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**INVESTIGATION OF AN ITS FRAMEWORK FOR
CONGESTION PRICING**

by

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ABSTRACT

This report documents an investigation of an ITS framework for congestion pricing. It begins with a review of the literature related to congestion pricing and ITS benefits prediction methods, which were used as a foundation for the development and analysis of an ITS framework for congestion pricing. In order to develop the framework, activities associated with congestion pricing were first described and then ITS elements were identified to perform these tasks. Analysis of the associated benefits of using the ITS framework for congestion pricing was attempted using two different computer based ITS analysis tools: SCReening for ITS (SCRITS) and ITS Deployment Analysis System (IDAS). Finally the results and findings of this study are presented.

EXECUTIVE SUMMARY

Traffic congestion is becoming a serious problem in virtually all large urban areas, and the problem will continue to worsen as the population and car ownership rates continue to grow. Traffic congestion in the U.S. leads to billions of dollars lost each year due to “lost time and productivity, air pollution, and wasted energy” (Berg and Young, 1999). From 1980 to 1997, there was a 4 percent increase in highway lane-miles, a 31 percent increase in registered motor vehicles, and a 67 percent increase the vehicle-miles traveled. During this same time period it is estimated that the largest U.S. metropolitan areas witnessed a 100 percent to 300 percent increase in the average annual hours of delay per vehicle (Skinner, 2000). As right of way becomes increasingly harder to obtain due to lack of available land and high land prices, roadway expansion is becoming nearly impossible in most metropolitan areas. In the future more transportation management strategies will need to be considered to aid the congestion problem, especially since roadway expansion is becoming less feasible. One possible traffic management method is to implement congestion pricing.

With congestion pricing variable tolls are charged to travel on designated roadways during congested periods. By charging a toll based on the level of congestion, some travelers may choose to reconsider their travel choices and choose to use alternate routes or modes or to travel during alternate times in order to avoid paying premium prices for their travel. These changes in travel patterns would allow the transportation system to be used more effectively and in effect would reduce the level of congestion, energy consumption, and automobile emissions (Finch, 1996).

Technological advances are making the idea of congestion pricing more feasible. In the past one major drawback of a congestion pricing project was the added time for toll collection. Over the last couple of decades there have been many technological advances to solve this problem. Electronic toll collection is now possible and other technologies can be used for enforcement and providing travelers with information. These technologies are referred to as intelligent transportation systems (ITS) and are necessary for a successful and efficient congestion pricing project.

The overall objective of this study was to develop and analyze an ITS framework to be used in conjunction with congestion pricing. A review of the literature related to congestion pricing and ITS benefits prediction methods was first provided, to serve as a foundation for the

development and analysis of the ITS framework. The ITS framework was then developed based on the necessary activities associated with congestion pricing, outlined in the literature, and the available technologies. It was determined that an electronic toll collection system, cameras, variable message signs, vehicle detection devices, and a management center would be necessary for a congestion pricing system.

In order to evaluate the ITS framework developed for congestion pricing, two different ITS benefits analysis tools, SCReening for ITS (SCRITS) and ITS Deployment Analysis System (IDAS), were used to attempt to analyze the potential benefits of deploying this framework. Although neither analysis tool had the capability of directly analyzing the benefits of a congestion pricing system, it was initially thought that a congestion pricing system could be analyzed by adding the individual elements to the corridor for analysis purposes. Unfortunately it was eventually found that neither analysis tool was able to analyze all of the components deemed necessary for congestion pricing, and it was not possible to directly analyze the benefits of using the proposed ITS framework.

Although these analysis tools were not able to predict all of the benefits associated with using the congestion pricing framework developed on this corridor, they may be more beneficial for analyzing other ITS applications. Future research should look at comparing the results of other ITS applications evaluated by these systems. From the results of this research, both analysis tools appear as if they could be used as a starting point for ITS analysis purposes.

