Framework for ITS Deployments to Enhance Highway Safety

The operational efficiency of a transportation system is greatly limited by incidents which result in great economic losses. In this research a framework for deployment of ITS applications is developed that will ensure effective management of incidents. The study focuses on improving safety of the access controlled highways using such deployments. A decision making methodology called ELECTRE I is used for selecting the best deployment strategy. The different alternative strategies are evaluated using new software tools such as ITS Deployment Analysis System (IDAS) in conjunction with spatial analysis and Highway Capacity Manual procedures to develop an overall benefits evaluation strategy that synthesizes both operational and economic benefits of different Incident Management strategies.
FRAMEWORK FOR ITS DEPLOYMENTS TO ENHANCE HIGHWAY SAFETY

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Research Report SWUTC/04/167828-1

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October 2003;
Revised October 2004
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ACKNOWLEDGEMENT

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers program to the Southwest University Transportation Center which is funded 50% with general revenue funds from the State of Texas.
ABSTRACT

The operational efficiency of a transportation system is greatly limited by incidents which result in great economic losses. In this research a framework for deployment of ITS applications is developed that will ensure effective management of incidents. The study focuses on improving safety of the access controlled highways using such deployments. A decision making methodology called ELECTRE I is used for selecting the best deployment strategy. The different alternative strategies are evaluated using new software tools such as ITS Deployment Analysis System (IDAS) in conjunction with spatial analysis and Highway Capacity Manual procedures to develop an overall benefits evaluation strategy that synthesizes both operational and economic benefits of different Incident Management strategies.
EXECUTIVE SUMMARY

Development of a safe transportation system is an implicit objective of any transportation planning process. Traditionally this has been attempted to be done through improvements to roadway geometry. However with the development of new computer, communication and surveillance technologies the transportation planning process has undergone a sea change. Intelligent Transportation System (ITS) has been defined as “the 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. Growth in the transportation sector can only occur if it is deemed to be safe by the users of the system. The Transportation Equity Act for the 21st Century (TEA-21) lays significant emphasis on programs to make multimodal transportation safer for the users. The evolution of the ITS planning process over the past decade has been characterized by ever-increasing complexity. The narrow focus on economic efficiency prevalent in 1990s has gradually given way to a consideration of many diverse economic, operational, environmental, safety and social objectives. On the other hand, the possible solutions for each problem considered have widened. The number of participants getting involved in the ITS planning process has increased, as the public sectors, as well as the private sectors, have been incorporated into the decision-making process.

In this project a framework for evaluating ITS deployment strategies is developed. The novelty of the method lies in the fact that it is a holistic method which integrates operational and economic evaluation methods. The framework utilizes a multi-criteria evaluation method called ELECTRE I for comparing between different ITS deployment strategies. The method compares not only the best performance of the different deployment strategies, but also their worst performance which helps in the identification of better strategies.

The framework utilizes the ITS planning tool IDAS (ITS Deployment Analysis System) for evaluating the different ITS strategies. The conceptualized framework is demonstrated through a case study for selecting the best ITS strategy for two access controlled highways in the city of Austin, the US-!83 corridor and the IH-35 corridor. Though the framework has been demonstrated for a safety enhancement study using ITS applications, the method is generic in nature and can be used for any ITS evaluation study where the objectives may vary.
TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION ........................................................................................................1
  1.1 Background ...............................................................................................................1
  1.2 Objectives of Study ...............................................................................................3
  1.3 Structure of the Report ........................................................................................4

CHAPTER 2: LITERATURE REVIEW .............................................................................5
  2.1 Background .........................................................................................................5
  2.2 ITS and Transportation Safety: Issues ...............................................................5
  2.3 Potential Safety Enhancing ITS Applications ....................................................7
    2.3.1 Infrastructure Based Systems .................................................................7
    2.3.2 Vehicle Based Systems .........................................................................9
    2.3.3 Cooperative System .............................................................................9
  2.4 ITS Planning Methods .......................................................................................11
  2.5 Summary .........................................................................................................13

CHAPTER 3: DATA ANALYSIS ....................................................................................15
  3.1 Introduction ......................................................................................................15
  3.2 Data Sources and Tools ....................................................................................15
  3.3 National Statistics and Trends ........................................................................16
  3.4 Data Analysis for Austin ................................................................................19
    3.4.1 Study Corridors ....................................................................................19
    3.4.2 Analysis Methodology ........................................................................20
    3.4.3 Corridor Level Analysis .......................................................................21
      3.4.3.1 IH-35 Corridor ............................................................................21
      3.4.3.2 US-183 Corridor .......................................................................23
    3.4.4 Spatial Analysis .....................................................................................24
    3.4.5 Summary ...............................................................................................25

CHAPTER 4: FRAMEWORK FOR EVALUATION OF ITS ALTERNATIVES .31
  4.1 Framework Outline ..........................................................................................31
CHAPTER 5: CALCULATIONS AND RESULTS ....................................................43

5.1 Selecting Sub-Corridor Level ITS Strategy....................................................43
  5.1.1 Sub-Corridor 1.................................................................................43
  5.1.2 Sub-Corridor 2.................................................................................45
  5.1.3 Sub-Corridor 3.................................................................................47

5.2 Criteria Evaluation.......................................................................................49

5.3 Selection of Superior Alternatives...............................................................54

5.4 Deployment Strategy ....................................................................................59

5.5 Summary .......................................................................................................60

CHAPTER 6: CONCLUSION .............................................................................61

6.1 Limitations and Recommendations for Future Study.....................................61

6.2 Conclusion .....................................................................................................61

APPENDIX A .......................................................................................................63

APPENDIX B .......................................................................................................65

REFERENCES .....................................................................................................67
LIST OF FIGURES

Figure 2.1: Short and Long Range Transportation Plan .......................................................... 12
Figure 3.1: Distribution of Crashes by Severity ................................................................. 16
Figure 3.2: Distribution of Fatal Crashes ........................................................................... 17
Figure 3.3: Fatality Rates in Texas as Percent of National Highest .................................. 19
Figure 3.4: Distribution of Incidents by Type on IH-35 (Year: 2000) ............................. 22
Figure 3.5: Distribution of Incidents by Type on IH-35 (Year: 2001) ............................. 22
Figure 3.6: Distribution of Incidents by Type on US-183 (Year: 2000) ......................... 23
Figure 3.7: Distribution of Incidents by Type on US-183 (Year: 2001) ......................... 24
Figure 4.1: Sub-Corridors for ITS Applications ............................................................... 32
Figure 5.1: Safety B/C Ratio for the ITS Strategies for Sub-Corridor 1 ....................... 45
Figure 5.2: Safety B/C Ratio for the ITS Strategies for Sub-Corridor 2 ....................... 47
Figure 5.3: Safety B/C Ratio for the ITS Strategies for Sub-Corridor 3 ....................... 49
Figure 5.4: Graph of Outranking Relation ........................................................................ 58
# List of Tables

Table 4.1: ITS Counter Measures for Sub-Corridors .............................................................33
Table 4.2: ITS Deployment Strategies .................................................................................34
Table 5.1: Results of Analysis for Sub-Corridor 1 ............................................................44
Table 5.2: Results of Analysis for Sub-Corridor 2 ............................................................46
Table 5.3: Results of Analysis for Sub-Corridor 3 ............................................................48
Table 5.4: Performance of Alternatives on the Economic Analysis Criteria .................50
Table 5.5: Density for Each of the Three Sub-Corridors ................................................52
Table 5.6: Effective Density for Each of the Sub-Corridors for the Different Alternatives ........................................................................................................53
Table 5.7: Weights Assigned to the Different Criteria .....................................................54
Table 5.8: Concordance Matrix ......................................................................................55
Table 5.9: Discordance Matrix .......................................................................................56
Table 5.10: Results of Sensitivity Analysis ....................................................................59
LIST OF MAPS

Map 3.1: Distributions of Traffic Fatalities by State ..........................................................18
Map 3.2: Distribution of Incidents by Type and Location (Year: 2000) ..............................26
Map 3.3: Distribution of Incidents by Type and Location (Year: 2001) ..............................27
Map 3.4: Lane Closure Due to Incidents (Year: 2000).........................................................28
Map 3.5: Lane Closure Due to Incidents (Year: 2001).........................................................29
CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

In general the growth in the United States economy and the transportation policies implemented over time has facilitated greater vehicle ownership levels and higher vehicle miles of travel. Today motor-vehicle travel forms the main mode of transportation in the country. The increase in the number of vehicles on the roads has resulted in increased concerns regarding issues such as national energy policy, air pollution, congestion and safety.

In the year 2000, there have been 6,394,000 police reported traffic crashes resulting in 41,821 fatalities and 3,189,000 injuries (NHTSA). The terrorist attacks on the World Trade Center on September 11th, 2001 brought to light the compelling need for developing effective emergency and incident management strategies. To develop a safe and secure transportation system is the implicit objective of any transportation planning process. There are various aspects related to highway safety and these are dependent on the location of the highway, the fleet mix of the vehicles, the volume and other such characteristics.

In the past advances in highway geometry and the experiences of highways have been implemented to meet the increase in demand. However the rapid strides made in the field of information technology have made it possible for real time information to be shared between users and operators of the transportation system. This has resulted in the development of effective management solutions to this problem by increasing the operational efficiency of the system. These advanced technologies applied to the field of Transportation are collectively known as Intelligent Transportation Systems (ITS). In a study conducted by Mitretek Systems it was found that compared to the no-ITS scenario full implementation of ITS technologies can reduce Fatal Crash rates in the country by 26% and Injury crash rates by 30% (McKeever, 1998).

