate the planning process. Next, in Chapter 3, a multicriteria decision analysis method for ITS alternative comparison is presented. A case study was conducted to illustrate the multicriteria approach. Finally, the conclusions of this study and recommendations for further research activities are summarized in Chapter 4.

CHAPTER 2. DEVELOP APPROPRIATE ITS STRATEGIES TO MEET LOCAL NEEDS

This chapter presents a method and a case study of applying the FHWA ITS Planning Process Version 2.1 to develop an ITS implementation plan for a mid-size metropolitan area (Wang and Walton 2004a). The National ITS Architecture is employed to identify the appropriate ITS strategies, and the IDAS program is then employed to evaluate those strategies. Following the FHWA ITS planning framework, appropriate ITS strategies are identified and evaluated for certain objectives. A case study is performed in Austin, Texas. The results indicate that by incorporating the National ITS Architecture and IDAS, the FHWA ITS Planning Process is applicable to the regional ITS planning and is helpful for decision-making on ITS investments and deployments.

2.1 THE FHWA ITS PLANNING PROCESS

Although technology is the foundation of ITS, the success of ITS is not dependent solely on the quality of the technical components, but also on the ability of ITS to function effectively as an integrated system. Therefore, sound ITS system planning is critical for the success of ITS implementation.

Recognizing the importance of system planning for ITS, the Federal Highway Administration (FHWA) initiated the early effort of ITS planning in 1992 (Smith et al. 1995). As the effort began, it gradually became clear that ITS planning was fundamentally different than planning of the traditional highway system or urban transportation system. In this situation, the FHWA developed a standard process to provide guidance for ITS planning (USDOT 1998).

The latest version of FHWA ITS Planning Process is version 2.1. It was developed on the basis of the FHWA ITS Planning Process Version 1.0, which was initially released in 1993 by the FHWA to aid local and regional agencies in developing ITS strategic plans. Figure 2.1 gives an overview of the FHWA ITS Planning Process Version 2.1.

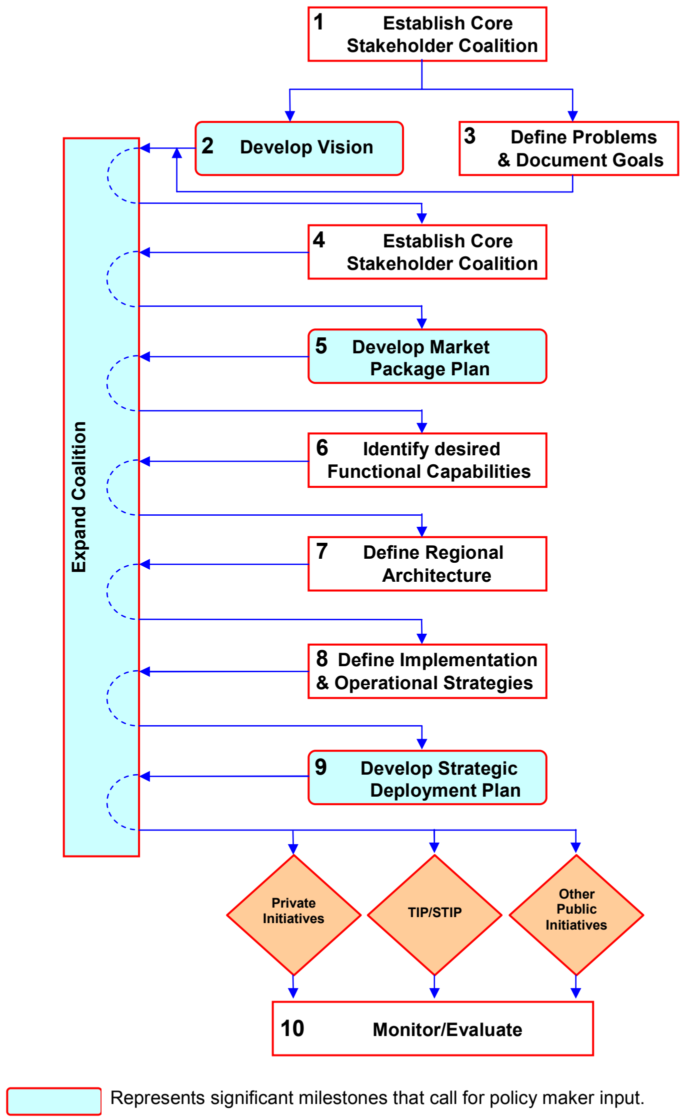

Figure 2.1: FHWA ITS Planning Process Version 2.1

The FHWA ITS Planning Process is developed based on a systems planning approach. It provides a framework for the preliminary planning of the application of ITS in metropolitan areas. As shown in the figure, it is a ten-task framework starting with establishing a core stakeholder coalition and ending with monitoring and evaluation of the project:

1. Establish core stakeholder coalition. This step establishes both a technical and institutional panel for the ITS planning effort. An inventory of regional transportation organizations is developed to serve as the basis for a coalition to support the deployment of ITS.
2. Develop vision. With the establishment of the core stakeholder coalition, this step identifies and quantifies characteristics of the existing regional transportation system.
3. Define problems and document goals. This step involves defining the existing surface transportation problems and the short-term, medium-term, and long-term goals of ITS implementation. A goal and need statement provides the foundation for explaining to the public and decision-makers why an ITS project is necessary and how the proposed strategies could address the problem. Failure to provide a convincing case of the need for the project would lead to the rejection of federal funds.
4. Screen market packages. This step identifies an inventory of the ITS market packages that address the problems and goals defined in step 3.
5. Develop market package plan. This step documents the interconnections of the market packages identified in step 4.
6. Identify desired functional capabilities. This step identifies the functions that are necessary to support the market packages. For instance, communications, traveler interface, data processing, and surveillance are desired functional capabilities for the pre-trip traveler information user service.
7. Define regional architecture. This step groups the functions identified in Step 6 into related subsystems so that the overall system architecture is formed. The architecture defines how the various market packages may be integrated to function as one system.
8. Define implementation and operational strategies. In this step, the possible technologies that will meet the functional requirements of the system architecture will be considered. However, this does not mean a technical design.
9. Develop strategic deployment plan. The strategic deployment plan provides guidance to the implementation of ITS projects that meet the needs and objectives documented in the market package plan.
10. Monitor/Evaluate. The purpose of this step is to monitor/evaluate the implementation of the plan.

2.2 THE NATIONAL ITS ARCHITECTURE

The National ITS Architecture provides a "common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc." (USDOT 2003). The newest version of the architecture is the National ITS Architecture 5.0. Since it also contains the documents which provide performance, cost, and benefits assessments, the National ITS Architecture 5.0 provides specific guidance for ITS planning and system design. At each stage of project development, it will help transportation agencies in determining how the ITS project fits into the regional context of transportation improvement.

The National ITS Architecture defines the following three major aspects of an ITS system:

1. The functions that are required for ITS. For example, broadcast traffic information or detect incidents)
2. The physical entities or subsystems where these functions reside. For example, the field or the vehicle
3. The information flows, or architecture flows, and data flows that connect these functions and physical subsystems together into an integrated system

The National ITS Architecture defines the framework of an ITS system, which usually includes the following components: user services, logical architecture, physical architecture, equipment packages, market packages, and standards. The interrelationships and data flows among these components are shown in Figure 2.2.

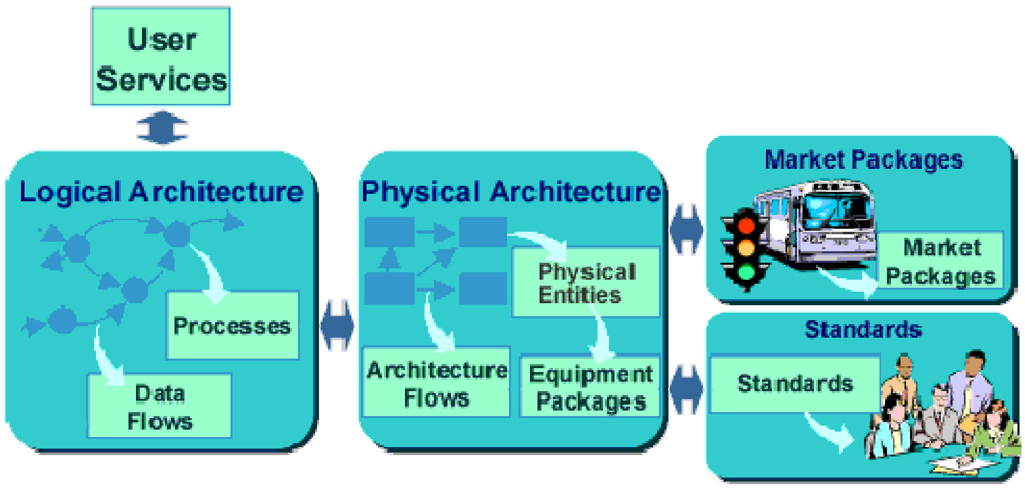

Figure 2.2: An Overview of the National ITS Architecture Information Flows

2.2.1 User Services

User service is an important concept in the national ITS architecture. It represents what the system will do from the perspective of the user, which might be either the public or a system operator.

As shown in Table 2.1, the national ITS architecture defines 33 user services, which are grouped into eight categories. Although the 33 user services are defined, the National ITS Architecture is open for new or updated user services. Namely, the user services can be customized according to local stakeholders' requirements and needs. With the concept of user services, the ITS planners can start the process of system or project definition by thinking about what high level services will be provided to address identified problems and needs.

To accomplish each user service, a variety of functions may be required. To reflect this, a concept of user requirements is introduced. User service requirements, also called functions, are more detailed functional statements about the user services. For example, the traffic control user service in the Travel and Traffic Management category is defined by more than 40 "functions." These user requirements "can be used as a departure point for the development of project functional requirements and system specifications" (Iteris website 2004).