Finally, it is recommended that future related research should consider use of analysis tools directly related to congestion pricing. This may be accomplished through the development of new analysis tools or through modifications of existing ones.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Traffic congestion is becoming a serious problem in virtually all large urban areas, and the problem will continue to worsen as the population and car ownership rates continue to grow. Traffic congestion in the U.S. leads to billions of dollars lost each year due to “lost time and productivity, air pollution, and wasted energy” (Berg and Young, 1999). From 1980 to 1997, there was a four percent increase in highway lane-miles, a 31 percent increase in registered motor vehicles, and a 67 percent increase in vehicle-miles traveled. During this same time period it is estimated that the largest U.S. metropolitan areas witnessed a 100 percent to 300 percent increase in average annual hours of delay per vehicle (Skinner, 2000). This large gap between the increase in vehicle miles traveled and the increase in highway lane-miles, can be attributable to the congestion problem in many urban areas.

Traditionally the solution to this problem has been to build more roads or to add additional capacity to existing roadways. This solution is becoming less feasible in most urban areas and in many cases impossible, as right-of-way becomes increasingly harder to obtain due to lack of available land and high prices. In the future, transportation planners must look to alternative approaches for alleviating the traffic congestion problem. Various traffic management strategies may prove to be successful in providing modest relief to the congestion problem and should seriously be considered.

1.2 TRAFFIC MANAGEMENT STRATEGIES

Traffic management strategies have been used throughout the world for managing congestion and influencing travel demand. These strategies are designed to improve the operating efficiency of the existing transportation system by increasing use of alternative modes, altering trip patterns, and improving traffic flow. There are two different categories of traffic management strategies: supply-side and demand-side.

Supply-side measures focus on increasing the existing transportation system capacity in order to improve overall traffic flow (Strickland and Berman, 1995). There are different options available to increase the capacity of a transportation network. One option would be to simply build more roads or add capacity to existing ones. The problem with this option is that in many areas available land is limited and is very expensive, making this option not very feasible.

Another option is to increase the availability of transit and non-motorized vehicle modes by adding bus and High Occupancy Vehicle (HOV) lanes, creating more pedestrian and bicycle facilities, and expanding existing transit services (Contreras, 2001). Transit services could also be expanded to include express bus services and park-and-ride facilities in addition to other service improvements (Strickland and Berman, 1995). Improving the efficiency of the existing facility is another supply side option. This could be done in a variety of ways, some of which include: adding ramp meters, use of traveler information systems, making signalization improvements, and improving incident management (Contreras, 2001).

Demand-side measures on the other hand, focus on reducing vehicle demand on the transportation network. The objective is to increase vehicle occupancy, increase public transit usage, reduce the need to travel during peak periods, and reduce the need to travel to specified locations (Strickland and Berman, 1995). There are a variety of alternatives that fall into the demand-side of traffic management. Communications substitutes are one alternative for reducing demand through telecommuting, teleconferencing, and teleshopping. Traveler information also falls into this category; providing pre-trip information to travelers may decrease the demand to make particular trips or to encourage alternative travel times. Administrative measures could be used such as trip reduction ordinances, alternative work schedules, auto restricted zones, and parking management. Finally economic measures could be used to deter single occupancy vehicle use and/or travel during peak periods. This could be done through use of congestion pricing, parking pricing, transportation allowances, and financial incentives for use of transit or ridesharing programs (Strickland and Berman, 1995).

Demand-side alternatives are appealing traffic management options because they typically do not require as large a financial investment as supply-side alternatives (Contreras, 2001). Roadway pricing projects are one demand-side alternative that has been used throughout the world and has been found to be successful in relieving congestion. There are various forms of roadway pricing that exist, some of which include: toll roads, vehicle user fees, high occupancy toll (HOT) lanes, Cordon area tolls, road space rationing, and congestion pricing. Although there are many similarities, they are all slightly different. Toll roads are commonly used to fund highway and bridge improvements through user service fees. Vehicle use fees, in the form of distance-based charges are sometimes used as a form of road pricing. HOT lanes allow single occupancy vehicles to buy their way into high occupancy vehicle (HOV) lanes. Cordon area tolls are fees charged to enter a particular area, typically a city center. Road space

rationing usually involves an allotment of a certain amount of vehicle-trips or vehicle-miles for each driver over a chosen time period (Victoria Transport Policy Institute, 2001). Congestion pricing involves paying a fee to use a roadway determined by the level of congestion and will be the focus of the next section.