There are various ITS technologies available today which can be used to enhance the safety of our highway system. In-vehicle systems such as Crash Avoidance Systems (CAS) reduce the risk of vehicle crashes. According to the Urban Mobility Report published by the Texas Transportation Institute in 1999, 57% of the country’s traffic congestion in 1997 was due to crashes and other incidents, while another 10% to 20% was found to be due to secondary incidents. Advanced Traveler Information Systems (ATIS) can be used to disseminate real time information about incidents to the users and prevent the occurrence of secondary incidents and
reduce congestion levels. ATIS improves travel time reliability of trips and changes the trip making behavior of individuals. This aids in reducing peak hour congestion levels. Incident management is quite a complex process as it involves coordination between various agencies such as departments of transportation, state and local law enforcement agencies, insurance agencies and towing and recovering companies. Incident Management Systems (IMS) can be used for immediate detection of incidents and passing on the information to the various agencies involved in the process. Early detection of incidents helps in faster clearance of the roadway making it available for the users. In-vehicle systems such as rural mayday systems help in providing immediate notification of the occurrence of an accident and thus reduce the time delay between occurrences of an accident and the arrival of Emergency Services. Traffic control devices such as Ramp meters and detection devices such as loop detectors and CCTV cameras can be used to effectively manage the flow of traffic on highways based on the ambient conditions. These Advanced Traffic Management Systems (ATMS) can be used to better enforce traffic laws and help in detecting non-complying or dangerous drivers.

The Intermodal Surface Transportation Efficiency Act of 1991 first authorized funding for the development of Intelligent Vehicle Highway Systems (IVHS). This legislation laid the foundation for the development of Intelligent Transportation Systems in the country. It stressed the development of benefit-cost estimates for such technologies to determine their economic viability. ISTEA led to a lot of research and development for ITS applications. ISTEA paved the way for The Transportation Equity Act for the 21st Century (TEA-21) which was authorized in 1998. It laid significant emphasis on programs to make multimodal transportation safer for the users. Some of the safety programs that have been included in this legislation as being thrust areas are alcohol programs, seat belt and occupant protection programs, automobile safety and information and railway-highway crossings. The legislation also emphasizes the need for research in the field of ITS to develop a seamless and efficient transportation system. Though these may seem to be disparate goals, in essence they are the same. Therefore deployment of ITS applications will aid in meeting the goals of each of these safety programs.

The evolution of the ITS planning process over the past ten years has been characterized by ever-increasing complexity. The narrow focus on economic efficiency prevalent in 1990’s has gradually given way to a consideration of many diverse economic, operational, environmental, safety and social objectives. On the other hand, the possible solutions for each problem
considered have widened. The number of participants getting involved in the ITS planning process has increased, as the public sectors, as well as the private sectors, have been incorporated into the decision-making process. Hence the issues such as what are the estimated benefits of the proposed ITS applications and how to identify the best ITS plan from a set of ITS alternatives need more investigation in order to make rational decisions on future commitments.

1.2 OBJECTIVES OF THE STUDY

A proper deployment strategy for ITS applications needs to be developed in order to realize the benefits of these applications. It is essential to have a proper deployment plan which takes into account the goals of the planning process. This is a rather challenging task as first the measures for evaluating these benefits must be clearly defined and then a common measure must be developed which will allow for comparison between different ITS alternatives. It should be ensured that the measures defined for comparing between alternatives properly reflect the operational impacts of ITS deployments on the transportation system. This factor becomes even more important when the deployment goals include improving the safety of the highway system as any measure taken directly impacts human life.

There are two major stumbling blocks in the ITS planning process. The first is lack of sufficient data regarding operational impacts of ITS applications. The second and more serious problem is caused by the dynamic and rapid changing nature of information technology and communication devices used for ITS applications. As a result the data collected becomes obsolete very fast. It has also been observed that there have been regional variations in the reported benefits of these applications. Thus it becomes essential to calibrate regional models with local data.

The objectives of the present study can be summarized as below:

• Identification of ITS applications that can be used to improve the safety of our highway system.
• Identification of tools that can be used for development of an ITS deployment framework.
• Development of a holistic ITS planning framework that integrates the economic and operational impacts of ITS applications.
• Development of a decision making methodology to select between different ITS deployment strategies.

1.3 STRUCTURE OF THE REPORT

This report presents in a structured manner the framework developed for deployment of ITS applications to increase the safety of the highways system. In Chapter 2 an in-depth review of literature is presented, pertaining to the different approaches to planning of ITS applications in the different regions of the country and their reported benefits. Chapter 3 covers the spatial and statistical analysis carried out to find zones having high incident density. Data for both the United States and Austin is analyzed and presented and trends summarized. Chapter 4 presents the framework developed. In Chapter 5 the conceptualized framework is illustrated through the application to the case study for evaluating the deployment strategy to be used for realizing safety benefits. The final chapter (Chapter 6) presents the conclusion from the study.
CHAPTER 2: LITERATURE REVIEW

2.1 BACKGROUND

One of the principal goals of any transportation planning process is to make the transportation system safer for users. Many factors have been found to affect traffic safety such as alcohol consumption, road characteristics, environmental factors, distraction, headway, speed-limit etc. These factors can be broadly divided into four categories. These are:

1. **Driver Characteristics**: An aggressive, drunk or fatigued driver will be more prone to make an error than others and thus make the roadway unsafe for other vehicles.

2. **Geometry of Roadway**: A roadway having badly designed horizontal or vertical curves or inadequate sight distance will result in more accidents due to the difficult driving conditions.

3. **Traffic Characteristics**: Factors such as traffic flow, headway and speed limit also affect the safety standards of the roadway. If the flow volume is very high a single accident may lead to several other accidents. The risk of multiple cars being involved in a crash increases with higher speeds and reduced headways.

4. **Environmental Factors**: These affect safety by impairing visibility, decreasing stability, and reducing controllability. Precipitation, fog, sunshine, and dust storms are responsible for reducing visibility. Rain, snow and ice cause road surfaces to become slippery and reduce vehicle stability. These also lead to reduced driver control. (6)

2.2 ITS AND TRANSPORTATION SAFETY: ISSUES

The safety issues associated with any transportation corridor are unique because they are caused by different combinations of the above factors. Also, the degree to which each factor is responsible varies from corridor to corridor. It has been noted that the most frequent cause of traffic incidents, such as crashes, vehicle breakdowns and other unpredictable events is traffic congestion (16). Reduction in congestion levels thus should lead to reduction in crashes, which in turn reduces congestion levels (12). Hence it is not surprising to note that more than 50% of congestion on urban highways today is incident induced. (16)

The two key issues in developing an effective ITS framework are, Institutional Issues and Technological Issues. Incident management involves various public agencies, such as the State
Department of Transportation, Department of Public Safety, local Police and the Emergency Management Agency each having their own jurisdictional boundaries. To develop an effective incident management program the roles and responsibility of each agency should be clearly defined. Also collaborative deployment strategies should be worked out to sustain an interagency, collaborative transportation management and operations program. A good example of such a system is the Louisiana Advanced Transportation Information System (LATIS), which is a collaborative effort of the Louisiana Department of Transportation and Development (DOTD), Louisiana Office of Emergency Preparedness (LOEP) and Louisiana State Police (LSP). It was found that all the three agencies could realize significant benefit by pooling resources, sharing common space and information and maximizing use of transportation information by providing transportation management services. It also helped solidify the statewide transportation, incident and emergency management program (8).

Technological issues regarding interoperability of devices and information flows between different agencies are answered by the National ITS Architecture which provides the physical elements on which ITS deployment standards and evaluation can be built. The framework consists of three layers: a transportation layer which includes the functions required to implement ITS user services, a communication layer which includes the communication technologies and systems required for data interchange and the institutional layer which provides structure to the forces specifying requirements and deployment architecture over time. The information flow and timeline for information flow between different agencies is explicitly defined in the form of Transaction Diagrams, between the client and the server. (29).

Another important factor that needs to be taken into account in developing an ITS framework is the understanding of human factors. These factors should be taken into account from the perspective of both the user and the system operators. In-vehicle systems which warn the user of hazardous driving conditions, or provide information regarding route events can potentially provide significant benefits. However the realization of such benefits is subject to user acceptance. If the provided information is not easy to decipher it may cause driver distraction and lead to unsafe driving. The greater the acceptance level for a technology the more will be its market penetration and hence faster return on the costs of implementation will be realized.
2.3 POTENTIAL SAFETY ENHANCING ITS TECHNOLOGIES

There are a host of ITS technologies today which have the capability to make vehicular travel much safer. Some of these technologies collecting information about traffic flow and help the agencies better manage the system. Yet, there are others which reduce the risk of crashes by taking direct or indirect control of the vehicle. Based on how these technologies achieve the goal of enhancing the safety of the system, McKeever (15) classifies these into three classes:

1. **Infrastructure Based Systems**: These involve adding ITS devices to the infrastructure for enforcement or for collection and dissemination of traffic related data, for more efficient traffic management.

2. **Vehicle Based Systems**: These involve adding ITS devices to the vehicle. They reduce the risk of collisions by taking control of the vehicles.

3. **Cooperative Systems**: These involve adding ITS elements to both the infrastructure and the vehicle with significant interaction between both.

In the following sections we will discuss in greater detail some of these applications. We will focus more on such technologies that have the potential of improving the safety of access controlled highways. Some of these technologies are still in the research phase and have not been widely implemented.

### 2.3.1 Infrastructure Based Systems

**1. Freeway Management Systems**: Freeway management has been defined by FHWA as the control, guidance and warning of traffic to improve the flow of people and goods on Freeway facilities. Freeway management systems reduce the likelihood of occurrence of collisions by limiting conflict among traffic streams. This is achieved through the use of devices such as Variable Message Signs (VMS) and Ramp Metering. A study of the impact of ramp metering conducted by Henry and Meyhan (1989), in the Seattle, Washington found a crash reduction of 62%. Piotrowicz and Robinson (1995) reported a crash reduction of 24% to 50%, on freeways where ramp meters were installed. McKeever (1998) considering the lower end value for crash reductions estimated that ramp metering could reduce about 853 fatal crashes a year. The 2001 ITS benefits update published by Mitretek Systems, estimates ramp metering to reduce crash rates by about 15-50%.
2. **Automated Enforcement:** Automated speed enforcement uses cameras to detect speeding vehicles. Installations of such cameras have led to a 20% to 80% reduction of crashes and a 50% reduction of fatalities and injuries in London (Jernigan). In Australia a 22-30% reduction in accident rate was reported after installation of over 800 speed cameras at various locations in New South Wales. Cameras have also been used to detect red light violators, work-zone speed violators and violators at railroad highway intersections. In Los Angeles, California, field trials have shown that Railroad Crossing Enforcement Systems have reduced violations by 78-92%.