Table 2.1: User Services Defined by the National ITS Architecture

User Service Bundle	User Service
Travel And Traffic Management	Pre-Trip Travel Information En-Route Driver Information Route Guidance Ride Matching And Reservation Traveler Services Information Traffic Control Incident Management Travel Demand Management Emissions Testing And Mitigation Highway-Rail Intersection
Public Transportation Management	Public Transportation Management En-Route Transit Information Personalized Public Transit Public Travel Security
Electronic Payment	Electronic Payment Services
Commercial Vehicle Operations	Commercial Vehicle Electronic Clearance Automated Roadside Safety Inspection On-Board Safety and Security Monitoring Commercial Vehicle Administrative Processes Hazardous Material Security and Incident Response Freight Mobility
Emergency Management	Emergency Notification And Personal Security Emergency Vehicle Management Disaster Response and Evacuation
Advanced Vehicle Safety Systems	Longitudinal Collision Avoidance Lateral Collision Avoidance Intersection Collision Avoidance Vision Enhancement For Crash Avoidance Safety Readiness Pre-Crash Restraint Deployment Automated Vehicle Operation
Information Management	Archived Data Function
Maintenance and Construction Management	Maintenance and Construction Operations

(Source: National ITS Architecture 5.0, USDOT 2003)

2.2.2 Logical Architecture

Logical architecture is also an important concept in the National ITS architecture. A logical architecture is used to aid in organizing complex entities and relationships in an ITS system. With the development of a logical architecture, the system functions and information flows will be identified. In addition, the logical architecture provides guidance to the development of functional requirements for new systems and improvements. However, a logical architecture does not define where or by whom functions are performed in the system, nor does it identify how functions are to be implemented.

2.2.3 Physical Architecture

A physical architecture provides agencies with a physical representation of how the ITS system should provide the required functionality. When a physical architecture is developed, the processes identified in the logical architecture are assigned to physical entities, or subsystems. In addition, the architecture flows are identified by grouping all data flows between any two subsystems. Namely, one architecture flow is one or a group of data flows between a pair of subsystems. There are four subsystems defined in the National ITS Architecture: travelers, management centers, vehicles, and rods. Development of a physical architecture will identify the desired communications and interactions between different transportation management organizations and subsystems.

It can be seen that the physical architecture is formed by two layers: one is the transportation layer, the other is the communications layer. The transportation layer describes the relationships among subsystems. The communications layer shows all the necessary communication services that connect the subsystems. The communications layer identifies the system interface where national ITS standards and communications protocols can be used.

Figure 2.3 depicts the physical entities defined in the National ITS Architecture. It also illustrates the interconnections among the physical subsystems.

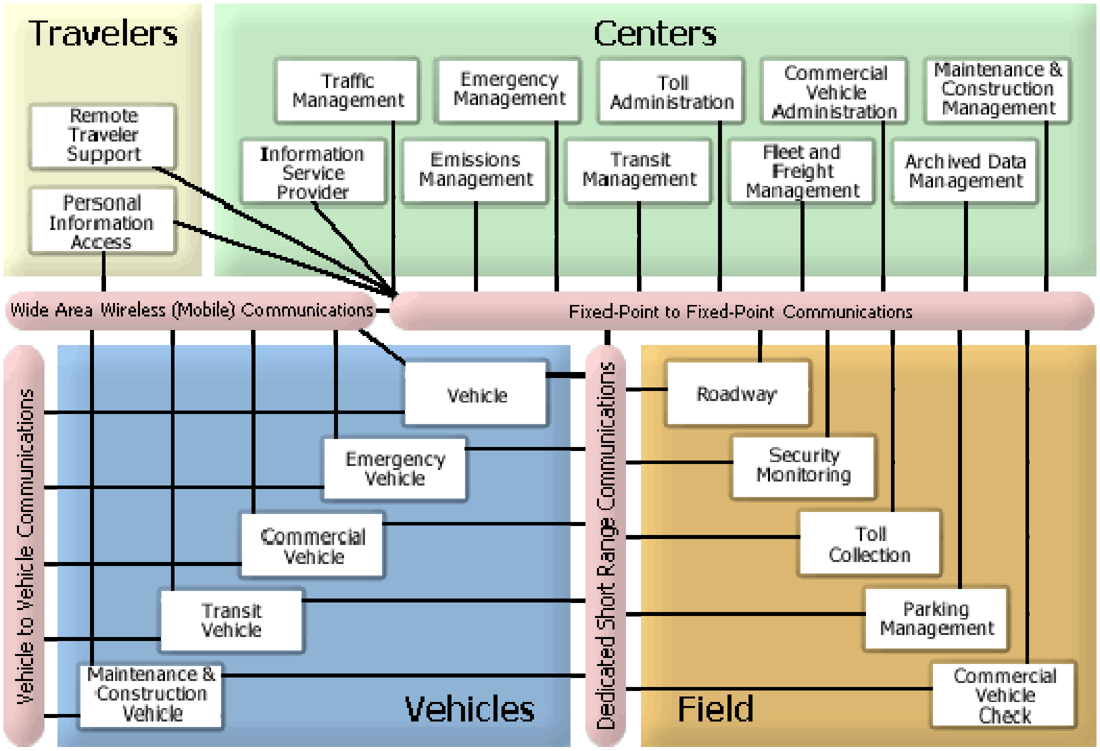

Figure 2.3: The Physical Entities Defined in the National ITS Architecture
(Source: National ITS Architecture 5.0, USDOT 2003)

2.2.4 Equipment Packages And Market Packages

With the development of the logical and physical architectures, all of the essential architecture elements are identified so that the user services can be provided. The term “equipment package” is used to represent the “implementable” package of hardware and software capabilities for the identified functions of a particular subsystem.

The equipment packages are associated closely with market packages and can be used as a basis for estimating deployment costs. The National ITS Architecture has defined 198 equipment packages in total. However, the specific set of equipment packages defined is merely illustrative and does not represent the only way to combine the functions within a subsystem.

The original impetus for defining market packages is that some of the user services are too broad in scope to be convenient in planning actual deployments. In the National ITS Architecture, market packages are defined from the original user services by sets of equipment packages required to work together to deliver a given transportation service. In other words, most market packages contain equipment packages in two or more subsystems.

The National ITS Architecture identified 85 market packages. With the evolvement of technology, the number of market packages may change. Table 2.2 gives a complete listing of these 85 market packages. As with equipment packages, the specific set of market packages defined is merely illustrative and does not represent the only way to combine the functions and equipment in order to provide ITS services. Appendix A provides a detailed but not complete list of ITS market packages associated with ITS user services.

Table 2.2: ITS Market Packages Defined in the National ITS Architecture

Traffic Management	Network Surveillance Probe Surveillance Surface Street Control Freeway Control HOV Lane Management Traffic Information Dissemination Regional Traffic Control Traffic Incident Management System Traffic Forecast and Demand Management Electronic Toll Collection Emissions Monitoring and Management Virtual TMC and Smart Probe Data Standard Railroad Grade Crossing Advanced Railroad Grade Crossing Railroad Operations Coordination Parking Facility Management Regional Parking Management Reversible Lane Management Speed Monitoring Drawbridge Management Roadway Closure Management
Public Transportation	Transit Vehicle Tracking Transit Fixed-Route Operations Demand Response Transit Operations Transit Passenger and Fare Management Transit Security Transit Maintenance Multi-modal Coordination Transit Traveler Information

Traveler Information	Broadcast Traveler Information Interactive Traveler Information Autonomous Route Guidance Dynamic Route Guidance ISP Based Route Guidance Integrated Transportation Management/Route Guidance Yellow Pages and Reservation Dynamic Ridesharing In-Vehicle Signing
Advanced Safety Systems	Vehicle Safety Monitoring Driver Safety Monitoring Longitudinal Safety Warning Lateral Safety Warning Intersection Safety Warning Pre-Crash Restraint Deployment Driver Visibility Improvement Advanced Vehicle Longitudinal Control Advanced Vehicle Lateral Control Intersection Collision Avoidance Automated Highway System
Commercial Vehicle Operations	Fleet Administration Freight Administration Electronic Clearance CV Administrative Processes International Border Electronic Clearance Weigh-In-Motion Roadside CVO Safety On-Board CVO and Freight Safety and Security CVO Fleet Maintenance HAZMAT Management Roadside HAZMAT Security Detection and Mitigation CV Driver Security Authentication Freight Assignment Tracking
Emergency Management	Emergency Response Emergency Routing MAYDAY Support Roadway Service Patrols Transportation Infrastructure Protection Wide-Area Alert Early Warning System Disaster Response and Recovery Evacuation and Reentry Management Disaster Traveler Information
Archived Data Management	ITS Data Mart ITS Data Warehouse ITS Virtual Data Warehouse

Maintenance & Construction Operations	Maintenance & Construction Vehicle and Equipment Tracking Maintenance & Construction Vehicle Maintenance Road Weather Data Collection Weather Information Processing and Distribution Roadway Automated Treatment Winter Maintenance Roadway Maintenance and Construction Work Zone Management Work Zone Safety Monitoring Maintenance & Construction Activity Coordination

(Source: National ITS Architecture 5.0, USDOT 2003)

In summary, the National ITS Architecture defines the functions of physical entities or subsystems, where these functions reside, the interfaces and information flows between subsystems, and the communications requirements for the information flows in order to address the identified user service requirements. It is a common structure for the planning and design of ITS.

2.3 ITS DEPLOYMENT ANALYSIS SYSTEM (IDAS)

IDAS is a computer program developed by the FHWA to assist in planning for ITS deployment. Working with the output of existing transportation planning models, IDAS is capable of predicting costs and benefits for more than 60 types of ITS options. Within IDAS, the users can:

1. Compare and screen ITS deployment alternatives
2. Estimate the impacts and traveler responses to ITS
3. Develop inventories of ITS equipment needed for proposed deployments and identify cost sharing opportunities
4. Estimate life-cycle costs including capital and O&M costs for the public and private sectors
5. Provide documentation for transition into design and implementation.

IDAS is a sketch-planning tool for ITS impact analysis and benefit-cost analysis. The performance of selected ITS options can be viewed by mode, facility type, and district. The performance measures used by IDAS include:

1. Changes in user mobility
2. Changes in travel time/speed

3. Changes in travel time reliability (non-recurring congestion duration)
4. Changes in fuel costs
5. Changes in operating costs
6. Changes in accident costs
7. Changes in emissions and noise

Like many other programs, IDAS also has some limitations. For example, it uses static traffic assignment techniques instead of dynamic assignment. Therefore, it is not a state-of-art simulation program. Figures 2.4 and 2.5 give two snapshots of IDAS analysis interface.