1.3 CONGESTION PRICING

Congestion pricing is based on an economic rationale. As the number of users on a road network increases, travel speeds decrease and user costs increase. Congestion pricing is the act of charging variable tolls or user fees to travel on a roadway during congested periods, based on the difference between the marginal social cost and the marginal private cost of making the trip. By charging a toll proportional to the level of congestion, some travelers may choose to reconsider their travel choices and choose alternate routes or modes or to travel during alternate times, in order to avoid paying premium prices for their travel. Equilibrium is attained through this process by travelers only choosing to make their trip if the benefit of traveling is greater than the associated cost. Traditionally when travelers decide to make a trip, the actual cost of the trip may not be perceived. For example, as speeds on a roadway decrease every additional driver imposes additional costs for those already on the roadway, by decreasing the travel speed even more. Drivers may not realize these costs associated with their travel, but by using congestion pricing the driver would come to understand the actual costs associated with their travel choices (May, 1993).

Use of congestion pricing has the potential to dramatically affect the travel patterns of a transportation system. Some of the possible changes in travel choices that may occur, include change in: route choice, time of travel, mode, destination, linked trips, trip frequency and activity selection, automobile ownership, and the location of residence or work (TRB, 1994). These changes in travel patterns would allow the transportation system to be used more efficiently and in effect would reduce the level of congestion, energy consumption, and automobile emissions (Finch, 1996). In addition, use of congestion pricing would produce revenues that could be used to expand and repair the transportation system (Decorla-Souza, 1993). Although there are many benefits associated with congestion pricing, there will still be some people that will lose. Equity and fairness issues associated with congestion pricing will be considered in greater detail in the next chapter.

The idea of congestion pricing is becoming a more attractive concept for congestion management throughout the world. Various pricing schemes have been introduced in Canada, Singapore, Norway, and other countries, and many more countries have projects that are in the planning stages. In 1991, the U.S. Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA), which was a six-year plan to help improve the nation's transportation system. Through ISTEA a national Congestion Pricing Pilot Program was authorized to aid in funding feasibility studies and pilot tests for a number of variable pricing projects nationwide. This program has funded pre-implementation studies in Portland, Oregon; Westchester County, New York; Minneapolis, Minnesota; Boulder, Colorado; Sonoma County, California; and Los Angeles, California. It has also funded pilot tests in San Diego, California; Lee County, Florida; and Houston, Texas (Schiller, 1998). The use of intelligent transportation systems is also playing a large role in the growth of congestion pricing projects.

1.4 INTELLIGENT TRANSPORTATION SYSTEMS

Technological advances are making the idea of congestion pricing more feasible. In the past one major drawback of a congestion pricing project was the added time for toll collection. Over the last couple of decades there have been many technological advances to solve this problem. Electronic toll collection is now possible and other technologies can be used for enforcement and providing travelers with information. These technologies are referred to as intelligent transportation systems (ITS) and are necessary for a successful and efficient congestion pricing project.

ITS technologies have been deployed in various locations throughout the world, with the ultimate goal of improving an area's transportation system. ITS applications cover a whole spectrum of transportation activities. They can be used to help manage arterial traffic, freeways, and incidents. They are being used to make commercial vehicle operations and public transit systems more efficient. They can also be used to provide travelers with up to date information on traffic conditions, whether it be pre-trip or in route. Whatever the application may be, they all work towards improving the transportation system.

In the U.S., the ITS Joint Program Office (JPO) established a set of goals for ITS projects back in the spring of 1996, which include "improving traveler safety, improving traveler mobility, improving system efficiency, increasing the productivity of transportation providers and conserving energy while protecting the environment" (Proper et al, 2001, pp. 4). In order to

evaluate these goals, the JPO also identified various measures of effectiveness commonly referred to as the “Few Good Measures.” These measures include safety, delay or travel timesavings, cost savings, improvements in effective capacity, customer satisfaction, and energy and environmental impacts (Proper et al, 2001).