3. **Incident Management Systems:** Incident Management systems use traffic surveillance devices such as CCTV cameras or loop detectors to provide real time information about traffic incidents to Traffic Management Centers. This helps in quicker response from incident management crews. Also information regarding such incidents can be given to other users of the system through Variable Message Signs, Highway Advisory Radio broadcasts and over the internet so that they can use alternate routes. This helps in reducing incident induced congestion and reduces the risk of occurrence of secondary incidents. In Maryland, the CHART (Chesapeake Highway Advisories Routing Traffic) incident response program resulted in a benefit cost ratio of over 7 to 1. The cost savings were attributed to reduction in delay, fuel savings and secondary incidents. In Brooklyn, New York, the Autoscope incident detection system along the Gowanus Expressway has reduced average incident clearing time from 1.5 hours to 19 minutes. McKeever estimates IMS to reduce fatal crashes by 18%. This was based on a study of an Automatic Incident Detection (AID) System on the M1 motorway in the United Kingdom.

4. **Advanced Warning Systems:** These help advise commercial vehicles and other heavy trucks of dangerous highway situations. Two such systems are the Ramp Rollover Warning System (RRWS) and the Down Grade Warning System (DGWS). RRWS warns trucks when safe speeds are exceeded at entry and exit ramps. In the first five years of operation the RRWS system installed at three sites on the Capital Beltway in Washington D.C. resulted in a 100% reduction in crashes. In the first two years of operation the DGWS system installed on the I-70 corridor in Colorado resulted in a 13% reduction in crashes due to excessive truck speeds.
5. **Road Weather Information Systems:** These link remote weather stations with VMS signs or in-vehicle devices improve safety by warning drivers of changes in weather conditions. Wolshon et al. (D16) describe how these ITS technologies are being used today for Hurricane Evacuation. Studies in Europe have indicated vehicle speed reductions of 10% and accident rate reductions of 30% during inclement weather conditions. Fatal and injury crashes were observed to have been reduced by 40%. It was also observed that weather-monitoring systems equipped with visibility sensors linked to variable message signs reduced accidents by as much as 85% on foggy days (McKeever).

2.3.2 **Vehicle Based Systems**

**Crash Avoidance Systems:** Vehicles can be equipped with three types of crash avoidance systems (CAS), Rear-end CAS, Lane-change/Merge CAS and Road Departure CAS (or Lane Keeping Systems). Rear end CAS measures the headway between the host vehicle and the lead vehicle. It changes the velocity of the car and/or provides a warning to the driver regarding a dangerous condition ahead. Lane-change/merge CAS monitors the position and velocity of the vehicles on the adjacent lanes and warns the driver of unsafe lane changing conditions. Rear-end CAS are estimated to reduce crash costs by 7.2% and crashes by 13.5% (Jernigan). A study conducted by NHTSA predicted that rear-end CAS had the potential of reducing rear-end crashes by 48%. It estimated that lane-change CAS would reduce such crashes by 37%. Lane keeping systems are capable of preventing run-off-road and head-on crashes. Based on 25% effectiveness for such systems they were estimated to reduce crash costs by 7.3%. A NHTSA study predicted that these systems would reduce single-vehicle run-off-road crashes by 24%.

2.3.3 **Cooperative Systems**

1. **In Vehicle Navigation:** These systems combine real time information with in-vehicle display systems such as digital maps to provide dynamic route guidance. These systems generally utilize GPS transponders to receive real time traffic network information. Results from the TravTek study have indicated that these systems have a potential of reducing crashes by 1%. One potential drawback of this system is that these displays may also cause driver distraction. To eliminate this problem, Heads up Displays (HUDs) are
being developed wherein the information can be displayed on the windshield. In vehicle navigation systems are the only Advanced Vehicle Control Systems (AVCS) that are being commercially produced on a large scale today.

2. **Emergency Mayday Systems:** These systems have on-board crash notification systems. They use GPS technology to locate the position of the vehicle and convey the information to the nearest Emergency Management Center. These have the potential of reducing incident detection times in rural areas and help reduce fatalities. It is estimated that these can help in providing speedier detection. It is estimated that on full implementation they will provide early identification in 60% of crashes and fatalities will be reduced by 12%. A study done by Evanco (47) predicted that a 100% market penetration for these systems would result in realization of annual benefits of $6.37 billion. A good example of such a system is the Puget Sound Help Me (PuSHMe) Mayday system. This system allows a driver to immediately send a response center a notification and incident location along with a request for needed assistance. The system includes cell phones and two way pagers which are used to transmit the nature of the problem, location of problem and the problem priority level to the response center. The devices may also send an automated signal when the driver may be incapable of manually initiating a signal. In a survey conducted in the region it was found that 95% of drivers equipped with voice communications felt more secure while 70% of those with only data communication said that they felt more secure with the system installed.

3. **Intelligent Speed Control Systems:** These systems attempt to fix traffic speeds based on the ambient traffic conditions. Roadside transmitters communicate this information to the vehicles. If a vehicle is traveling at a higher speed then either a warning message is given to the driver or the vehicle speeds are automatically adjusted to comply with the communicated speed. Much research has been done in Europe in this area. It has been estimated that these systems can reduce injury crashes by 20-35%.

4. **ITS For CVO:** Motor carrier safety and compliance to weight regulations has always been a concern for transportation agencies. The mechanical condition of the vehicle and the physical condition of the driver are contributors to vehicle safety. The CVO technologies include Weigh in Motion (WIM) systems, automated roadside safety inspections and hazardous material incident notification. In New South Wales, Australia,
a system of remote automated cameras linked to a central processing center is used to monitor commercial vehicle operations and enforce vehicle safety. The central processing site processes the information received to determine average vehicle speed over highway segments. It also determines if there is need for driver fatigue notification. An evaluation of the system, using reduction in lives lost and travel time savings as metrics showed a cost-benefit ratio of 2.5 to 1. (28)

5. **ITS For Transit:** This includes applications such as Automatic Vehicle Location (AVL), route planning systems for managing fleets and advanced monitoring and maintenance systems. Safety and security enhancing applications of transit ITS include on-board video surveillance, emergency phones and video cameras at transit centers. A survey of transit passengers at Ann Arbor, Michigan indicated that people rated such improvements very highly and indicated that these measures gave them an added sense of security.

### 2.4 ITS PLANNING METHODS

The traditional approach to Transportation Planning has been the four step transportation modeling process, consisting of Trip Generation, Trip Distribution, Mode Split and Traffic Assignment. This has been used for long range transportation planning having a horizon of 20 years and is updated every three years in air-quality non-attainment areas and every 5 years in other areas. These plans are carried out through The transportation improvement program (TIP) for metropolitan areas and through statewide transportation improvement program (STIP) for other areas.
As we have seen in the preceding section, ITS technologies can play a very important role in making our transportation system safer. However due to the dynamic nature of such technologies they cannot be used for long term planning. Thus they have to be planned as part of a TIP or STIP.

Over the last decade researchers have developed various models using different tools for ITS planning and evaluation. One of the approaches to evaluation of the impacts of ITS applications has been simulation modeling. Boxill and Yu (2000) concluded from a detailed analysis of all the different simulation software available that CORSIM and INTEGRATION are the most appropriate for evaluation of the impacts of ITS applications. Wunderlich et al.(1999) developed a model called Process for Regional Evaluation of Integrated ITS networks (PRUEVIN) to study the impacts of different ITS and Non-ITS strategies for the Seattle network. The process used the four step transportation planning model with simulation to capture the regional and corridor level impacts of different ITS applications. Shah and Wunderlich (2001), use INTEGRATION along with scenario generation to study the impacts of ITS applications on different traffic corridors in Detroit. Cragg and Demetsky (1995) studied route diversion strategies for freeway incident management using CORSIM. Chaterjee et. al. use survey data to develop a logistic regression model to study the diversion response of drivers to VMS signs.
installed in London. Another approach that has been used for the studying the impacts of ITS applications has been an economic analysis. Gillen et. al.(1999) present a detailed description of a framework for evaluation of ITS applications considering both direct benefits as well as indirect benefits. They present a cost-benefit analysis approach and cost-effectiveness analysis approach for selection of ITS applications. Jeannotte (2000) presents the software model IDAS which can be used for estimating the potential benefits and costs of ITS applications. Zavergiu et. al presented a goal oriented benefit-cost analysis method for selection among ITS alternatives. They defined three levels of client-ITS relationship – the traveler, the transportation network and the affected regional economy. Peng and Beimborn (2000) presented a break even analysis approach to assess the benefits of ITS applications. They used the spreadsheet model SCRITS (Screening for ITS) to demonstrate this approach.

Simulation models are useful for understanding the operational impacts of ITS applications. However, comparing different alternatives, especially between ITS and non-ITS alternatives using this approach is very difficult. Economic analysis approaches on the other hand are useful for decision makers in comparing different alternatives. The major shortcoming of economic analysis tools is that, the operational impacts of the strategies are not always evident. Thus when the goal of a planning agency is to make a corridor safer for the users, understanding of the operational impacts of the different strategies is very important to see that the goals are met. In this report a hybrid ITS evaluation framework is conceptualized which combines both the above approaches.

2.5 SUMMARY

Over the years various tools and methodologies have been developed for evaluating the benefits of ITS applications. These approaches have varied from statistical modeling of observed impacts to using micro-simulation modeling. Benefits evaluation forms an important step in integrating ITS planning into the transportation planning process. In this study a simple scaleable framework is developed for selecting ITS applications and deployment methodology. The framework utilizes the new ITS planning tool IDAS (ITS Deployment Analysis System) in conjunction with the spatial analysis tool, ArcGIS. The framework builds on previous research efforts as it utilizes both operational and economic criteria for selecting the best deployment strategy.
CHAPTER 3: DATA ANALYSIS

3.1 INTRODUCTION

In this chapter we will first look at the different causes of incidents and accidents. First a brief overview is presented of the state of practice in the nation today. This will give us an understanding of the primary concerns regarding transportation safety. In the second part of the chapter a more detailed analysis is presented of the causes and impacts of incidents in Austin study corridors. This data analysis provides a valuable insight into the operations of these corridors and helps us in deciding on the appropriate ITS applications to be deployed for the mitigation of the experienced problems. A proper understanding of the operational impacts of incidents will help us develop models that can be used for estimating the impacts of such incidents and the effect of ITS countermeasures.