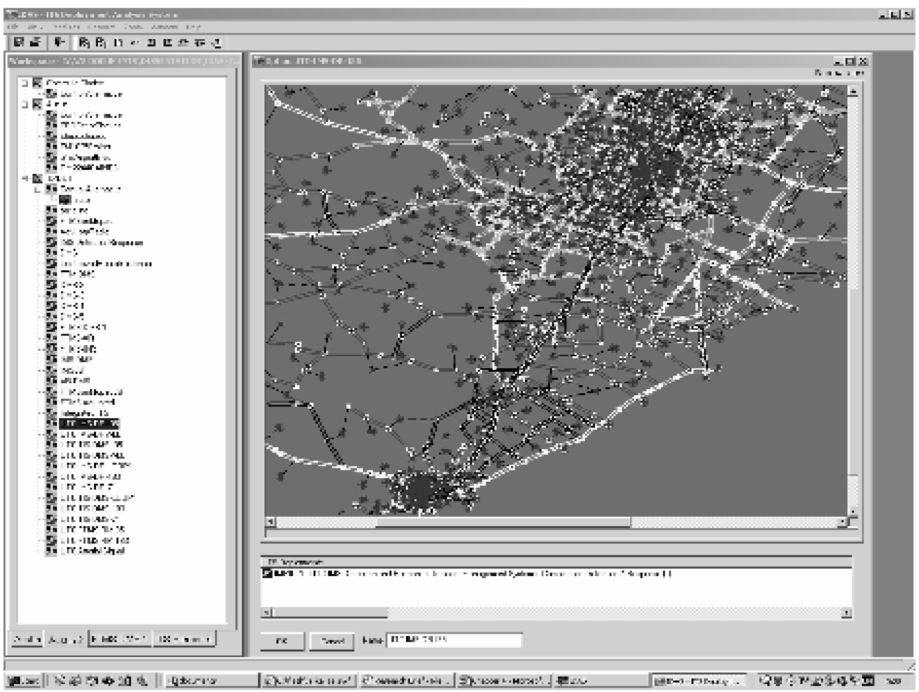

Figure 2.4: Evaluate ITS Options with IDAS

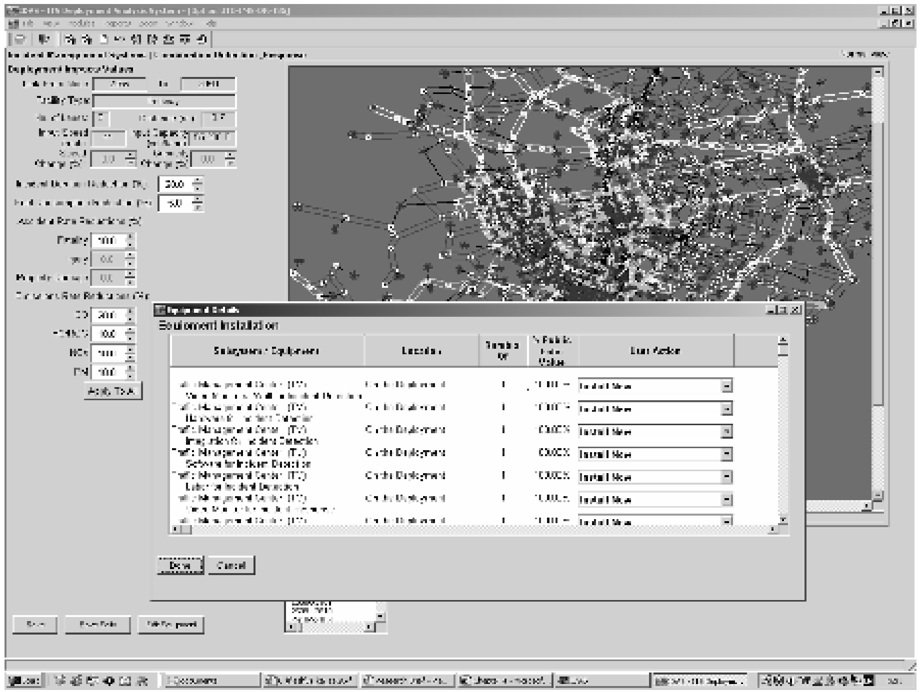

Figure 2.5: Edit Equipment of ITS Options in IDAS

2.4 PLANNING ITS STRATEGIES FOR LOCAL NEEDS

The FHWA ITS Planning Process is a very good reference for regional ITS strategic planning. However, it is essentially a conceptual framework. Practitioners have to find proper methods and relevant information to complete each task.

In the last decade, many field tests were conducted on ITS project benefit evaluation in the United States. The test results are very useful references for ITS planning. Meanwhile, to assist ITS development and planning, some analytical tools and computer software programs have either been released or are in the final stages of development. With these useful assisting tools and field test experiences, the FHWA ITS Planning Process becomes more applicable in practice.

Following the identification of the study area's stakeholders, development of project vision, and definition of goals, appropriate ITS market packages that can address the problems and meet the local needs need to be identified and developed. This will be done by tasks 4 and 5 in the FHWA ITS Planning Process. Appendix B shows the relationships between problems, conventional approaches, and ITS strategies. The available ITS market package screening tools include the field test experiences and the National ITS Architecture, which was initially designed by FHWA to identify and develop ITS market packages for local needs.

After the appropriate ITS market packages are identified for implementation, the cost effectiveness and the impact of the ITS project need to be analyzed. This task is not included in the FHWA ITS Planning Process. However, in practice, it is necessary to do it to help decision makers with budget decisions. Therefore, a pre-evaluation of the screened ITS market packages will be added in the case study.

Today there are several programs available for ITS impact evaluation. In this case study, IDAS is chosen for analysis because it is capable of showing users the benefit-cost analysis results of the specified ITS deployments.

With the evaluation of selected ITS market packages, the recommendations for implementation can be made to answer the questions of which ITS strategies are appropriate to address the local problems and which ITS components should be deployed to achieve the best cost-effectiveness results.

2.5 A CASE STUDY IN AUSTIN, TEXAS

The case study was performed in Austin, Texas. Figure 2.6 gives an overview of the city's transportation network and traffic V/C ratios on roads. The City of Austin has grown from a population of 465,000 in 1990 to over 650,000 people in 2000. Hays, Travis, and Williamson Counties' combined 2000 population of 1.16 million is projected to increase to over 1.4 million by 2010. The rapid growth of population results in a rapid increase of travel demand. Austin is now facing a big challenge of reducing the mobile source emissions without adversely reducing the mobility of the community.

The majority of Austin's ground level ozone is caused by gasoline powered engines. Although Austin is not considered a "nonattainment" area for pollution standards now, it has come close on numerous occasions. Since the ideas of congestion pricing, emission charges, and increased fuel tax are usually difficult to implement due to the complex political environment, it is necessary to explore other options that may result in potential air quality benefits. ITS technology is considered one of the candidates to address the dilemma. The objective in the case study is to find the appropriate ITS strategies to mitigate the emissions. Specifically, with the deployment of ITS, the following two goals are expected to be achieved:

1. Maintain or improve air quality in the Austin metropolitan area and make it consistent with requirements of the Clean Air Act Amendments of 1990
2. Reduce energy consumption and environmental cost

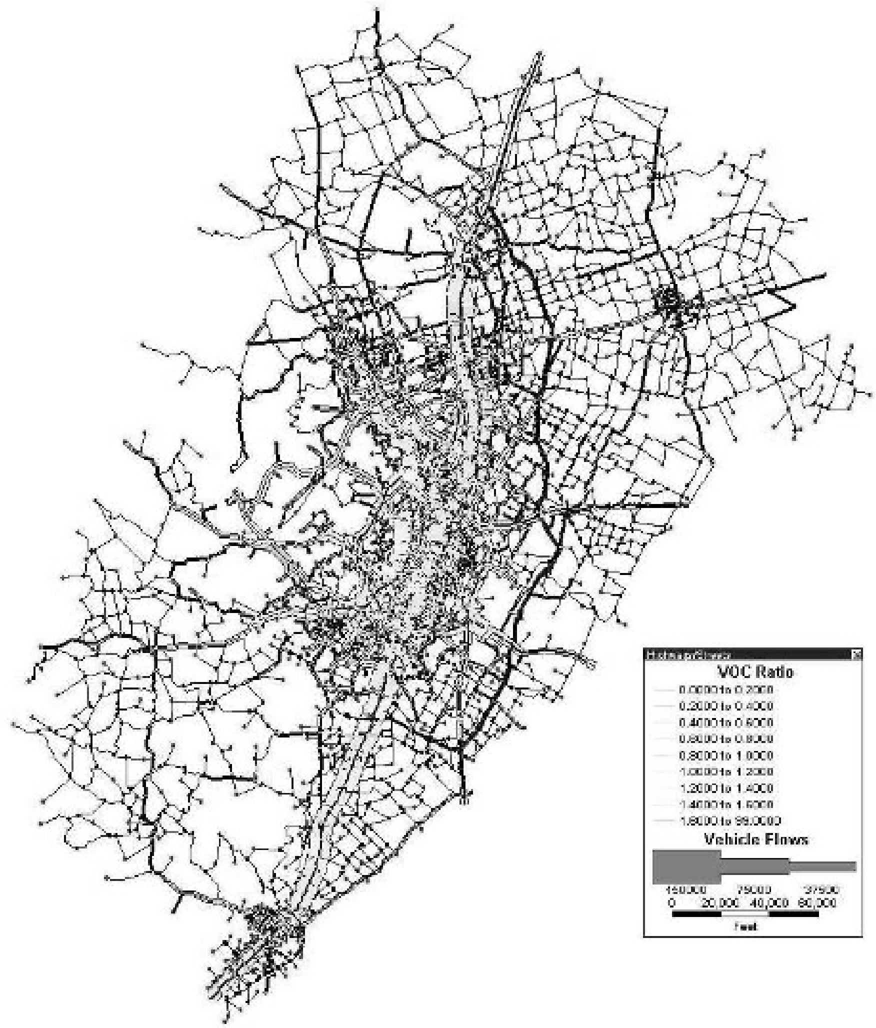

Figure 2.6: Austin’s Transportation Network and Traffic Flow
(Source: CAMPO Travel Demand Forecasting Model 2000)

According to the FHWA ITS Planning Process, after the area’s stakeholders, project vision and goals are identified, the tasks left can be summarized into three stages:

1. ITS market packages screening
2. ITS market packages evaluation
3. Implementation plan development

The case study will follow the FHWA ITS Planning Process and focus on these three stages.

2.4.1 ITS Market Packages Screening

ITS market packages represent various ITS improvement strategies that can be deployed as a unit to address current surface transportation problems; for example, the air quality. As described before, while market packages are defined from the perspective of equipment and technologies, ITS user services represent the ITS strategies from the perspective of customers/users. The identification of user services answers the question of what is to be achieved, and the identification of market packages answers how to achieve it. There is substantial flexibility in how a region may wish to refer to ITS strategies. For instance, some may prefer user services, some may prefer market packages, and others may simply refer to ITS strategies. No matter what terms are in use, it is important to use terms that are meaningful to the stakeholders involved in the local process. In this study, we use both “market packages” and “ITS strategies.”

It is important to define strategies in a way that benefits, costs, and impacts can be measured. Substantial information exists on nationwide ITS evaluations and field tests. The field tests report that ITS can bring significant benefits and support particular objectives. Table 2.3 shows a summary of the observed metropolitan ITS environmental benefits by program area.