These “Few Good Measures” commonly used to evaluate the effectiveness of various ITS projects are each associated with their own measures of effectiveness. The overall objectives of safety are to reduce the number of crashes and also to reduce the probability of the occurrence of a fatal crash. In order to quantify safety, typically “the overall crash rate, fatality crash rate, and injury crash rate” are considered (Proper et al, 2001, pp. 4). Mobility improvements can be made through reductions in delay and travel time and is commonly measured by the amount of delay or travel time variability. The efficiency of a transportation system can be improved by increasing its effective capacity. Although measuring the effective capacity would be very difficult, so throughput is typically used for this measure, which is “the number of persons, goods, or vehicles traversing a roadway section or network per unit time” (Proper et al, 2001, pp. 5). The cost savings attributable to their deployment, compared to traditional transportation improvement methods, typically measures the productivity of ITS projects. In order to measure the impacts of ITS projects on the environment and energy usage, emission levels (CO, NO_x, and HC) and fuel usage is commonly used. The fuel use is typically quantified by fuel use in liters or gallons and fuel economy in kilometers per liter or miles per gallon. Customer satisfaction is harder to directly measure than most of the other measures. Other measures related to satisfaction are typically used for this purpose, such as: “amount of travel in various modes, mode choices, and the quality of service as well as the volume of complaints and/or compliments received by the service provider” (Proper et al, 2001, pp. 6).

The goals laid out here for using ITS are quite similar to those of using congestion pricing, and it is easy to understand how together, they could be used to provide an efficient traffic management system. Understanding the goals behind these measures of effectiveness will be important later in this report, when the benefits of using various ITS technologies with congestion pricing are being analyzed.

1.5 OBJECTIVE AND STRUCTURE OF REPORT

The overall objective of this study is to develop and analyze an ITS framework to be used in conjunction with congestion pricing. The framework will be based on the necessary activities

associated with congestion pricing and the available technologies, and the analysis will be carried out using two different computer based ITS benefit analysis tools.

The structure of the report will be as follows: Chapter 2 will present a comprehensive literature review on the more heavily studied areas of congestion pricing and some case studies. It will also discuss many of the different techniques that have been used for predicting ITS benefits in the past. This will give a foundation for many of the basic considerations necessary to account for when planning a congestion pricing project and will also help for analyzing the results of the computer software packages used for analysis. Chapter 3 will identify the basic activities associated with a congestion pricing project and identify the necessary ITS elements for carrying out these tasks. Chapter 4 will discuss the computer software packages used for analysis and their capabilities. The sources of data and the various assumptions made for the analysis will also be discussed. Chapter 5 will present an analysis and comparison of the results obtained from the computer software packages, and finally Chapter 6 will give final conclusions and recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

When considering congestion pricing as a traffic demand management alternative for a region, there are many considerations that need to be accounted for in the decision making process. In order to better understand these considerations, this chapter will discuss many of the findings of past congestion pricing studies, as well as discuss a few case studies. The intent is to give a foundation of the basic considerations necessary for future congestion pricing feasibility studies.

Since developing and analyzing an ITS framework to be used with congestion pricing are the ultimate goals of this report, various studies that have been conducted to predict the benefits of using different ITS packages will also be presented. This is important in order to help assess the results of the models that will be presented later in this report.

This chapter will be broken down into two main parts: the congestion pricing literature and the ITS benefits prediction studies.

2.2 CONGESTION PRICING

Throughout the years there have been many different aspects of congestion pricing studied. This section will present some of the more heavily studied areas including: public and political acceptability, value of time estimates, equity and fairness considerations, and the effects of pricing on travel behavior. Since ITS applications associated with congestion pricing are of particular interest in this report, studies relating advanced traveler information and congestion pricing will also be discussed. Finally a few selected case studies will be presented.