3.2 DATA SOURCES AND TOOLS

The data for national trends has been obtained from the National Highway Traffic Safety Administration (NHTSA) published report, “Traffic Safety Facts 2000” and the Bureau of Transportation Statistics, TransStats website. The primary source of data for these is the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES). The way in which these two datasets are compiled is quite different. FARS data is compiled from existing documents such as, police accident reports, death certificates, State vehicle registration files, State driver license files, Hospital medical service reports, Emergency medical services reports etc. The GES data is obtained from a nationally representative sample of police reported crashes. NHTSA combines the data from these two sources to form a single data set to understand national trends and concerns.

The data for the city of Austin corridors was obtained from TxDOT, Austin. The data consists of all reported and detected incidents occurring in these corridors, the cause of these incidents, affected traffic lanes and a brief description of the incident. The GIS maps of the streets of Austin were obtained from the city of Austin website.

The statistical analysis of the data was performed using Microsoft Excel while spatial Analysis of the data was performed using ArcGIS developed by Environmental Systems Research Institute (ESRI).
3.3 NATIONAL STATISTICS AND TRENDS

There has been substantial improvement in the standards of safety of our highways over the past few years but a lot still needs to be done. In 2000, the fatality rate per 100 million vehicle miles of travel fell to a new historic low of 1.5. However, there was still a 0.2% increase in the number of fatalities occurring on our highways. The percent of fatal crashes has remained almost constant over the last decade at 0.6%. In the year 2000, on an average 113 persons died each day due to motor vehicle accidents. Vehicle occupants accounted for about 87% of the fatalities resulting from traffic accidents. Thus we can envision significant benefits from the use of in-vehicle crash avoidance systems which have the potential of greatly reducing the risk of crashes.

![Fig. 3.1 Distribution of Crashes by Severity](source)

Source: FARS &GES
Looking at Fig. 3.2 we see that towards the early part of the last decade there had been a significant reduction in the number of fatal crashes. However there was again an increase in fatal crashes after 1992 and in the latter half of the decade the number of fatal crashes remained constant at about 37,000 per year.

The following map (Fig. 3.3) shows the distribution of traffic fatalities in the different states, in the year 2001.
Map 3.1  Distribution of Traffic Fatalities by State

It is observed that Texas ranks amongst the states having highest number of traffic fatalities. In the year 2001, 3724 traffic fatalities were recorded in Texas and ranked second in terms of number of traffic fatalities. The graph below presents the rate of fatalities in the state of Texas compared to the highest national values observed for the year 2000.

Source: BTS, Transtats
As observed from the graph the fatality rates for Texas are more than 50% of the highest observed values in all cases. The fatality rate per 100 million travel miles was recorded as 1.72 for Texas, compared to a national average of 1.5. All these statistics bring to light the need for improving the safety standards of our transportation system today.

It has been seen in the previous chapter that various ITS technologies exist today which have the potential of greatly reducing the risk of collision or response time of Emergency and Incident management personnel. Hence what we need to do today is to develop deployment strategies of these various ITS applications which will help us reap the maximum benefits of such applications. These small steps taken today will help us move towards the realization of the futuristic world with no fatalities due to traffic accidents.

3.4 DATA ANALYSIS FOR AUSTIN

3.4.1 Study Corridors

The present study will focus on the access controlled highways and incidents occurring on such highways. The corridors considered for the present study are the US-183 corridor and
the IH-35 corridor. The US-183 corridor forms the major east-west connector in the city whereas the IH-35 corridor forms the major north-south corridor in the city. The segment of the US-183 corridor considered for the present study extends from Manor Road on the east to McNeil Drive in the west. The IH-35 corridor extends from Braker Lane in the north to Cesar Chavez in the south. For the purpose of analysis these corridors were further broken down into smaller sections. The US-183 corridor was broken down into three sections. These are:

1. Section 1: Manor Road to Lamar Boulevard.
2. Section 2: Lamar Boulevard to Capital of Texas Highway.
3. Section 3: Capital of Texas Highway to McNeil Drive

Similarly, the IH-35 corridor was subdivided into four sections. These are:

1. Section 4: Braker Lane to Anderson Lane (US-183)
2. Section 5: Anderson Lane to 51st Street
3. Section 6: 51st Street to 26th Street
4. Section 7: 26th Street to Cesar Chavez (1st Street)

### 3.4.2 Analysis Methodology

It is well known that graphical representation of data is much easier to absorb and more meaningful to human comprehension. Therefore, it makes better sense to graphically represent the incidents occurring on the corridors. Pie charts and bar graphs are easy to understand, but in this case, it is much more meaningful and practical to integrate the graphical representation of the incident data in the actual Austin road map. Hence the principal tool used for the analysis was ArcGIS.

A vector shape file representing the Austin network was downloaded from the city of Austin website. From this shape file the study corridors were extracted using the Map Query tool. These corridors were further divided into sections as described above. The data file for detected and recorded incidents on these corridors was obtained from TxDOT, Austin. These data files were analyzed and processed using Microsoft Excel and were made compatible with the attributes file of the city of Austin road network. The two files were then merged and the attributes were displayed on the map using pie-charts for each of the sections using the charting tools of the ArcGIS software.
In the present study two levels of analysis was performed. A corridor level analysis, to find the distribution of the incidents. A spatial analysis was also performed using the methodology described above to find the distribution of incidents by location and type as well as the resulting lane closures due to these incidents.

3.4.3 Corridor Level Analysis

3.4.3.1 IH-35 Corridor. It was observed that there was a significant reduction in the number of incidents detected on this corridor from 2000 to 2001. In 2000, the corridor recorded 1169 incidents, whereas in 2001 only 554 incidents were recorded. The principal cause of incidents recorded in 2000, was found to be congestion. Out of the 1169 incidents, 749 incidents accounting for about 64% of the incidents were attributed to high congestion levels. However in 2001, 154 of the 554 incidents recorded, accounting for about 28% of the incidents was attributed to high congestion levels. In 2001 the number of incidents due to vehicle stalls went up to 186 from 107 recorded the previous year. Another disconcerting fact noticed is that in 2001 the number of collisions went up to 141 from 112 reported the previous year. The sectional analysis performed later in the chapter will help us understand if these observations represent trends or are due to aggregation of the data.
Fig 3.4 Distribution of Incidents by Type on IH-35 (Year: 2000)

Fig 3.5 Distribution of Incidents by Type on IH-35 (Year: 2001)
3.4.3.2 US-183 Corridor. In 2000, 923 incidents were recorded in the US-183 corridor. This number fell to 484 recorded incidents in 2001. Congestion was the primary cause of incidents in the year 2000, and accounted for about 47% of all the incidents. In 2001, the primary cause of incidents was found to be stalled vehicles which accounted for about 49% of the recorded incidents. Congestion accounted for only 27% of the recorded incidents. It is also worth noting that only 7 collisions were reported on this corridor in 2001, compared to 90 collisions in 2000.

Austin is in the process of development of its ITS infrastructure. Hence with each passing year more ITS components are being deployed and data collection efforts are also improving. Thus it can be inferred that these reduction in the number of incidents on these corridors is due to improved traffic management on these corridors using these advanced technologies.

Fig 3.6 Distribution of Incidents by Type on US-183 (Year: 2000)
3.4.4 Spatial Analysis

From the map 3.2 and map 3.3 we note that in 2000, the major cause of incidents on sections 1, 2 and 3 was due to high congestion levels. However in 2001 the major cause of incidents on these sections was due to abandoned, overturned and stalled vehicles. For sections 4 and 5 the major cause of incidents for both years have been abandoned, overturned and stalled vehicles. Congestion is seen to be the major cause of incidents occurring in sections 6 and 7.

Thus the ITS countermeasures that need to be taken for sections 1, 2, and 3 are congestion management and incident detection and response strategies. For sections 4 and 5 ITS applications for incident detection and response needs to be used. The recommended strategy for reducing incidents in sections 6 and 7 would be congestion management strategies such as ramp metering.

In the following two maps the incident related lane closures have been mapped for each of the sections. Only single lane closures have been considered for the analysis since the majority of the incident related lane closures observed are single lane closures. Very few of the incidents resulted in more than single lane closure. The lanes have been numbered from median outwards as 1, 2 and 3.
3.5 SUMMARY

Data analysis forms an important first step for any study. Analysis of the data will help us extract valuable information from it. Due to the inherent spatial nature of transportation data, spatial analysis tools such as ArcGIS is used along with statistical analysis of the data. First national level traffic safety data is analyzed to emphasize the need to improve the safety of our highways. Then the data for the city of Austin corridors is analyzed to study the distribution of the causes of incidents on these corridors and their impacts on lane closure.
Map 3.2  Distribution of Incidents by Type and Location (Year: 2000)
Map 3.3  Distribution of Incidents by Type and Location (Year: 2001)
Map 3.4 Lane Closure Due to Incidents (Year: 2000)
Map 3.5  Lane Closure Due to Incidents (Year: 2001)
CHAPTER 4: FRAMEWORK FOR EVALUATION
OF ITS ALTERNATIVES

4.1 FRAMEWORK OUTLINE

The framework conceptualized for planning ITS countermeasures consists of four major steps. These are:

1. Data Analysis and Problem Identification
2. Sub-Corridor level ITS Strategies
3. Stepwise Integration
4. Multi-Criteria Evaluation

A flowchart of the framework is presented in Appendix A. Though the framework presented here is used for evaluation of safety benefits, it is generic in nature and can easily be used for planning for ITS applications for a different objective. A detailed description of each of the steps along with its application in the present case study has been presented in the following sections.

4.1.1 Data Analysis and Problem Identification

This step forms the basis on which the analysis would be performed. In this study statistical and spatial analysis was used to identify the causes of incidents and their impacts. This analysis has been presented in detail in Chapter 3. As seen there we divided the study corridors into smaller sections to prevent the problem of spatial aggregation. A section level analysis helps us identify the problems at each section. A corridor level analysis of the data can be quite misleading in this regard as an enormously large number of incidents occurring at any one section may make us believe that to be the principal cause for the occurrence of incidents over the entire corridor. However the corridors should not be divided into too many sections as it would not be possible to frame a different strategy for each section and will lead to logistical difficulties in framing deployment strategies.
4.1.2 Sub-Corridor Level ITS Strategies

Based on the data analysis we identify adjacent sections having the same principal cause for occurrence of incidents. These sections are combined to form sub-corridors. Thus the 7 sections are combined as shown in Fig. 4.1. Since each of the corridors have different principal causes of incidents we select different ITS countermeasures for each of the sub-corridors. The ITS countermeasures for each of the three sub corridors is presented in Table 4.1. We see that the principal cause of incidents on sub-corridors 1 and 2 are causes such as stalled or overturned vehicle, while the principal cause of incidents on sub-corridor 3 is congestion hence incident management strategies need to be employed for sub-corridors 1 and 2. However for sub-corridor 3 we can use either congestion mitigation strategies or incident management strategies. The preferred ITS strategy for each corridor will be the one yielding the highest safety benefits per unit cost of putting the system in place.