To assist the ITS planners, the National ITS Architecture development joint team has developed qualitative judgments of the benefits that can be expected from each of the market packages. Appendix C summarizes the benefits of market packages for achieving certain ITS system goals. Considering the specific goals of this study, Table 2.4 shows a summary of the effectiveness of ITS market packages to reduce fuel consumption and negative environmental impacts.

By mapping the benefits of ITS market packages and the objective, which in this study is to mitigate emissions generated by traffic, the following ITS strategies can be easily identified in the National ITS Architecture:

1. ATMS04 — Freeway Control (moderate benefits)
2. ATMS07 — Regional Traffic Control (high benefits)
3. ATMS08 — Incident Management System (high benefits)
4. ATMS11 — Emissions and Environmental Hazard Sensing (high benefits)
5. ATIS1 — Broadcast Traveler Info (low benefits)

Table 2.3: Observed Metropolitan ITS Environmental Benefits by Program Area

METROPOLITAN BENEFITS BY PROGRAM AREA		
Program Area	**Benefits Measure**	**Summary**
Arterial Management Systems	Delay Savings	Adaptive signal control has reduced delay from 14% to 44%
	Environmental	Improvements to traffic signal control have reduced fuel consumption 2% to 13%
Freeway Management Systems	Delay Savings	11 to 93.1 vehicle hours reduced due to ramp metering I-494: Minneapolis; Ramp Metering has shown 8% to 60% increases in speed on freeways
	Environmental	N/A
Incident Management System	Delay Savings	Reductions range from 95 thousand to 2 million hours per year
	Environmental	TransGuide reduced fuel consumption up to 2600 gal/major incident
Transit Management Systems	Delay Savings	Reported improvements in on-time performance from 9% to 23% with CAD/AVL
	Environmental	N/A
Emergency Management Systems	Delay Savings	N/A
	Environmental	N/A
Electronic Toll Collection	Delay Savings	Carquinez Bridge, CA: person time savings of 79,919 hours (per year) or about $1.07 million
	Environmental	Florida: Reduced CO 7.3%, HC 7.2%, Increased NOx 34% with 40% ETC usage
Electronic Fare Payment	Delay Savings	N/A
	Environmental	N/A
Highway-Rail Intersections	Delay Savings	N/A
	Environmental	Automated horn warning system reduced noise impact area by 97%
Regional Multimodal Traveler Information	Delay Savings	San Antonio modeling results indicate a 5.4% reduction in delay for web site users
	Environmental	SmartTraveler Boston: estimated reductions NOx 1.5%, CO 33%

Table 2.4: Benefits of ITS Market Packages on Environment and Fuel Consumption

Market Packages		Effectiveness of Reducing Fuel Consumption and Environmental Costs
APTS	Transit Vehicle Tracking	*
	Fixed-Route Operations	*
	Demand Responsive Operations	*
ATIS	Broadcast Traveler Info	*
	Interactive traveler info	*
	Dynamic Route Guidance	*
	Integrated Transportation Management/Route Guidance	**
	Dynamic Ridesharing	*
ATMS	Network Surveillance	*
	Probe Surveillance	*
	Surface Street Control	**
	Freeway Control	**
	Regional Traffic Control	***
	HOV and Reversible Lane Management	*
	Incident Management System	***
	Traffic Information Dissemination	*
	Emissions and Environmental Hazard Sensing	***
	Virtual TMC and Smart Data	*
EM	Emergency Response	*
	Emergency Routing	*
ITS	ITS Planning	**

Key: * = low benefits, ** = moderate benefits, *** = high benefits

6. ATIS6 — Integrated Transportation Management/Route Guidance (moderate benefits)

Note: The labels above are inventory numbers of the ITS market packages defined in the National ITS Architecture.

2.4.2 ITS Market Packages Evaluation

While the ITS market packages targeting regional goals are identified, their benefits need to be examined. ITS market packages evaluation plays an important role in the overall ITS planning process. It is well known that the focus of the ITS planning is on making decisions. Various elements of the planning process will provide information to decision makers so that good decisions and wise investments can be made in the transportation system. One such element is the evaluation of the identified market packages. The evaluation task can be performed with an ITS evaluation tool—the IDAS program.

The IDAS program is capable of evaluating most of the six ITS market packages described above, except the market package of Emissions and Environmental Hazard Sensing. In IDAS, under each market package, an ITS option must be developed to represent it. The following ITS options are selected to represent the corresponding market packages:

1. Central Controlled Ramp Metering Systems — Freeway Control (ATMS04)
2. Central Controlled Corridor Traffic Signal Coordination System — Regional Traffic Control (ATMS07)
3. Incident Detection and Response Systems — Incident Management System (ATMS08)
4. Highway Advisory Radio — Broadcast Traveler Info (ATIS1)
5. Freeway Dynamic Message Signs — Integrated Transportation Management/Route Guidance (ATIS6)

These ITS options are tested within the IDAS program. Some freeways and arterials with heavy emissions are selected for experiments. The numerical results from IDAS are shown in Table 2.5.

Table 2.5: ITS Deployment Pre-evaluation Results from IDAS

ITS Deployment	Description	Environmental Benefits	Total Annual Benefits	Total Annual Costs	B/C Ratio
Incident Management System	IMS on IH35	2,030,195	3,912,355	1,510,538	2.59
	IMS on LOOP1	990,307	1,946,877	1,510,538	1.29
	IMS on US183	732,329	1,432,102	1,510,538	0.95
	IMS on US71	1,164,365	2,338,372	1,510,538	1.55
Freeway Dynamic Message Sign	DMS on IH35	N/A	31,528,354	2,369,269	13.31
	DMS on LOOP1	N/A	12,690,698	1,159,699	10.94
	DMS on US183	N/A	9,698,951	932,904	10.40
	DMS on US71	N/A	14,007,000	1,054,914	13.28
Broadcast Traveler Information Systems	Highway Advisory Radio in Austin Area	N/A	2,983,655	181,195	16.47
Regional Traffic Control Systems	Central Controlled Arterial Signal Coordination Systems on Lamar Blvd, 38th St., Guadalupe Blvd, 5th and 6th St.	1,377,407	11,844,446	1,012,582	11.70
Freeway Control System	Central Controlled Ramp Metering Systems on LOOP1	624,798	4,190,151	591,684	7.08
	Central Controlled Ramp Metering Systems on I35	−350,615	12,199,830	1,918,576	6.34
	Central Controlled Ramp Metering Systems on US183	356,138	9,672,360	1,289,912	7.50

According to the benefit-cost analysis results, most of the proposed ITS market packages yield positive net benefits, which makes the benefit-cost ratios greater than 1. Among the ITS market packages tested, the Incident Management Systems (incident detection and response option), the Freeway Control Systems (central controlled ramp metering systems option), and the Regional Traffic Control System (central controlled arterial signal coordination systems) show significant benefits on reducing emissions. However, the market packages of Integrated Transportation Management/Route Guidance System (freeway dynamic message sign option) and Broadcast Traveler Information Systems (highway advisory radio option) do not show benefits in emission reduction. This is because the benefits of these two market packages on environment, safety, and energy consumption are not counted directly in the IDAS program.

By comparing the benefit/cost ratios, it can be seen that the highway advisory radio option has the highest benefit/cost ratio, which is 16.47. It is the relatively low cost of this option that results in the high benefit/cost ratio. Field test experience has proven that the highway advisory radio is a low-cost ITS deployment that can bring significant user mobility and safety benefits to the community.

The benefit-cost ratios of the incident detection and response option vary from 0.95 to 2.59 on different freeway segments. The cost of this option is relatively high compared to other ITS options, which pulls the benefit-cost ratio down.

The central controlled arterial signal coordination system also shows a high benefit-cost ratio. Its environmental benefits are high because the signal coordination system helps to reduce the number of vehicle stops, therefore increasing average vehicle speed and reducing the delays, all of which contribute to emission reduction. This option could be a very good system for emissions reduction and traffic operation improvement if properly implemented.

The central controlled ramp metering option in freeway control systems yields both positive and negative impacts on emission reduction, depending on where it is deployed. The effectiveness of this option in addressing user mobility and environmental issues seems unclear according to the output of IDAS. Since the IDAS program does not have a submodule to optimize the ramp metering deployments, it may not be a proper tool for assessing the impacts of the ramp metering option. In practice, this option should be carefully assessed with other methods before deployment.

2.4.3 Recommendations for Implementation

Based on the evaluation results discussed above, some recommendations can be made. The following four market packages are highly recommended for implementation:

1. Traffic Management Center – although TMC is not evaluated in the case study, a TMC is necessary to integrate and manage all the ITS components.
2. Incident Management Systems – the recommendation is to deploy incident detection and response systems along the major corridors of IH-35, Loop 1, US 183, and US 290/71.
3. Regional Traffic Control – the recommendation is to deploy a signal coordination system along the major arterials in the central area of the city.
4. Environmental Hazard Sensing – the recommendation is to set up air quality monitoring stations and establish communication links between these stations and the traffic management center.

The following two market packages are recommended, but with lower priority than the four market packages described above:

5. Broadcast Traveler Information — it is recommended to set up the highway advisory radio station and broadcast the real-time traffic information to drivers in the whole metropolitan area.
6. Integrated Transportation Management/Route Guidance — the recommendation is to deploy central-controlled freeway dynamic message signs to deliver relevant real-time traffic information to drivers.

2.6 CONCLUSIONS

The overall objective of this study is to develop a procedure for using the FHWA ITS Planning Process to develop appropriate ITS strategies for local needs. A case study in Austin, Texas shows that by incorporating the National ITS Architecture and the evaluation program IDAS to the FHWA ITS Planning Process, the planning goal and good results can be achieved. Compared to solely using the National ITS Architecture to develop a regional ITS plan, this method provides more information to guide the implementation. That is, with the pre-evaluation and comparison of different ITS market packages, the ITS planners will have a better understanding of the outcomes from the ITS deployments. The case study also shows the ITS market packages that could help reduce mobile source emissions.

CHAPTER 3. A MULTICRITERIA APPROACH FOR ITS EVALUATION AND ALTERNATIVE SELECTION

The National Intelligent Transportation Systems (ITS) Architecture provides good guidance for ITS planning and deployment. However, due to limited funding availability, it is not feasible to deploy a complete ITS framework immediately. Thus, some applications should get higher priority according to the local needs. Identifying the best implementation plan among several alternatives becomes an issue in practice. This chapter presents a multicriteria approach to identify the best ITS alternative among several candidates. The ITS Deployment Analysis System (IDAS) is employed to assist the benefits evaluation of different ITS alternatives. An iterative ELECTRE-I procedure is then employed to compare these ITS alternatives and identify the best ITS alternative (Wang and Walton 2004b).