2.2.1 Public and Political Acceptability

Without public and political acceptance, it is impossible to implement a new congestion pricing project. In the past, public and political barriers have often been the obstacles of proposed congestion pricing projects. Political barriers led to the abandonment of a project proposed in Cambridge, England. In this case a technological field trial was in place, but when a new council came into power in 1993, the project was discarded due to lack of support from the new governing body. During this same time period, Hong Kong also had an electronic road

pricing scheme in the planning stages, but the idea ended up being rejected due to public resistance (Small and Gomez-Ibanez, 1994).

Public and political barriers of congestion pricing have been the topic of numerous research papers over the past couple of decades. Many of these studies have drawn on lessons learned from existing projects, as well as failed attempts. Frick et al. (1996), Dittmar et al. (1994), and Small and Gomez-Ibanez (1994) are a few specific examples. Other studies have tried to determine some of the implementation barriers through public opinion surveys and interest groups. This approach was used by Harrington et al. (2001), Adler et al. (1999), Burris and Swenson (1998), and Yelds and Burris (2000). Papers by Giuliano (1992) and Jones (1998) provide a good comprehensive summary of the results of various studies.

The variable-pricing project in Lee County, Florida is a good example of a successful project that considered public and political concerns in the early planning stages. This project involves value pricing two bridges that connect an area that is mainly residential to an area that contains most of the job market. In order to gain public and political acceptance, surveys were conducted to understand public and political concerns. These results indicated that the typical form of congestion pricing, raising tolls during peak periods, was not going to be accepted by the public. In this case, it was found that the public would be much more receptive to a program that lowered tolls by 50 percent during the shoulders of the peak periods. It was determined that some of the peak period traffic would shift to the shoulders of the peak periods, in order to save 50 percent of the toll normally charged during the peak periods. Toll pricing varying by the time of day was introduced into the area on August 3, 1998 (See Burris and Swenson, 1998 and Yelds and Burris, 2000).

2.2.2 Value of Time Estimates

Being able to accurately predict the value of traveler time is of great importance for implementing a successful congestion pricing project. If the amount charged is not high enough, travelers will not change their travel behavior and congestion pricing has done nothing to help alleviate the congestion problem. On the other hand, if the price is set too high equity issues may arise. Many travelers may not be able to afford the toll and will have to use other roadways, not make their trip at all, or find an alternate mode of transportation. These options may not be feasible in all cases and may adversely affect travelers who cannot afford high tolls and may also adversely affect travel on roadways that are not tolled. It is also important to consider that the

value of time estimates may not necessarily be the same for different regions or cities, and should be accounted for when determining an appropriate pricing scheme for a particular area. In addition, the traveler's value of time may also differ by time of day.

In the past, value of time estimates have often been made from revealed preference data or from stated preference surveys. Kazimi et al (2000) used revealed preference data from San Diego's I-15 corridor to estimate traveler's value of time for the a.m. peak period. They found that in order to reduce travel time, a median value of \$31 was estimated as the traveler's willingness to pay. It was also estimated that travelers were willing to pay a median value of \$20 to reduce the variability of their trip. Ghosh (2001) used this same data, but also considered the p.m. peak period. From this study, the value of time was estimated to be between 50 and 101 percent of the commuters' hourly rates, but the value of time estimates were much greater for the a.m. peak than for the p.m. peak. This may be because people's morning schedules do not allow for as much variability as their evening schedules, possibly due to restrictive work schedules.

Calfee and Winston (1998) used a stated preference survey to estimate the amount of money drivers are willing to pay in order to reduce their travel time. This study found that drivers are willing to pay between 14 and 26 percent of their gross hourly wage. This is drastically lower than the values estimated by Kazimi et al. and Ghosh and may partially be due to the difference in revealed preference and stated preference data. People may not always state what they would actually do in a given situation, possibly distorting results. In addition, the data used by Kazimi et al. and Ghosh comes from a corridor that is currently using High Occupancy Toll (HOT) lanes, and the people that choose to pay to use this facility may have a higher than average value of time.