Fig. 4.1 Sub-Corridors for ITS Applications
Table 4.1  ITS Counter Measures for Sub-Corridors

<table>
<thead>
<tr>
<th>Principle Causes of Incidents</th>
<th>ITS Counter Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SUB-CORRIDOR 1</strong></td>
<td></td>
</tr>
<tr>
<td>Stalled, Overturned &amp; Abandoned Vehicles</td>
<td>Incident Detection and Verification</td>
</tr>
<tr>
<td></td>
<td>Incident Response Management</td>
</tr>
<tr>
<td></td>
<td>Combined Detection and Response</td>
</tr>
<tr>
<td><strong>SUB-CORRIDOR 2</strong></td>
<td></td>
</tr>
<tr>
<td>Stalled, Overturned &amp; Abandoned Vehicles</td>
<td>Incident Detection and Verification</td>
</tr>
<tr>
<td></td>
<td>Incident Response Management</td>
</tr>
<tr>
<td></td>
<td>Combined Detection and Response</td>
</tr>
<tr>
<td><strong>SUB-CORRIDOR 3</strong></td>
<td></td>
</tr>
<tr>
<td>Congestion</td>
<td>Ramp Metering</td>
</tr>
<tr>
<td></td>
<td>Incident Detection and Verification</td>
</tr>
<tr>
<td></td>
<td>Incident Response Management</td>
</tr>
<tr>
<td></td>
<td>Combined Detection and Response</td>
</tr>
</tbody>
</table>

4.1.3 Stepwise Integration

Having selected the preferred ITS Strategy for each sub-corridor we now need to find the preferred deployment strategy. We will move from deployment of the Preferred Alternative (PA) for each sub-corridor to full deployment on all the sub-corridors. The seven deployment combinations that will be evaluated are presented in Table 4.2. The ‘X’ in the table denotes no deployment.
Table 4.2 ITS Deployment Strategies

<table>
<thead>
<tr>
<th>ITS Alternative</th>
<th>Sub-Corridor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PA</td>
<td>X</td>
<td>X</td>
<td>PA</td>
<td>X</td>
<td>PA</td>
<td>PA</td>
<td>PA</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>PA</td>
<td>X</td>
<td>PA</td>
<td>PA</td>
<td>X</td>
<td>PA</td>
<td>PA</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>X</td>
<td>PA</td>
<td>X</td>
<td>PA</td>
<td>PA</td>
<td>PA</td>
<td>PA</td>
</tr>
</tbody>
</table>

From these 7 alternatives the preferred alternative is selected using multi-criteria evaluation approach described in the next section.

4.1.4 Multi-Criteria Evaluation

A multi-criteria evaluation approach is used for selection of the preferred deployment strategy. The method used here is ELECTRE I which was developed by Benayoun, Roy and Sussman (1966) and later improved by Roy (1971). This method yields a preferred subset of alternatives. The method has been described in detail in Appendix B. In this study we use Economic benefits evaluation measures as well as operational measures for selection of the best alternative. The novelty of this approach lies in the fact that unlike previous approaches which have focused on evaluating either operational or economic benefits, this approach uses both these sets of measures. Thus this evaluation method can be said to be a hybrid evaluation method.

4.2 ITS COUNTER MEASURES

4.2.1 Ramp Metering

This is hypothesized to reduce the level of congestion in Sub-Corridor 3 as the principal cause for the occurrence of incidents there is high congestion levels. All the on ramps were metered in the sub-corridor. The deployments required for the strategy included –

- 9 Ramp Meters
- 18 Loop Detectors
- 9 Variable Message Signs
The loop detectors would be used to detect the flow on the freeway segments which would enable metering of the ramps. The VMS signs were deployed on the frontage roads leading the ramps to inform the users if the ramp ahead was metered. This would prevent formation of queues on the ramps. However one possible drawback of this strategy is that though congestion levels may reduce on the sub-corridor it may increase in the alternative routes. The following values were assumed for the system:

- Percent Reduction in accidents = 24%
- Percent Vehicles passing VMS that save time= 25%
- Percent time VMS sign is turned on and disseminating information= 25%
- Average amount of Time savings in minutes =10 minutes

These values are conservative estimates of nationally experienced impacts of ramp metering.

### 4.2.2 Incident Detection/Verification

This strategy helps in faster detection of incidents. This system is implemented for each of the sub-corridors. The requirements for the system are a Traffic Management Center (TMC), communications cable and hardware and software for incident detection. Since Austin already has a TMC owned and operated by the city it is assumed that this same center can be used for incident detection. The hardware for incident detection will consist of CCTV cameras. Though loop detectors can also be used for detection the maintenance and installation costs are much higher for loop detectors compared to CCTV cameras. Also it is much easier to detect incidents using cameras as the real time view of the freeway sections can be viewed from the TMC. Loop detectors on the other hand depend on complex algorithms to detect incidents. The impacts of Incident detection and verification are estimated from the values estimated by McKeever and from the default values given in IDAS (ITS Deployment Analysis System). It is estimated that the system will reduce incident response times by 9% and will result in fatality reductions by 18%.

### 4.2.3 Incident Response Management

The prerequisites for Incident Response Management include a Traffic Management Center and an Emergency Management Center. The system helps in early response to an incident
through co-ordination of the efforts of both the above mentioned centers and helps in faster clearance of an incident site. Both these centers are assumed to be pre-existing in the present study. This system is deployed for each of the sub-corridors to get an estimate of the costs and benefits of putting such a system in place. It is assumed that such a system by itself will help in reducing incident duration by 33% and reduce traffic fatalities by 18%. These values have been derived in the same way as in the previous case. The requirements for such a system include communication linkages between the two centers, emergency management personnel and emergency management vehicles.

4.2.4 Combined Incident Detection and Response

This system combines both the above mentioned systems, namely Incident Detection and Verification and Incident Response Management. Thus the TMC will be responsible for detection of an incident and based on the severity will notify the EMC. This combined system is assumed to reduce incident durations by as much as 55%. As in the above two cases this system too is assumed to reduce fatalities by 18% on all the linkages which are covered by the system. This system is deployed on each of the sub-corridors to estimate the benefits and costs of having such a system in place. The deployments required for this system is the combination of all the deployments required for putting the above two systems in place.

4.3 ANALYSIS APPROACHES AND MEASURES

4.3.1 Economic Analysis

The Economic Analysis for these different ITS counter measures and their combinations are performed using the software tool IDAS. A description of this tool is presented in the following section.

4.3.1.1 ITS Deployment Analysis System (IDAS). IDAS was developed by Cambridge Systematics under contract to Oak Ridge National Laboratory and the Federal Highway Administration (FHWA). It was designed to be used as a sketch-planning analysis tool for evaluating the potential benefits and costs of ITS applications. It directly uses the travel demand models used by the Metropolitan Planning Organizations (MPO) and State Department of
Transportation (DOT). It utilizes the Traffic Assignment and the Modal Split steps of the traditional transportation planning model, to estimate the change in mode, route and temporal decisions of the travelers due to deployment of ITS applications.

The IDAS software consists of three resources for analyzing the impacts of ITS deployments. These are:

- Default ITS Impact Settings
- Equipment Database Spreadsheet
- ITS Library

The default settings have been determined through the review of observed impacts which have been documented in the ITS library. The Equipment Database consists of a detailed inventory of ITS equipments and the costs associated with the various ITS improvements.

IDAS consists of five different analysis modules. These are:

- Input/Output Interface Module
- Alternatives Generator Module
- Benefits Module
- Costs Module
- Alternatives Comparison Module

The benefits module further comprises of four sub modules: Travel time/ Throughput, Environment, Safety and Travel time Reliability.

The IDAS software consists of two different databases, IDASEMPTY.DB and IDAS.DB. The empty database, IDASEMPTY.DB is a template database which is used to create a new database when the user begins an IDAS session. The program reads the data input by the user and from the IDAS.DB database and writes to the new database. This database is dynamically updated as the program is run using a Sybase SQL Anywhere 5.5 database engine which runs in the background.

When an analysis is performed using IDAS it first creates a Control Alternative based on the travel demand model data to serve as a baseline for comparing various ITS alternatives. New alternatives can then be generated by the user using the Alternatives Generator module. These alternatives can then be compared using the Alternatives Comparison Module.

IDAS is capable of analyzing 60 different ITS components either individually or in combination. These components are grouped together into 11 market packages. These are:
1. Arterial Traffic Management Systems
2. Freeway Management Systems
3. Advanced Public Transit Systems
4. Incident Management Systems
5. Electronic Payment Systems
6. Railroad Grade Crossing Monitors
7. Emergency Management Services
8. Regional Multimodal Traveler Information Systems
9. Commercial Vehicle Operations
10. Advanced Vehicle Control and Safety Systems
11. Supporting Deployments

The Supporting Deployments consists of ITS components such as CCTV cameras, Traffic Management Center, Emergency Management Center etc., which do not yield any benefits when deployed alone but will yield benefits when deployed as part of any of the other market packages.

4.3.1.2 Economic Analysis Criteria. Normally selection between different ITS alternatives is based on a single criterion which is the benefit to cost ratio. However this method suffers from a serious drawback. It has been observed that certain alternatives yield very high benefit to cost ratios principally due to the fact that the costs for the deployment of the alternative are very low. So these alternatives get selected over others which yield much higher benefits. In the present study the different ITS alternatives will be compared across the following criteria.

1. Internal Safety Benefits
2. External Safety Benefits
3. Travel Time Reliability
4. Total Cost

All these measures are reported in terms of dollar values. Internal safety Benefits measure the safety benefits experienced by the users of the system due to reduction in fatalities, injuries and property damage, due to application of an ITS countermeasure. External Safety Benefits measure the benefits experienced by the system operators. Travel time reliability measures the
benefits experienced by the users of the system due to reduced variability of estimated travel times occurring due to faster clearance of incidents.