3.1 BACKGROUND

Due to limited funding availability, it is not always feasible to deploy a complete ITS framework immediately. Limited resources have to be invested on the applications with higher rewards according to the local needs. Based on the overall vision of ITS implementation, there should be a sense of priorities to guide the development of the ITS elements under financial constraint. Thus, the selection of the "best" ITS alternative becomes an important issue in practice. Typically, the factors need to be considered in developing the priorities include:

1. Urgency of needs for the project
2. Project effectiveness versus cost
3. Sequencing as related to other non-ITS projects
4. Types of funds available and their applicability to ITS

It can be seen that it is the local needs, cost, and the effectiveness of the project that determine the priorities of the ITS applications. When the ITS alternatives are evaluated, these factors should be considered as project measures. Transportation projects and programs, including ITS deployments, are usually evaluated in two ways in most metropolitan areas (USDOT 1998):

1. Through a top-down examination of alternatives
2. Through a bottom-up submission of projects and evaluation using a criteria-based analysis

Therefore, ITS plans can be developed through comparing a set of alternatives. The alternatives usually revolve around main objectives. On the other hand, ITS plans can be developed and evaluated based on the examination of individual projects against a set of criteria. In different situations, the criteria set could vary in type and number. Sometimes the evaluation criteria could be supported by data from the project studies. However, sometimes no specific data on the project may be available. When no data are available from existing studies, one possible way to obtain necessary information is through research studies or other generalized information on similar project types.

Over the past decade, the ITS planning process has become more and more complicated. The available technologies have been expanded and the goal of system integration has been emphasized. At the ITS deployment planning stage, there are two major concerns: the cost effectiveness of the project and the consideration of diverse economic, operational, environmental, safety, and social objectives.

The benefit-cost ratio is traditionally used as a criterion for decision-making. However, in many situations, the ITS planning is characterized by multiple objectives and multiple stakeholders. Here, the opportunity to introduce multicriteria decision analysis to compare ITS alternatives presents itself. Levine and Underwood (1996) addressed a multiattribute analysis of goals for ITS Planning. A multicriteria decision analysis approach was applied to evaluate stakeholder valuation of broad goals of ITS system planning. With a modified Analytical Hierarchy Process (AHP), the author derived preference weights for transportation planning goals and made inter-group and intra-group comparisons. Giuliano (1985) also investigated a multicriteria method for transportation investment planning. The author states that, since under some circumstances there are no optimal solutions, the outcome of the evaluation process should be the identification of a small set of alternatives which come closest to achieving the stated objectives. Concordance analysis is used to identify the best compromise alternative, which is defined as the alternative that is not dominated by others across a range of objective weights. Teng and Tzeng (1996) developed a multiobjective programming approach for comparing the alternatives that consists of non-independent transportation investments. The authors present a method utilizing a heuristic algorithm that attempts to maximize the objectives subject to resource constraints. One advantage of this method is that a near-optimal solution can be attained and the sensitivity analysis can be easily performed.

In general, these decision analysis methodologies share the common notion that decisions under multiple objectives are aided by specifying the quantified outcomes and the preference-based weight schemes (Goicoechea et al. 1982). Theoretically, these methodologies can be applied to decision making in ITS planning as well. However, there are some difficulties: the criteria to measure ITS impacts are very hard to scale because the data is unavailable at the stage of planning; on the other hand, some methods are too complicated to apply and may have poor performance.

In this chapter, the authors are trying to address these problems and propose an applicable multicriteria method for ITS projects comparison.

3.2 MULTICRITERIA APPROACH FOR ITS EVALUATION

The ITS alternatives comparison and selection problem can be considered as a multicriteria evaluation problem:

Knowing the impact matrix, a given set of alternatives {O1, O2, …, On} is evaluated with respect to a set of criteria {C1, C2, …., Cm}. However, in practice, the impact matrix of the ITS alternatives is always hard to construct before the ITS projects are laid out and are evaluated on site. To solve this problem and establish the impact matrix, a sketch-planning tool to evaluate the benefits and impacts of ITS applications is introduced in this study. The software package is called ITS Deployment Analysis System (IDAS). With the impact matrix constructed, the multicriteria evaluation problem can be easily solved by identifying the best subset of alternatives from a finite set of candidates. ELECTRE-I is a popular algorithm for the multicriteria evaluation problems. In this study, a modified ELECTRE-I analysis procedure is introduced, in which the ELECTRE-I procedure is used in an iterative way to identify the best compromise solution. This procedure is very similar to the method presented by Giuliano (1985), but the graph theory employed in this paper makes the whole procedure easily understood.

The ELECTRE-I procedure is a technique with which alternatives are evaluated by a series of pair-wise comparisons across the criteria set. It has been developed and used widely in engineering evaluation, and it is especially applicable for problems with a finite number of alternatives. The ELECTRE-I procedure works on the alternative impact matrix, which contains a vector of scores for each alternative on each of the chosen criteria. Two indices, the concord index and the discord index, are calculated in ELECTRE-I. The formulation has been well documented by Goicoechea et al. (1982) as follows:

The concord index represents the degree to which one solution plan is preferred to another with a given weight scheme on the criteria. Let I = {1, 2, …m} represent the criteria set and let {wk: k = 1, 2, …m} represent the weight set associated with the m criteria. Then divide the set I into three subsets:

$$I^+ = I^+(i, j) = \{k \in I: i > j\}$$
$$I^= = I^=(i, j) = \{k \in I: i = j\}$$
$$I^- = I^-(i, j) = \{k \in I: i < j\}$$

Define

$$W^+ = \sum_{k \in I^+} w_k$$
$$W^= = \sum_{k \in I^=} w_k$$
$$W^- = \sum_{k \in I^-} w_k$$

The concord index is computed as

$$c(i, j) = (W^+ + \frac{1}{2}W^=)/(W^+ + W^= + W^-)$$

The discord index represents the degree to which one alternative is dominated by another. It is computed as

$$d(i, j) = \frac{\text{maximum interval where } i < j}{\text{total range of scale}}$$

In the ELECTRE-I procedure, the outranking relation R is defined with a concordance condition and a discordance condition. Then the outranking relation R is used to construct a composite graph G_c. That is, alternative i is preferred to alternative j (i.e., an arc (i,j) will appear in the composite graph) if and only if

$$c(i, j) \geq p \text{ and } d(i, j) \leq q$$

After the outranking relation is defined and the composite graph is constructed, the kernel of the graph, which contains the nodes representing those preferred solutions, can be determined. The remaining nodes that are not in the kernel will be eliminated from further consideration.

Assigning weights to the criteria is a critical part of the multicriteria evaluation problem. A weight is assigned to each criterion to represent that criterion's relative importance. However, when different decision-makers have emphasis on different objectives/criteria, it is possible that the preferences expressed by them are conflicting. That is, when an alternative is evaluated with a different emphasis, the weights need to be adjusted. One set of weights may not represent decision makers' various points of view or emphasis. In this situation, a set of representative weight schemes is more useful if each weight scheme represents a different point of view or emphasis. The subset of the best alternatives is identified by systematically altering the objective weights in the iterative ELECTRE-I procedure. The alternative(s) remaining in the non-dominated set when the weights are varied will be defined as the best compromise solution(s). However, that alternative is not guaranteed to be the best solution under each weight scheme, which means that it may not be the top-ranking alternative under each weight scheme, although it fulfills the threshold requirements of the iterative ELECTRE-I procedure (Giuliano 1985).

Figure 3.1 is a flowchart of the ITS projects evaluation and alternative selection problem proposed in this paper. The basic idea is to establish the impact matrix according to the evaluation results from IDAS, and then using the iterative ELECTRE-I procedure, to identify the best compromise solution(s) which remains in all non-dominated sets under different weight schemes.

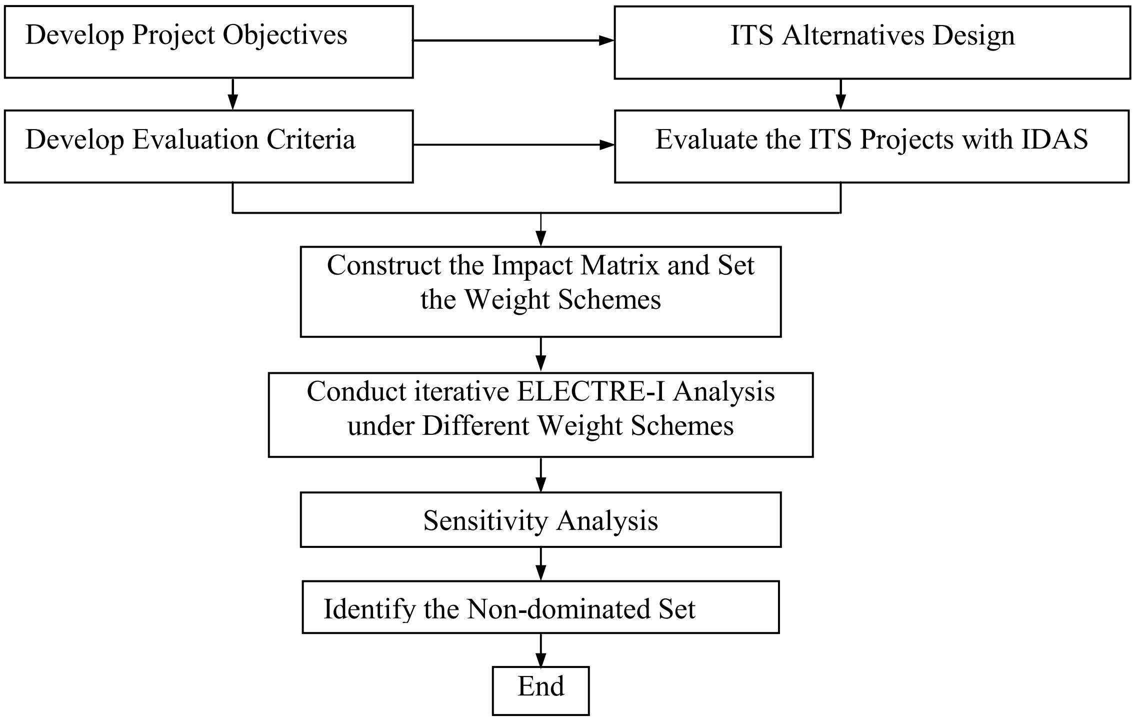

Figure 3.1: ITS Alternatives Evaluation and Decision Making Process

3.3 A CASE STUDY IN AUSTIN, TEXAS

A case study was performed to test the method proposed in this paper. Loop 1 (Mopac) in Austin, Texas was selected as the freeway that would be improved with ITS deployments. Austin lies in Travis County. Loop 1 is a main corridor for the traffic heading south and north in west Austin. Because of the rapid growth of economy and population in Austin and the resulting travel demand increase, the congestion levels on this corridor become higher and higher during the peak hours. Six ITS alternatives are proposed to be deployed on the segment from Far West Road to FM 2244, in both directions.