4.3.2 Operational Analysis

The impact of the different ITS countermeasures is computed using density as a measure. Density for each of the sub-corridors is computed using the Highway Capacity Manual (HCM) procedure for calculation of Level of Service of a basic freeway section. A Basic freeway section is defined as a section of a freeway which is free from the influence of any ramp or weaving area. In the HCM procedure the parameters that are used for computing the density are Free Flow Speed and Flow Rate. In the present study since field measurements of free flow speed is not possible it is estimated using the following relationship.

\[ FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \]

Where:

- \( FFS \) = Free Flow Speed, 70 mi/h (urban) and 75 mi/h (rural)
- \( BFFS \) = Base Free Flow Speed
- \( f_{LW} \) = Adjustment for lane width
- \( f_{LC} \) = Adjustment for right shoulder lateral clearance
- \( f_N \) = Adjustment for number of lanes
- \( f_{ID} \) = Adjustment for Interchange Density

These Adjustment factors are computed from exhibits provided in HCM 2000. The other parameter required for determining density is flow rate. The flow rate is computed using the following relationship.

\[ V_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \]

Where:

- \( V_p \) = 15 minute passenger car equivalent flow rate (pc/hr/ln)
- \( V \) = Hourly volume (veh/hr)
PHF = Peak Hour Factor
N = Number of Lanes
$f_{HV}$= Heavy Vehicle adjustment factor
$f_p$= Driver population factor

The heavy vehicle adjustment factor is computed using the following expression:

$$f_{HV} = \frac{1}{1 + P_T (E_T - 1) + P_R (E_R - 1)}$$

$E_T, E_R$ = passenger car equivalents for trucks/buses and recreational vehicles in the traffic stream
$P_T, P_R$ = proportion of trucks/buses and recreational vehicles in the traffic stream respectively

We can then calculate the density using the relationship:

$$D = \frac{V_p}{FFS}$$

In order to measure the impact of the ITS countermeasure we define effective density as below:

Density without application of ITS Countermeasure = $D_1$
Density after single lane closure due to incident = $D_2$
Density after right shoulder closure due to incident = $D_3$
Percentage Reduction in Incident Duration due to application of ITS Countermeasure = $X$

Fraction of single lane closures = $K_1$
Fraction of right shoulder closures = $K_2$
Effective Density = $(X/100)*D_1 + (1-X/100)(K_1*D_2 + K_2*D_3)$

The operational criterion used for comparing between the alternatives is the average effective density which is the mean of the effective densities of each of the sub-corridors. This operational criterion along with the four economic analysis criteria will be used in the decision making model to select the best alternatives and deployment strategy.
4.4 SUMMARY

Numerous ITS applications exist today that can be used for effective management of incidents and hence enhancing the safety of highways. In this chapter the conceptualized framework for selection of ITS applications and deployment is described. The operational and economic analysis criterion used for multi-criteria decision making using the ELECTRE I method is presented. The framework uses benefit to cost ratios to decide the preferred ITS application for each corridor. This forms the first level screening of the applications. In the second level the best deployment strategies for the corridors is decided using multi-criteria evaluation of the various deployment alternatives.
CHAPTER 5: CALCULATIONS AND RESULTS

This chapter demonstrates the utilization of the framework described in the previous chapter for selecting the appropriate ITS Alternative. We proceed from the step after data analysis and problem identification since the procedure has been demonstrated for the present case study in Chapter 3. We first select the preferred alternative for each of the sub-corridors. The ITS strategy selected for each sub-corridor is the one having the highest safety benefits per unit cost for deployment of the strategy. This process of selecting the preferred alternative for each sub-corridor is demonstrated in the section below.

5.1 SELECTING SUB-CORRIDOR LEVEL ITS STRATEGY

5.1.1 Sub-Corridor 1

The primary motivation behind application of ITS strategies to this corridor is to improve the safety of the sub-corridor through the application of Incident Management Systems (IMS). Hence the three ITS counter measures that we apply to this sub-corridor are Incident Detection and Verification (IDV), Incident Response Management (IRM) and Combination of Incident Detection and Response. This Analysis is performed using IDAS. In all these analyses the sub-modules used for benefits evaluation are the safety and the travel time reliability sub-modules. The results of the analysis for sub-corridor 1 are presented below:
Table 5.1 Results of Analysis for Sub-Corridor 1

<table>
<thead>
<tr>
<th></th>
<th>IDV</th>
<th>IRM</th>
<th>CDR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time</td>
<td>$14,784,477</td>
<td>$55,240,535</td>
<td>$74,536,179</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Accident Costs</td>
<td>$538,288</td>
<td>$615,982</td>
<td>$576,368</td>
</tr>
<tr>
<td>External Accident Costs</td>
<td>$94,992</td>
<td>$108,703</td>
<td>$101,712</td>
</tr>
<tr>
<td>Total Benefits</td>
<td>$15,417,757</td>
<td>$55,965,220</td>
<td>$75,214,259</td>
</tr>
<tr>
<td><strong>COSTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Costs</td>
<td>$1,241,854</td>
<td>$415,243</td>
<td>$1,658,513</td>
</tr>
<tr>
<td><strong>MEASURES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Benefits</td>
<td>$14,175,903</td>
<td>$55,549,977</td>
<td>$73,555,746</td>
</tr>
<tr>
<td>Benefit/Cost</td>
<td>12.42</td>
<td>134.78</td>
<td>45.35</td>
</tr>
<tr>
<td>Safety Benefits/ Cost</td>
<td>0.51</td>
<td>1.75</td>
<td>0.41</td>
</tr>
</tbody>
</table>
From the above results we can clearly see that the preferred alternative for Sub-Corridor 1 will be Incident Response Management. The cost and benefit figures given in the table are the average annual values for these given in 2002 dollars. The costs involved in putting the system in place are relatively low and it yields the highest overall as well as safety benefits per unit cost. The safety benefits realized from the system will be enough to get the returns on the costs involved in deployment of the system. It also results in the highest internal as well as external accident cost reductions, amongst all the three ITS strategies.

5.1.2 Sub-Corridor 2

The causes of occurrence of incidents on sub-corridor 2 are similar to that of sub-corridor 1. Hence for this sub-corridor too we apply the above three incident management strategies to the sub-corridor. The results of the analysis of these three strategies using IDAS are presented in the table below (Table 5.2)
### Table 5.2 Results of Analysis for Sub-Corridor 2

<table>
<thead>
<tr>
<th></th>
<th>IDV</th>
<th>IRM</th>
<th>CDR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time</td>
<td>$103,037</td>
<td>$329,970</td>
<td>477,571</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Accident</td>
<td>$84,498</td>
<td>$84,471</td>
<td>$84,471</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Accident</td>
<td>$14,911</td>
<td>$14,907</td>
<td>$14,907</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Benefits</td>
<td>$202,446</td>
<td>$429,347</td>
<td>$576,949</td>
</tr>
<tr>
<td><strong>COSTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Costs</td>
<td>$1,241,854</td>
<td>$415,243</td>
<td>$1,658,513</td>
</tr>
<tr>
<td><strong>MEASURES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Benefits</td>
<td>-$1,039,408</td>
<td>$14,104</td>
<td>-$1,081,564</td>
</tr>
<tr>
<td>Benefit/Cost</td>
<td>0.16</td>
<td>1.03</td>
<td>0.35</td>
</tr>
<tr>
<td>Safety Benefits/ Cost</td>
<td>0.08</td>
<td>0.24</td>
<td>0.06</td>
</tr>
</tbody>
</table>
From the results it is clear that for this corridor too Incident Response management is the preferred alternative. Not only are the safety benefits per unit cost highest for this alternative the overall benefit to cost ratio is also greater than 1, which indicates that the return on the investment made for the system deployment.

5.1.3 Sub-Corridor 3

This sub-corridor is different from the other two sub-corridors, because unlike the other two the principal cause for occurrence of incidents is high congestion levels. So for this corridor we can either have a system to reduce congestion levels or we can go in for the incident management strategies as in the previous two cases. Thus for this case we also consider implementing a Ramp Metering (RM) strategy to reduce congestion levels on the freeway and thus prevent occurrence of incidents. All these four alternatives were analyzed using IDAS to come up with the preferred alternative. The results of the analysis are presented in Table 5.3.
### Table 5.3 Results of Analysis for Sub-Corridor 3

<table>
<thead>
<tr>
<th></th>
<th>RM</th>
<th>IDV</th>
<th>IRM</th>
<th>CDR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time</td>
<td>-$879,287</td>
<td>$5,022,987</td>
<td>$16,399,243</td>
<td>$23,732,219</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal</td>
<td>-$3,543,460</td>
<td>$209,526</td>
<td>$248,099</td>
<td>$249,606</td>
</tr>
<tr>
<td>Accident Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External</td>
<td>-$625,305</td>
<td>$36,975</td>
<td>$43,782</td>
<td>$44,048</td>
</tr>
<tr>
<td>Accident Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Benefits</td>
<td>-$5,048,053</td>
<td>$5,279,487</td>
<td>$16,691,124</td>
<td>$24,025,873</td>
</tr>
<tr>
<td><strong>COSTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Costs</td>
<td>$651,999</td>
<td>$1,241,854</td>
<td>$416,659</td>
<td>$1,658,513</td>
</tr>
<tr>
<td><strong>MEASURES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Benefits</td>
<td>-$5,700,052</td>
<td>$4,037,633</td>
<td>$16,274,465</td>
<td>$22,367,360</td>
</tr>
<tr>
<td>Benefit/Cost</td>
<td>-7.74</td>
<td>4.25</td>
<td>40.06</td>
<td>14.49</td>
</tr>
<tr>
<td>Safety</td>
<td>-6.39</td>
<td>0.2</td>
<td>0.7</td>
<td>0.18</td>
</tr>
<tr>
<td>Benefits/ Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thus, we see that the Ramp Metering strategy is not a viable alternative as the system behaves worse than the control alternative. This happens because the congestion moves away from the freeway to the arterials and frontage roads leading to the freeway. Since IDAS measures network level benefits rather than just the corridor level benefits, we get negative benefits for the application. Like the previous two cases we find that in this sub-corridor the most viable ITS strategy is Incident Response Management.

5.2 CRITERIA EVALUATION

Having determined the preferred alternative for each sub-corridor individually we now need to find the best deployment strategy. We will consider all possible combinations of the preferred alternatives for the three sub-corridors (described in section 4.1.3). The results of the economic evaluation are presented in the following table (Table 5.4).
<table>
<thead>
<tr>
<th></th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
<th>Alternative 5</th>
<th>Alternative 6</th>
<th>Alternative 7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal Safety</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits</td>
<td>$615,982</td>
<td>$84,471</td>
<td>$248,099</td>
<td>$700,377</td>
<td>$332,466</td>
<td>$864,005</td>
<td>$948,448</td>
</tr>
<tr>
<td><strong>External Safety</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits</td>
<td>$108,703</td>
<td>$14,907</td>
<td>$43,782</td>
<td>$123,596</td>
<td>$58,670</td>
<td>$152,471</td>
<td>$167,343</td>
</tr>
<tr>
<td><strong>Travel Time</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>$55,240,535</td>
<td>$329,970</td>
<td>$16,399,243</td>
<td>$55,570,505</td>
<td>$16,728,896</td>
<td>$71,639,620</td>
<td>$71,969,590</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>$415,243</td>
<td>$415,243</td>
<td>$416,659</td>
<td>$830,486</td>
<td>$831,902</td>
<td>$831,902</td>
<td>$1,247,145</td>
</tr>
</tbody>
</table>
The criteria for operational analysis are the Effective Density for the sub-corridors. The procedure for the operational analysis is outlined in section 4.3.2. Wherever possible local data has been used, however for values that could not be ascertained default values given in HCM 2000 has been used. All lanes were assumed to be 12 feet wide, the right shoulder lateral clearance was assumed to be 6 feet unless an incident occurs there when no clearance is assumed, and the number of lanes in a direction was taken as three except for the case when incident related closure occurs when this number is reduced to two. The interchange density for each of the sub-corridors was calculated to be:

- Sub-Corridor 1 = 0.95
- Sub-Corridor 2 = 0.5
- Sub-Corridor 3 = 1.15

The number of vehicles per lane was calculated to be 1420 veh/hr/ln for IH-35 and 1015 veh/hr/ln for US-183. A Peak Hour Factor (PHF) of 0.95 is used for all computations and the driver population factor (fp) is assumed to be 1.00. The density for the sub-corridors is calculated for three cases, when no incident occurs on the freeway, when an incident results in a single lane closure and when an incident results in the closure of the right shoulder. The values used and the computed densities are presented in Table 5.5. The effective density for each sub-corridor for the seven alternative deployment strategies is presented in Table 5.6.
<table>
<thead>
<tr>
<th>Sub-Corridor</th>
<th>BFFS (mi/hr)</th>
<th>( f_{LC} ) (mi/hr)</th>
<th>( f_N ) (mi/hr)</th>
<th>( f_{ID} ) (mi/hr)</th>
<th>FFS (mi/hr)</th>
<th>V (veh/hr)</th>
<th>PHF</th>
<th>N</th>
<th>( f_{HV} )</th>
<th>( V_p ) (veh/hr)</th>
<th>Density (D) (pc/hr/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NI</td>
<td>70</td>
<td>0</td>
<td>3</td>
<td>2.26</td>
<td>64.74</td>
<td>3045</td>
<td>0.95</td>
<td>3</td>
<td>0.98</td>
<td>1090.23</td>
</tr>
<tr>
<td></td>
<td>SLC</td>
<td>70</td>
<td>0</td>
<td>4.5</td>
<td>2.26</td>
<td>63.24</td>
<td>3045</td>
<td>0.95</td>
<td>2</td>
<td>0.98</td>
<td>1635.34</td>
</tr>
<tr>
<td></td>
<td>RSC</td>
<td>70</td>
<td>2.4</td>
<td>3</td>
<td>2.26</td>
<td>62.34</td>
<td>3045</td>
<td>0.95</td>
<td>3</td>
<td>0.98</td>
<td>1090.23</td>
</tr>
<tr>
<td>2</td>
<td>NI</td>
<td>70</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>67</td>
<td>4260</td>
<td>0.95</td>
<td>3</td>
<td>0.816</td>
<td>1831</td>
</tr>
<tr>
<td></td>
<td>SLC</td>
<td>70</td>
<td>0</td>
<td>4.5</td>
<td>0</td>
<td>62.5</td>
<td>4260</td>
<td>0.95</td>
<td>2</td>
<td>0.816</td>
<td>2747.67</td>
</tr>
<tr>
<td></td>
<td>RSC</td>
<td>70</td>
<td>2.4</td>
<td>3</td>
<td>0</td>
<td>64.6</td>
<td>4260</td>
<td>0.95</td>
<td>3</td>
<td>0.816</td>
<td>1831</td>
</tr>
<tr>
<td>3</td>
<td>NI</td>
<td>70</td>
<td>0</td>
<td>3</td>
<td>3.22</td>
<td>63.78</td>
<td>4260</td>
<td>0.95</td>
<td>3</td>
<td>0.816</td>
<td>1831</td>
</tr>
<tr>
<td></td>
<td>SLC</td>
<td>70</td>
<td>0</td>
<td>4.5</td>
<td>3.22</td>
<td>62.28</td>
<td>4260</td>
<td>0.95</td>
<td>2</td>
<td>0.816</td>
<td>2747.67</td>
</tr>
<tr>
<td></td>
<td>RSC</td>
<td>70</td>
<td>2.4</td>
<td>3</td>
<td>3.22</td>
<td>61.38</td>
<td>4260</td>
<td>0.95</td>
<td>3</td>
<td>0.816</td>
<td>1831</td>
</tr>
</tbody>
</table>

NI ---- No Incident  
SLC --- Single Lane Closure  
RSC --- Right Shoulder Closure
Table 5.6 Effective Density for Each of the Sub-Corridors for the Different Alternatives.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Sub-Corridor</th>
<th>X</th>
<th>K1</th>
<th>K2</th>
<th>Effective Density (pc/hr/ln)</th>
<th>Average Effective Density (pc/hr/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>55</td>
<td>0.54</td>
<td>0.46</td>
<td>19.17</td>
<td>30.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0.15</td>
<td>0.85</td>
<td>30.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0.88</td>
<td>0.12</td>
<td>42.40</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0.54</td>
<td>0.46</td>
<td>22.01</td>
<td>31.08</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55</td>
<td>0.15</td>
<td>0.85</td>
<td>28.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0.88</td>
<td>0.12</td>
<td>42.40</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0.54</td>
<td>0.46</td>
<td>22.01</td>
<td>29.18</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0.15</td>
<td>0.85</td>
<td>30.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>55</td>
<td>0.88</td>
<td>0.12</td>
<td>34.86</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>55</td>
<td>0.54</td>
<td>0.46</td>
<td>19.17</td>
<td>30.13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55</td>
<td>0.15</td>
<td>0.85</td>
<td>28.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0.88</td>
<td>0.12</td>
<td>42.40</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0.54</td>
<td>0.46</td>
<td>22.01</td>
<td>28.57</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55</td>
<td>0.15</td>
<td>0.85</td>
<td>28.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>55</td>
<td>0.88</td>
<td>0.12</td>
<td>34.86</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>55</td>
<td>0.54</td>
<td>0.46</td>
<td>19.17</td>
<td>28.24</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0.15</td>
<td>0.85</td>
<td>30.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>55</td>
<td>0.88</td>
<td>0.12</td>
<td>34.86</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>55</td>
<td>0.54</td>
<td>0.46</td>
<td>19.17</td>
<td>27.62</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55</td>
<td>0.15</td>
<td>0.85</td>
<td>28.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>55</td>
<td>0.88</td>
<td>0.12</td>
<td>34.86</td>
<td></td>
</tr>
</tbody>
</table>
5.3 SELECTION OF SUPERIOR ALTERNATIVES

The subset of better alternatives and the deployment strategy to be adopted is decided using the multi-criteria decision making model ELECTRE I. The first step involves assigning weights to the different criteria. In this study the following weights have been assigned to the five criteria (Table 5.7). It should be borne in mind that for the first three criteria higher values are desired, but for the remaining two criteria lower values are desired.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Safety Benefits</td>
<td>25</td>
</tr>
<tr>
<td>External Safety Benefits</td>
<td>20</td>
</tr>
<tr>
<td>Travel Time Reliability</td>
<td>15</td>
</tr>
<tr>
<td>Total Costs</td>
<td>25</td>
</tr>
<tr>
<td>Average Effective Density</td>
<td>15</td>
</tr>
<tr>
<td>(pc/hr/ln)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.7 Weights Assigned to the Different Criteria

Using these weights we now compute the Concordance Matrix (refer Appendix B). The elements of the matrix, \( C(I,J) \) gives a measure of how much better Alternative I performs over Alternative J. It is computed by summing the weights of those criteria in which I performs better than J and half the weights of those criteria in which both perform equally well and then dividing this sum by the sum of all weights. A few sample calculations for elements of the matrix and the concordance matrix has been presented below:

\[
C(1,2) = (25+20+15+15+25/2) = 87.5
\]
\[
C(2,5) = (0+0+0+15+10/2+10/2+0) = 25
\]
Table 5.8 Concordance Matrix

<table>
<thead>
<tr>
<th>Alternative</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>---</td>
<td>0.875</td>
<td>0.85</td>
<td>0.25</td>
<td>0.45</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>0.125</td>
<td>---</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>0.15</td>
<td>0.75</td>
<td>---</td>
<td>0.40</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>0.75</td>
<td>0.75</td>
<td>0.60</td>
<td>---</td>
<td>0.85</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>0.55</td>
<td>0.75</td>
<td>0.75</td>
<td>0.15</td>
<td>---</td>
<td>0.125</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.875</td>
<td>---</td>
<td>0.25</td>
</tr>
<tr>
<td>7</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>---</td>
</tr>
</tbody>
</table>

We now calculate the Discordance Matrix which gives a measure of the worst performance of one alternative relative to the other normalized to a scale from 0 to 1. Thus the discordance matrix element, $D(I,J)$ measures the worst performance of Alternative I relative to Alternative J. Thus the value $D(I,J)$ is defined as:

$$
D(I,J) = \max \left( \frac{V_{I,C} - V_{J,C}}{V_{\text{max}} - V_{\text{min}}} \right)
$$

where:

- $V_{I,C}$ = Value of Alternative I on Criterion C
- $V_{J,C}$ = Value of Alternative J on Criterion C
- $V_{\text{max}}$ = Maximum observed value for any alternative on Criterion C
- $V_{\text{min}}$ = Minimum observed value for any alternative on Criterion C

$C$ is an element of the set of criteria where Alternative J performs better than Alternative I. A sample calculation for the discordance matrix element $D(2,3)$ is presented. Alternative 3 performs better than Alternative 2 on all criteria except Total Cost.
Internal Safety Benefits: $D_1(2,3) = \frac{(24,8099-84,471)}{(94,8448-84,471)} = 0.19$

External Safety Benefits: $D_2(2,3) = \frac{(43,782-14,907)}{(167,343-14,907)} = 0.19$

Travel Time Reliability Benefits: $D_3(2,3) = \frac{(16,399,243-329,970)}{(71,969,590-329,970)} = 0.22$

Average Effective Density: $D_4(2,3) = \frac{(31.08-29.18)}{(31.08-27.62)} = 0.55$

Thus, $D(2,3) = \max \{0.19, 0.19, 0.22, 0.55\} = 0.55$

The Discordance matrix has been presented in Table 5.9.