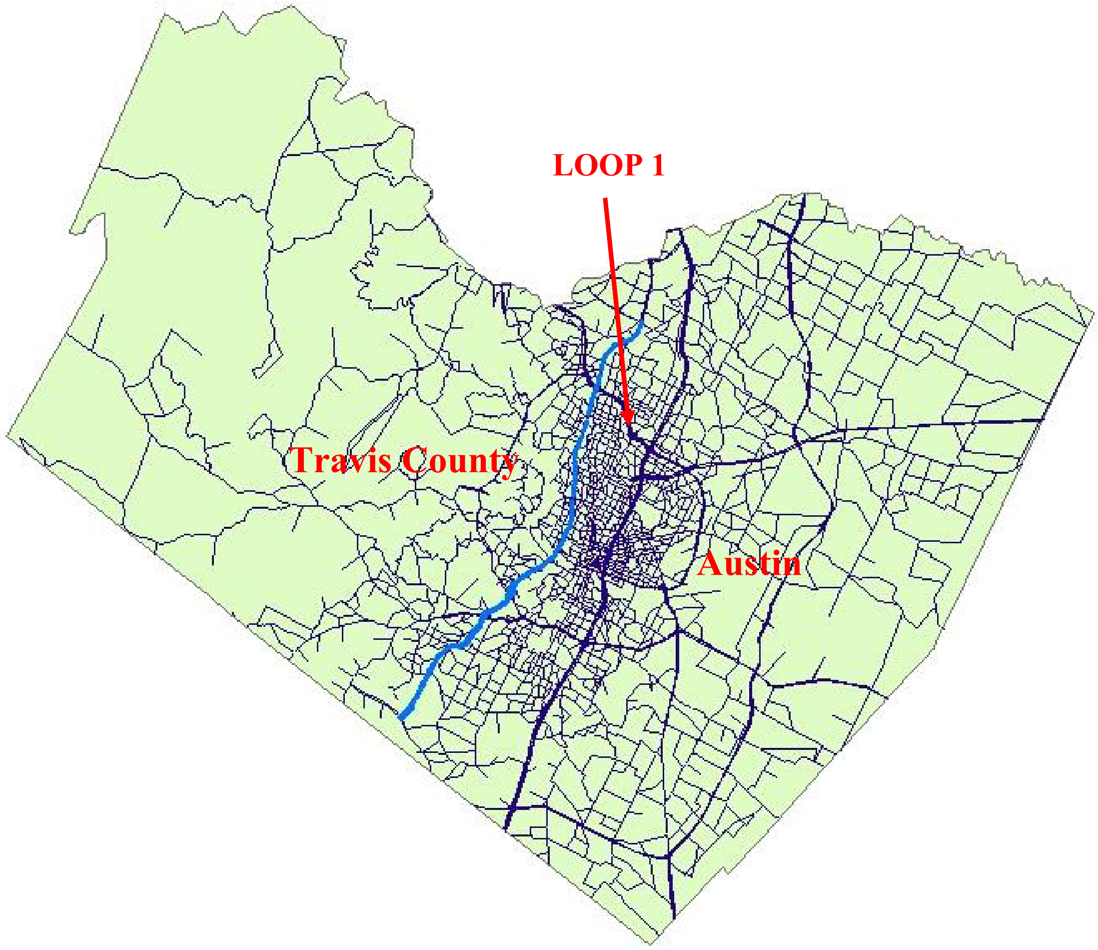

Figure 3.2: An Overview of LOOP 1 in Austin, TX

3.3.1 ITS Alternatives

The first step in the decision analysis is to define the alternatives to be ranked. In this study, the iterative ELECTRE-I procedure is applied on the evaluation of six ITS alternatives described in Table 3.1. These alternatives consist of various improvements designed to provide a balanced transportation system for the Austin area. They are defined based on the goals of ITS implementation in the Austin area and the functions of the ITS market packages defined in the National ITS architecture.

Table 3.1: The Loop 1 (Mopac) Study ITS Alternatives

ITS Alternative	Description
1. FTMS*	Freeway Traffic Management System
2. FTMS / IMS** integration	Freeway Traffic Management System + Incident Management System
3. FTMS/ATIS*** integration	Freeway Traffic Management System + Advanced Traveler Information System
4.FTMS/ATIS/IMS integration	Freeway Traffic Management System + Advanced Traveler Information System + Incident Management System
5. FTMS/HOV Lane integration	Freeway Traffic Management System + Exclusive lane for bus and HOV
6. ATIS/HOV Lane Integration	Advanced Traveler Information System + Exclusive lane for bus and HOV

*: The FTMS option includes ramp metering on all entrance ramps to Loop 1

**: The IMS option includes incident detection and response system

***: The ATIS option includes dynamic message signs and highway advisory radio

3.3.2 Goals and Evaluation Criteria

Project goals enable decision makers to define the concerns important for ITS implementation. As mentioned before, the typical goals of ITS projects include:

1. Increase operational efficiency and capacity of the transportation system
2. Enhance personal mobility, convenience, and comfort of the transportation system
3. Improve the safety of the nation's transportation system
4. Reduce energy consumption and environmental costs
5. Enhance the present and future economic productivity of individuals, organizations, and the economy as a whole
6. Create an environment in which the development of ITS can flourish

Considering the goals of ITS deployments, the evaluation criteria can be developed accordingly. As suggested by the ITS Joint Program Office (ITS JPO) in the FHWA, there are six measures important for ITS evaluation. These are: mobility, safety, efficiency, productivity, energy and environment, and consumer satisfaction. With the consideration of typical ITS evaluation measures (Brand 1998) and the functional capabilities of the software IDAS, a list of objectives and corresponding criteria are presented in Table 3.2.

Table 3.2: Objectives and Measures Used to Evaluate ITS Alternatives

Objective	**Criterion**
Maximize Reduction in User's Mobility	Reduction of the total VMT
Minimize Total Travel Delay	Reduction of total delay
Maximize Safety Improvement	Accident rate reduction.
Maximize Environment Improvement	Emissions reduction
Minimize Cost	Installment cost and operating cost

3.3.3 Impact Matrix

Once we have the ITS project alternatives and the criteria for evaluation, the impact matrix of ITS alternatives can be constructed. In this study, the impact matrix is established based on the evaluation results of IDAS. As mentioned before, IDAS is a sketch planning analysis tool for predicting the impacts of ITS improvements. It is designed to "assist public agencies and consultants in integrating ITS in the transportation planning process" by estimating potential impacts, benefits, and costs of different ITS improvements (Jeannotte 2000). IDAS uses the travel demand models that are used by the Metropolitan Planning Organization (MPO) and the State Department of Transportation.

The data required by IDAS are obtained from the Capital Area Metropolitan Planning Agency (CAMPO) in Austin, Texas. Node coordinates, network links, and origin-destination matrices were exported from CAMPO data. Once all these data files are imported into IDAS, it is ready to create different ITS alternatives for analysis. (One thing that needs to be mentioned is that IDAS is not able to predict the benefits of the HOV option directly and users have to do the HOV benefits analysis separately.) The impact matrix is constructed by getting the scores for each criterion for each of the six alternatives. The alternative impact matrix is presented in Table 3.3.

Table 3.3: Original Alternative Impact Matrix*

Criterion	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
Reduction in User's Mobility (VMT)	3,152,648	3,152,648	2,389,645	2,389,645	4,483,182	4,068,255
Reduction of Travel Delay (hrs.)	142,494	184,765	228,347	292,895	397,588	336,728
Safety Improvement (%)	14.7	25.8	16.8	27.6	18.3	17.5
Emission Reductions (%)	2.16	2.97	3.12	3.36	4.3	-4.0
Annual Cost ($)	409,748	1,455,811	588,658	1,643,721	683,402	340,756

*: The numbers in this impacts matrix are annual values.

3.3.4 The Iterative ELECTRE-I Procedure

In this study, we proposed an iterative ELECTRE-I procedure to identify the best ITS alternatives consisting of the following steps:

1. Choose the different weight schemes
2. Calculate the concord index and the discord index for each alternative
3. Identify the non-dominated subset and best compromise alternative
4. Sensitivity analysis

3.3.4.1 Weight Schemes. Six different weight schemes are selected for the ELECTRE-I analysis in this study. The first weight scheme weighs the criteria equally over the five impact areas. The other five schemes each represent an emphasis on one of the criteria. For example, weight scheme II emphasizes the impact of each ITS alternative on increasing mobility and weight scheme III emphasizes each ITS alternative's effectiveness of reducing delay. With different weight schemes on the criteria set, and by avoiding the extreme weights, the best solution identified by the ELECTRE-I procedure is more likely to be close to the theoretical optimal solution. The detailed weight schemes are shown in Table 3.4.

Table 3.4: Weight Schemes for ELECTRE-I Analysis

	Mobility	**Delay**	**Safety**	**Emission**	**Cost**
Scheme I (Equal Weights)	0.2	0.2	0.2	0.2	0.2
Scheme II (Emphasis on Mobility)	0.3	0.175	0.175	0.175	0.175
Scheme III (Emphasis on Delay)	0.175	0.3	0.175	0.175	0.175
Scheme IV (Emphasis on Safety)	0.175	0.175	0.3	0.175	0.175
Scheme V (Emphasis on Environment)	0.175	0.175	0.175	0.3	0.175
Scheme VI (Emphasis on Cost)	0.175	0.175	0.175	0.175	0.3

3.3.4.2 Concord Index and Discord Index. The concord index and discord index are calculated for each of the six selected weight schemes. The results are shown below:

Concord Matrix:

Weight Scheme I:

$$C_I = \begin{vmatrix} & 0.325 & 0.475 & 0.475 & 0.175 & 0.000 \\ 0.675 & & 0.475 & 0.475 & 0.175 & 0.175 \\ 0.525 & 0.525 & & 0.325 & 0.175 & 0.000 \\ 0.525 & 0.525 & 0.675 & & 0.175 & 0.175 \\ 0.825 & 0.825 & 0.825 & 0.825 & & 0.825 \\ 1.000 & 1.000 & 1.000 & 0.825 & 0.175 & \end{vmatrix}$$