### Table 5.9 Discordance Matrix

<table>
<thead>
<tr>
<th>Alternative</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td>0.63</td>
<td>0.73</td>
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<td>0.81</td>
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<td>0.49</td>
<td>0.50</td>
<td>---</td>
<td>0.45</td>
<td>0.55</td>
<td>0.73</td>
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<tr>
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<td>0.50</td>
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<td>0.54</td>
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<tr>
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<td>0.50</td>
<td>0.50</td>
<td>0</td>
<td>0</td>
<td>---</td>
<td>0.18</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>---</td>
</tr>
</tbody>
</table>

We now define the outranking relationship that will be used for developing the graph and selecting the kernel of superior Alternatives (Refer Appendix B). An Alternative I will outrank Alternative J if, the following two conditions are satisfied:

$C(I,J) \geq C^*$ and $D(I,J) \leq D^*$

The values $C^*$ and $D^*$ are known as the Concordance and Discordance Index respectively. These values are specified by the decision maker. However it is observed that the set of superior alternatives is insensitive to these values. A sensitivity analysis can be performed by changing the level of these values.
To construct a graph of the outranking relationship first each of the alternatives are represented as nodes. Now, if an Alternative I outranks Alternative J, this relationship is represented by drawing an arrow from Node I to Node J. The kernel for the graph is the set of nodes which satisfy the following two conditions.

1. No outranking relationship exists amongst nodes which form the kernel.
2. All nodes not in the kernel are outranked by at least one node in the kernel.

Presented below is the graph of the outranking relationship for a concordance index of 0.7 and a discordance index of 0.5.
From the graph we see that the alternatives forming the Kernel are Alternatives 1 and 7.

Sensitivity Analysis for the results was performed by changing the values of the concordance and discordance indices. The results of the Analysis are presented in Table 5.10.
Table 5.10  Results of Sensitivity Analysis

<table>
<thead>
<tr>
<th>Concordance Index</th>
<th>Discordance Index</th>
<th>Alternatives in Kernel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.3</td>
<td>1,3,6,7</td>
</tr>
<tr>
<td>0.6</td>
<td>0.4</td>
<td>1,3,6,7</td>
</tr>
<tr>
<td>0.6</td>
<td>0.5</td>
<td>1,7</td>
</tr>
<tr>
<td>0.7</td>
<td>0.3</td>
<td>1,3,6,7</td>
</tr>
<tr>
<td>0.7</td>
<td>0.4</td>
<td>1,3,6,7</td>
</tr>
<tr>
<td>0.7</td>
<td>0.5</td>
<td>1,7</td>
</tr>
<tr>
<td>0.8</td>
<td>0.3</td>
<td>1,3,4,6,7</td>
</tr>
<tr>
<td>0.8</td>
<td>0.4</td>
<td>1,3,4,6,7</td>
</tr>
<tr>
<td>0.8</td>
<td>0.5</td>
<td>1,4,6,7</td>
</tr>
</tbody>
</table>

We see that the Alternatives 1 and 7 are insensitive to changes in the Concordance and Discordance indices and hence these will be the set of alternatives that will be used to develop the deployment strategy.

5.4 DEPLOYMENT STRATEGY

Alternative 1 involves application of Incident Response Management to only US-183 while Alternative 7 involves its application to both the US-183 and the IH-35 corridors. A significant deciding factor at this point would be the funding available for the ITS application. If sufficient funds are available we can go for alternative 7 however if funds are limited the applications can be deployed to cover the US-183 corridor and later the system can be expanded to cover both the corridors.
5.5 SUMMARY

A demonstration of the framework presented in Chapter 4 for selection and deployment of ITS applications is presented in this chapter. It is used to decide the potential ITS deployments that can be utilized to realize safety benefits from these applications on the US-183 and IH-35 corridors in Austin. This numerical example is presented for a better understanding of the framework. The various steps involved in the process are presented in detail. It is observed that the preferred alternative for all the corridors is Incident Response Management. And the best deployment strategies involve application of the system to either US-183 corridor or to both the corridors.
CHAPTER 6: RECOMMENDATIONS AND CONCLUSION

6.1 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDY

It should be borne in mind that an analysis is as good as the data it utilizes. Hence to gain meaningful information from the framework developed good quality data should be used. A major limitation of the present study is the use of default values to estimate the impacts of ITS applications. Though these values have been derived from documented national experiences, it has also been observed that there have been significant local variations of the impacts.

One major limitation that the ITS planning process suffers today is the lack of simulation models. Simulation models will help us in gaining a better understanding of how ITS applications impact traffic operations. In future studies the operational impacts can be estimated using simulation models. Though no simulation model exists today which can estimate the impacts of ITS applications much work is being done in this direction. Hopefully in the future when such models are developed they can be integrated into the framework.

6.2 CONCLUSION

Today we are moving away from building of new highway systems to increasing the operational efficiency of the existing systems, and ITS technologies are playing a critical role in helping us achieve this goal. Thus selection of ITS applications and developing proper deployment strategies is an important part of the transportation planning process today. Most frameworks developed in the past have relied solely on evaluation of either economic or operational benefits of such applications. The framework developed in this study is important in this regard as it is hybrid in nature and integrates both operational and economic benefits evaluation criteria. It also demonstrates how the results from new ITS planning tools such as IDAS can be used for selecting between alternatives. Traditionally the selection between different alternatives is based on benefit to cost ratio, that is, the alternative with the highest benefit to cost ratio is selected. However this method often results in selection of alternatives with low benefits as they have relatively low deployment and operational costs.

It is important to note that the framework developed here is fully scaleable and can be used for any ITS planning process. Though the method uses five criteria for selection of the
deployment strategies, it can be applied to more complex metropolitan areas as well where more criteria can be used in the process.
APPENDIX A

FLOWCHART FOR THE EVALUATION FRAMEWORK

1. SELECT CORRIDORS FOR EVALUATION
2. DIVIDE CORRIDORS INTO SUB-CORRIDORS
3. ANALYZE DISTRIBUTION AND CAUSES OF INCIDENTS ON SUB-CORRIDORS
4. DEVELOP ITS STRATEGIES FOR EACH SUB-CORRIDOR
5. SCREEN APPLICATIONS BASED ON SAFETY B/C

A
STEPWISE INTEGRATE DEPLOYMENTS TO FORM DIFFERENT ALTERNATIVES

PERFORM ECONOMIC ANALYSIS OF DEPLOYMENT ALTERNATIVES

PERFORM OPERATIONAL ANALYSIS OF DEPLOYMENT ALTERNATIVES

SELECT EVALUATION CRITERIA

FIND BEST DEPLOYMENT STRATEGY USING MULTI-CRITERIA EVALUATION
APPENDIX B

MULTI-CRITERION EVALUATION USING ELECTRE I

ELECTRE I is a multi-criteria evaluation tool for selecting between different alternatives. The method is utilized in reducing the number of alternatives to a small number. Let the set of different alternatives be represented by A and the set of criteria be represented by C.

Thus, \[ A = \{ a_1, a_2, a_3, a_4 \ldots a_k \} \]
\[ C = \{ c_1, c_2, c_3, c_4 \ldots c_n \} \]

The decision maker is initially asked to specify weights for each of the alternatives. Let these be represented by the set W.

\[ W = \{ w_1, w_2, w_3, w_4 \ldots w_n \} \]

We first construct the concordance matrix. The element \( C(i,j) \) measures the concordance of alternative I over alternative J.

\[
C(i,j) = \frac{W^+ + 0.5*W^=}{W^+ + W^- + W^=} 
\]

where,

\( W^+ \) is the sum of all weights for which I performs better than J.
\( W^- \) is the sum of all weights for which J performs better than I.
\( W^= \) is the sum of all weights for which alternatives I and J perform equally well.

We next construct the discordance matrix. An element \( d(i,j) \) measures the worst performance of Alternative I relative to J.

\[
d(i,j) = \max\left(\frac{V_{J,C} - V_{I,C}}{V_{max} - V_{min}}\right) 
\]

\( V_{J,C} \) = Performance of option J on criterion C
\( V_{I,C} \) = Performance of option I on criterion C.
\( V_{max} \) = Maximum performance for any alternative on criterion C
\( V_{min} \) = Minimum performance for any alternative on criterion C.
The next step involves fixing the concordance and discordance index, by the decision maker.

CI = Concordance Index
DI = Discordance Index.

Based on these values we define an outranking relationship. Alternative I is said to outrank Alternative J if the following two conditions are satisfied;

\[
\begin{align*}
C(i, j) & \geq CI \\
D(i, j) & \leq DI
\end{align*}
\]

We then construct the graph of the outranking relationship. The graph is constructed by representing the alternatives by nodes and drawing an arc from node I to J if alternative I outranks alternative J.

From the graph we select the subset of superior alternatives which form the Kernel. The alternatives in the kernel should satisfy the following two criterion.

No outranking relation ship exists between alternatives in the kernel.

All alternatives not in the kernel are outranked by at least one element in the kernel.
REFERENCES


    http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_pr/45v01!.PDF

    http://www.fhwa.dot.gov/tea21/sumover.htm