Weight Scheme II:

$$C_{II} = \begin{vmatrix} & 0.325 & 0.475 & 0.475 & 0.175 & 0.000 \\ 0.675 & & 0.475 & 0.475 & 0.175 & 0.175 \\ 0.525 & 0.525 & & 0.325 & 0.175 & 0.000 \\ 0.525 & 0.525 & 0.675 & & 0.175 & 0.175 \\ 0.825 & 0.825 & 0.825 & 0.825 & & 0.825 \\ 1.000 & 1.000 & 1.000 & 0.825 & 0.175 & \end{vmatrix}$$

Weight Scheme III:

$$C_{III} = \begin{vmatrix} & 0.263 & 0.350 & 0.350 & 0.175 & 0.000 \\ 0.738 & & 0.350 & 0.350 & 0.175 & 0.175 \\ 0.650 & 0.650 & & 0.263 & 0.175 & 0.000 \\ 0.650 & 0.650 & 0.738 & & 0.175 & 0.175 \\ 0.825 & 0.825 & 0.825 & 0.825 & & 0.825 \\ 1.000 & 1.000 & 1.000 & 0.825 & 0.175 & \end{vmatrix}$$

Weight Scheme IV:

$$C_{IV} = \begin{vmatrix} & 0.263 & 0.350 & 0.350 & 0.175 & 0.000 \\ 0.738 & & 0.350 & 0.350 & 0.300 & 0.300 \\ 0.650 & 0.650 & & 0.263 & 0.175 & 0.000 \\ 0.650 & 0.650 & 0.738 & & 0.300 & 0.300 \\ 0.825 & 0.825 & 0.825 & 0.700 & & 0.825 \\ 1.000 & 1.000 & 1.000 & 0.700 & 0.175 & \end{vmatrix}$$

Weight Scheme V:

$$C_V = \begin{vmatrix} & 0.263 & 0.350 & 0.350 & 0.175 & 0.000 \\ 0.738 & & 0.350 & 0.350 & 0.175 & 0.175 \\ 0.650 & 0.650 & & 0.263 & 0.175 & 0.000 \\ 0.650 & 0.650 & 0.738 & & 0.175 & 0.175 \\ 0.825 & 0.825 & 0.825 & 0.825 & & 0.825 \\ 1.000 & 1.000 & 1.000 & 0.825 & 0.175 & \end{vmatrix}$$

Weight Scheme VI:

C_{VI} =

	0.388	0.475	0.475	0.300	0.000
0.613		0.475	0.475	0.175	0.175
0.525	0.525		0.388	0.300	0.000
0.525	0.525	0.613		0.175	0.175
0.700	0.700	0.700	0.825		0.700
1.000	1.000	1.000	0.825	0.300	

Discord Matrix:

D =

	0.86	0.45	0.59	0.64	0.87
0.85		0.7	0.42	0.83	0.9
1	0.7		0.83	1	0.8
0.95	0.36	0.85		1	1
0.22	0.58	0.07	0.57		0.26
0	0.49	0	0.63	0.24	

3.3.4.3 Non-Dominated Set. Define a minimum concordance condition of p = 0.70 and a maximum discordance condition of q = 0.30; that is c(i, j) ≥ 0.70 and d(i, j) ≤ 0.30. With this specification, the graph G_c can now be constructed. The directed paths which appear in the graph are determined by the set of indices that simultaneously satisfy the requirement that c(i, j) ≥ 0.70 and d(i, j) ≤ 0.30.

Under weight scheme I, the indices are: (5, 1), (5, 3), (6, 1), (6, 3), and (5, 6). The resulting graph is depicted below in Figure 3.2. The kernel of this graph is easily determined to be {2, 4, 5}.

Under weight scheme II, the indices that satisfy the requirements are (5, 1), (5, 3), (6, 1), (6, 3), and(5, 6), which is the same as that in weight scheme I. The same results are also obtained in weight scheme III, IV, V, and VI. Therefore, when p = 0.7 and q = 0.3, the non-dominated subset contains nodes {2, 4, 5}.

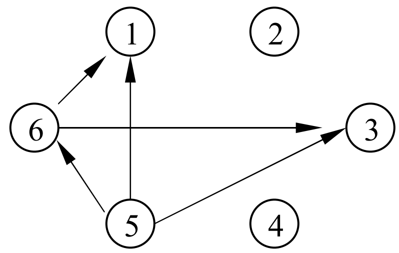

Figure 3.3: Identify the Best ITS Alternative (p = 0.7, q = 0.3)
Kernel = {2, 4, 5}

3.3.4.4 Sensitivity Analysis. To determine how sensitive the above solution is to the values of p and q, a sensitivity analysis is performed. The increase of discordance requirement (holding p constant) changes the solution when q = 0.58. When q = 0.58, an outranking relationship develops between nodes 5 and 2, nodes 5 and 4, and between nodes 6 and 2. As seen in the graph in Figure 3.3, nodes 1, 2, 3, 4, and 6 will be eliminated from the graph. The choice set now consists of only one node: node 5. So alternative 5 is identified as the best compromise solution to this problem.

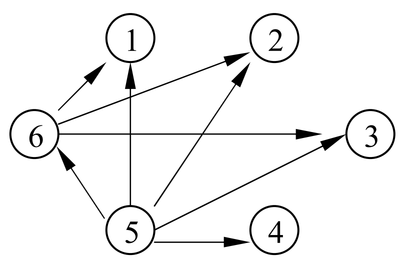

Figure 3.4: Identify the Best ITS Alternative (p = 0.7, q = 0.58)
Kernel = {5}

Other changes in concordance and discordance conditions do not yield significant difference in the results. From the above sensitivity analysis, it is noticed that, under every proposed weight scheme, alternative 5 is always the alternative in the non-dominated set. Therefore, it can be concluded that alternative 5 is the best choice. It is the solution closest to the "ideal point" in the non-dominated subset according to the iterative ELECTRE-I procedure with six different weight schemes.

3.4 CONCLUSIONS

In this study, the impact matrix of ITS alternatives is constructed based on the estimation results of IDAS. Then, an iterative ELECTRE-I analysis is employed to identify the best compromise solution(s). The ELECTRE-I method identifies a non-dominated set of alternatives for a given weight scheme. By varying the weight schemes to emphasize different criteria, the alternatives remaining in the non-dominated set are identified as the best alternatives. In the case study performed in Austin, Texas, only one non-dominated alternative is obtained, which is the alternative of FTMS/HOV lane integration. In practice, the multicriteria approach proposed in this study will help the ITS planners and decision makers select the best ITS alternatives with respect to certain objectives. The major limitation of this method is that the accuracy of the evaluation results has significant impact on the results of ELECTRE-I analysis. This problem can be avoided by choosing high-performance evaluation tools.

CHAPTER 4. CONCLUSIONS

The overall objective of this study is to assist transportation agencies in developing appropriate ITS strategies based on local needs. Through a one-year effort, this study intended to answer the following specific questions:

1. What should be the procedure for developing appropriate ITS strategies to meet local needs?
2. Given the defined problems and goals and constraints, how can decision makers identify the best ITS strategies?
3. When ITS applications are planned, what actions can be taken to provide the greatest likelihood of success?

As a final product, this report summarizes the effort in developing innovative methods for ITS planning and ITS evaluation. There are two major parts in this report:

First, in Chapter 2, the authors present a study of using FHWA ITS Planning Process Version 2.1 to develop appropriate ITS strategies to accommodate local needs. The National ITS Architecture is employed to screen the appropriate ITS strategies. The IDAS program is then employed to evaluate those strategies. Following the FHWA ITS planning framework, appropriate ITS strategies for regional goals are identified and evaluated. A case study was performed in Austin, Texas to illustrate the whole procedure. The results indicate that by incorporating the National ITS Architecture and IDAS, the FHWA ITS Planning Process is more applicable to regional ITS planning. The proposed procedure would be valuable for decision-making on ITS investments and deployments.

Next, in Chapter 3, a multicriteria decision analysis method is presented for ITS alternative comparison and selection. The multicriteria approach developed in this study can be applied to identify the best ITS alternative among several candidates. The ITS Deployment Analysis System (IDAS) is employed to assist the benefits evaluation of different ITS alternatives. An iterative ELECTRE-I procedure is then employed to compare these ITS alternatives and identify the best one. With a case study in Austin, TX, the approach was illustrated and its value was proven.

However, like many research efforts, this study also has some limitations. Further research activities are recommended in the following areas:

1. With many documents, tools, and computer programs available, an integrated framework to take full advantage of these resources should be developed for ITS planning. This framework should be "implementable" for regional ITS planning at both the strategic level and the implementation level.
2. The evaluation of ITS applications is still an issue in practice although it has been significantly improved over the past decade. Since the planning of ITS is usually financially constrained planning, the quality of ITS evaluation needs to be improved as much as possible.
3. The multicriteria decision analysis can be applied for ITS alternative comparison. The results from this study are very positive. However, due to the limits of the evaluation tool, the measures used in this study are mostly quantitative. The qualitative measures should be included in further research. Potential difficulties exist in the data support for the qualitative measures.

REFERENCES

Brand, D, 1998. Criteria and Methods for Evaluating Intelligent Transportation System Plans and Operational Tests. Transpn. Res. Rec. 1453, National Research Council, Washington D.C.

Giuliano, G., 1985. A Multicriteria Method for Transportation Investment Planning. Transpn. Res.-A 19, pp.29-41.

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

Iteris website 2004. An Introduction of the National ITS Architecture. http://itsarch.iteris.com/itsarch/

ITS America and USDOT, 2002. National Intelligent Transportation Systems Program Plan: A Ten-Year Vision.

ITS America website, 2005: www.itsa.org

Jeannotte, K., 2000. Estimating Potential ITS Benefits and Costs Using IDAS. Prepared for ITE District 6 Annual Meeting—June 2000.

Khattak, A. and Kanafani, A., 1996. Case-Based Reasoning: A Planning Tool for Intelligent Transportation Systems. Transportation Research-C, Vol. 4, No.5, pp.267-287.

Levine, J. and Underwood, S. E., 1996. A Multiattribute Analysis of Goals for Intelligent Transportation System Planning. Transportation Research-C, Vol. 4, No.2, pp.97-111.

Lockheed Martin Federal Systems, Odetics Intelligent Transportation Systems Division, 1996. ITS Performance and Benefit Study. Report prepared for FHWA, USDOT, Washington, D.C.

McGurrin, M. F. and Shank, D. E., 1997. ITS Versus New Roads: A Study of Cost-Effectiveness. ITS World, July/August 1997.

Mitretek Systems Inc, 2001. Intelligent Transportation Systems Benefits: 2001 Update. Federal Highway Administration, U.S. DOT, Washington D.C.

Smith, B., Taylor, R., Pindur, W., and Yacus, G., 1995. Evaluation of the ITS Planning Process. Federal Highway Administration Project No. IVH-9351 (602). Virginia Transportation Research Council, Charlottesville, Virginia.

Stockton, W., Walton, C. M., Turner, S., James, S., and Rother, T., 1998. ITS Benefits: Review of Evaluation Methods and Reported Benefits. Texas Transportation Institute/Center for Transportation Research, Report Number: FHWA/TX-99/1790-1, Texas.

Teng, J. Y. and Tzeng, G. H., 1996. A Multiobjective Programming Approach for Selecting Non-Independent Transportation Investment Alternatives. Transpn. Res.-B, Vol.30, No.4, pp.291-307.

U.S. Department of Transportation, 1997. ITS Benefits: Continuing Successes and Operational Test Results. Federal Highway Administration, Washington, D.C.

U.S. Department of Transportation, 1998. Integrating Intelligent Transportation System within the Transportation Planning Process: An Interim Handbook. Report FHWA-SA-98-048.

U.S. Department of Transportation, 2003. National ITS Architecture version 5.0.

Wang, Z. and C.M. Walton, 2004a. A Case Study of Using the FHWA ITS Planning Process to Develop Appropriate ITS Strategies to Meet Local Needs. Proceedings of the 11th ITS World Congress, Nagoya, Japan 2004.

Wang, Z. and C.M. Walton, 2004b. A Multicriteria Approach for Evaluation and Alternative Selection of ITS Deployments. Proceedings of the 11th ITS World Congress, Nagoya, Japan 2004.

APPENDIX

Appendix A: The Relationships between Market Packages and User Services

(Source: National ITS Architecture 5.0, USDOT 2003)

Group	Market Packages	1.1 - Pre - Trip Travel Information	1.2 - En - Route Driver Information	1.3 - Route Guidance	1.4 - Ride Matching And Reservation	1.5 - Traveler Services Information	1.6 - Traffic Control	1.7 - Incident Management	1.8 - Travel Demand Management	1.9 - Emissions Testing And Mitigation	1.10 Highway-Rail Intersection	2.1 - Public Transportation Management	2.2 - En - Route Transit Information	2.3 - Personalized Public Transit	2.4 - Public Travel Security	3.1 - Electronic Payment Services	4.1 - Commercial Vehicle Electronic Clearance	4.2 - Automated Roadside Safety Inspection	4.3 - On - Board Safety Monitoring	4.4 - Commercial Vehicle Administrative Process	4.5 - Hazardous Material Incident Response	4.6 - Commercial Fleet Management	5.1 - Emergency Notification And Personal Security	5.2 - Emergency Vehicle Management	6.1 - Longitudinal Collision Avoidance	6.2 - Lateral Collision Avoidance	6.3 - Intersection Collision Avoidance	6.4 - Vision Enhancement For Crash Avoidance	6.5 - Safety Readiness	6.6 - Pre - Crash Restraint Deployment	6.7 - Automated Vehicle Operation
ATMS	Network Surveillance						✓																								
	Probe Surveillance						✓																								
	Surface Street Control						✓	✓																							
	Freeway Control						✓	✓	✓																						
	HOV and Reversible Lane Management						✓		✓																						
	Traffic Information Dissemination						✓				✓																				
	Regional Traffic Control						✓																								
	Incident Management System							✓																							
	Traffic Network Performance Evaluation						✓		✓																						
	Dynamic Toll/Parking Fee Management								✓							✓															
	Emissions and Environmental Hazards Sensing									✓																					
	Virtual TMC and Smart Probe Data		✓				✓	✓																							
	Standard Railroad Grade Crossing										✓																				
	Advanced Railroad Grade Crossing										✓																				
	Railroad Operations Coordination										✓																				
APTS	Transit Vehicle Tracking											✓	✓	✓	✓																
	Transit Fixed-Route Operations											✓	✓																		
	Demand Response Transit Operations											✓	✓	✓																	
	Transit Passenger and Fare Management												✓			✓															
	Transit Security											✓			✓																
	Transit Maintenance											✓																			
	Multi-modal Coordination						✓		✓			✓																			
ATIS	Broadcast Traveler Information	✓	✓										✓																		
	Interactive Traveler Information	✓	✓										✓	✓		✓															
	Autonomous Route Guidance		✓	✓																											
	Dynamic Route Guidance		✓	✓																											
	ISP Based Route Guidance	✓	✓	✓												✓															
	Integrated Transportation Mgmt/Route Guidance		✓	✓												✓															
	Yellow Pages and Reservation	✓	✓			✓										✓															
	Dynamic Ridesharing	✓	✓		✓								✓	✓		✓															
	In Vehicle Signing		✓				✓				✓																				
AVSS	Vehicle Safety Monitoring																												✓	✓	
	Driver Safety Monitoring																												✓		
	Longitudinal Safety Warning																								✓				✓		
	Lateral Safety Warning																									✓			✓		
	Intersection Safety Warning										✓																✓		✓		
	Pre-Crash Restraint Deployment																												✓	✓	
	Driver Visibility Improvement																											✓			
	Advanced Vehicle Longitudinal Control																								✓						
	Advanced Vehicle Lateral Control																									✓					
	Intersection Collision Avoidance										✓																✓				
	Automated Highway System																														✓
CVO	Fleet Administration																					✓									
	Freight Administration																				✓										
	Electronic Clearance																✓			✓											
	CV Administrative Processes																✓			✓											
	International Border Electronic Clearance																✓			✓											
	Weigh-In-Motion																✓														
	Roadside CVO Safety																	✓													
	On-board CVO Safety																		✓												
	CVO Fleet Maintenance																		✓			✓									
	HAZMAT Managment							✓													✓	✓									
EM	Emergency Response																							✓							
	Emergency Routing																							✓							
	Mayday Support																						✓	✓							
	ITS Planning											✓																			

Appendix B: Relationships between Problems, Conventional Approaches and ITS Approaches

(Source: National ITS Architecture Implementation Strategy , USDOT 2003)

Problem	Possible Solutions	Conventional Approach	ITS Approach	Supporting Market Packages
Traffic Congestion	Increase roadway capacity (vehicular throughput)	▪ New roads ▪ New lanes	▪ Advanced traffic control ▪ Incident management ▪ Electronic toll collection ▪ Corridor management ▪ Advanced vehicle systems (Reduce headway)	▪ Surface street control ▪ Freeway control ▪ Incident management system ▪ Dynamic toll/parking fee management ▪ Regional traffic control ▪ Railroad operational coordination ▪ Advanced vehicle longitudinal control ▪ Automated highway system
	Increase passenger throughput	▪ HOV lanes ▪ Car pooling ▪ Fixed route transit	▪ Real-time ride matching ▪ Integrate transit and feeder services ▪ Flexible mode transit ▪ Personalize public transit	▪ Dynamic ridesharing ▪ Multi-modal coordination ▪ Demand response transit operations
	Reduce demand	▪ Flex time programs	▪ Telecommuting ▪ Other telesubstitutions ▪ Transportation pricing	▪ Dynamic toll/parking fee management
Lack of Mobility and Accessibility	Provide user friendly access to quality transportation services	▪ Expand fixed-route transit and paratransit service ▪ Radio and TV traffic reports	▪ Multi-modal pre-trip and en-route traveler information ▪ services ▪ Respond dynamically to changing demand ▪ Personalized public transportation ▪ Common, enhanced fare card	▪ Interactive traveler information ▪ Demand response transit operations ▪ Transit passenger and fare management
Disconnected Transportation Mode	Improve intermodality	▪ Inter-agency agreements	▪ Regional transportation management systems ▪ Regional transportation information clearinghouse ▪ Disseminate multi-mode information pre-trip and en-route	▪ Regional traffic control ▪ Multimodal coordination ▪ Interactive traveler information
Severe Budget Constraints	Use existing funding efficiently	▪ Existing funding authorization and selection process	▪ Privatize market packages ▪ Public-private partnerships ▪ Barter right-of-way ▪ Advanced maintenance strategies	▪ Transit maintenance
	Leverage new funding sources		▪ Increased emphasis on fee-for-use services	
Transportation Following Emergencies	Improve disaster response plans	▪ Review and improve existing emergency plans	▪ Establish emergency response center (ERC) ▪ Inter-network ERC with law enforcement emergency units, traffic management, transit, ...	▪ Emergency response ▪ Incident management system ▪ Emergency routing

Appendix C: Benefits of Market Packages for Achieving ITS System Goals

(Source: ITS Performance and Benefit Study, Lockheed Martin 1996)

	Market Packages	ITS System Goals: Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
APTS	Transit Vehicle Tracking	*	**	*		*	*
APTS	Fixed-Route Operations	*	**	*		*	*
APTS	Demand-Responsive Operations	*	**	*		*	*
APTS	Passenger and Fare Management					**	*
APTS	Transit Security				**		*
APTS	Transit Maintenance					*	*
APTS	Multi-modal Coordination	*	*			*	
ATIS	Broadcast Traveler Info	*	**	*			***
ATIS	Interactive Traveler Info	**	***	*			***
ATIS	Autonomous Route Guidance	**	***				***
ATIS	Dynamic Route Guidance	**	***	*	*		***
ATIS	ISP-Based Route Guidance	**	***	*	*		***
ATIS	Integrated Transportation Mgmt / Route Guidance	***	***	**	*		**
ATIS	Yellow Pages and Reservation		*				**
ATIS	Dynamic Ridesharing	**	*	*			*
ATIS	In Vehicle Signing		*		*		***
ATMS	Network Surveillance	*	*	*			*
ATMS	Probe Surveillance	*	*	*			**
ATMS	Surface Street Control	**	***	**	**		*
ATMS	Freeway Control	**	***	**	*		*
ATMS	Regional Traffic Control	***	***	***	**		*
ATMS	HOV and Reversible Lane Management	*	**	*			*
ATMS	Incident Management System	**	**	***	**		*
ATMS	Traffic Information Dissemination	**	*	*			*
ATMS	Traffic Network Performance Evaluation	**	**				*
ATMS	Dynamic Toll / Parking Fee Management					**	*
ATMS	Emissions and Environ. Hazards Sensing			***			**
ATMS	Virtual TMC and Smart Probe Data	*	*	*		*	*
CVO	Fleet Administration		***			***	**
CVO	Freight Administration		***			***	**
CVO	Electronic Clearance	**	***			***	**
CVO	CV Administrative Processes					**	*
CVO	International Border Electronic Clearance	**	***			***	**
CVO	Weigh-In-Motion	**	***			***	**
CVO	CVO Fleet Maintenance	*			**	**	*
CVO	HAZMAT Management	*			**	**	*
CVO	Roadside CVO Safety	*	**		**	**	**
CVO	On-board CVO Safety				***	**	**

Key: * = low benefit, ** = moderate benefit, *** = high benefit