2.2.3 Equity and Fairness Considerations

Whether or not congestion pricing is fair to all users is one of the major social issues up for debate. Unfortunately there will probably be both winners and losers associated with any congestion pricing project. Bhatt (1993) has identified various winners and losers of congestion pricing. There are a variety of potential winners of using congestion pricing. Some of these groups include: existing users of high occupancy vehicle (HOV) modes, single occupancy vehicle (SOV) users that change to an HOV mode due to service improvements, road users that have a high value of time, businesses that can provide more efficient delivery systems, and those that benefit from the use of the revenues. Unfortunately there will still be those that will lose:

travelers that cannot afford the congestion pricing fees, businesses that may not be able to compete with companies that are outside the congested region, and neighborhoods that may incur cut through traffic.

Many papers have been written that address the equity and fairness considerations of congestion pricing. Richardson and Bae (1998), Bhatt (1993), and Giuliano (1994) all provide good summaries of the major issues. The main focus of the equity issue is the belief that low-income people will ultimately lose with a congestion pricing project, while higher income drivers will reap most of the benefits. In actuality, the impact on different income groups will depend on their tendency to travel and their value of time (Bhatt, 1993). It has often been argued that low-income travelers make fewer trips when compared to higher income groups and that they represent a disproportionately larger fraction of transit trips (Bhatt, 1993). This was found to be true in the San Francisco area; the average salary of the commuters using the Bay Bridge was 50 percent higher than the area's average salary and only three percent of the commuters were under 150 percent of the U.S. poverty rate (Schiller, 1998). In addition, although low income groups may not be able to afford to use the roadways all of the time, they could occasionally pay for trips associated with a higher value of time and take advantage of the time savings.

Gender equity is another issue of concern with congestion pricing. Women commuters would tend to be more adversely affected by congestion pricing than their male counterparts. Women workers comprise a much larger portion of low-income commuters and are more likely to hold jobs with less flexible work schedules (Bhatt, 1993). In addition, women typically take care of the majority of the shopping trips and errands associated with children in a household, all of which are harder to do using alternate travel modes.

The way that congestion pricing revenues are spent may help address some of the equity concerns. The revenues could be used to reduce taxes on gasoline or to reduce the area's sales tax, if there is currently a percentage of the tax used for transportation. They could also be used to help subsidize travel for low-income travelers. And finally, improving and expanding public transit service in an area would give more travelers alternate options to driving. All of these options could be used to help alleviate some of the cost burden imposed on low-income commuters with congestion pricing.

2.2.4 Effects of Pricing on Travel Behavior

When considering congestion pricing it is important to consider the effects implementation might have on travel behavior. Implementing congestion pricing may impact the choices that travelers make. Some examples include: the amount of time they allot for travel, departure time, route choice, mode choice, trip frequency, automobile ownership, locations of residence and employment, and selection of activities (Harvey, 1994). Most of these choices will ultimately impact the effectiveness of congestion pricing as a traffic demand management strategy.

Various models have been developed to predict travel behavior in response to congestion pricing. Yamamoto et al. (2000) came up with a regression model for travel time allocation for discretionary activities in order to develop a multinomial logit model of route and departure time choice behavior. Harvey (1994) discusses a study in which data from the San Francisco Bay Area was used in a microsimulation model. Predictions of mode choice, destination choice, trip frequency, and automobile ownership were used in the model to predict the effects on trip making in various pricing scenarios: regionwide congestion pricing, regionwide employer parking charges, regionwide non-employee charges, mileage and smog based registration fees, and an increase in gasoline taxes. Li and Wong (1994) used survey results in a logit regression model to analyze route choice in response to differential pricing on a mass transit railway in Hong Kong.

The effects of pricing on travel behavior have also been studied using data from existing pricing projects. Gifford and Talkington (1996) analyzed data collected from the San Francisco Bay Bridge from 1979 to 1984 to study travel demand elasticity under time varying pricing schemes. During the time that the data was collected there were three different pricing periods: (1) the toll charged to cross the Bay Bridge was constant at \$1.00, (2) the toll increased for all days of the week to \$1.25, and (3) the toll was lowered to the original rate of \$1.00 for crossings Monday through Thursday and increased to \$2.00 for crossings on Friday and Saturday. Although in this case the toll varied by day of week instead of by time of day, it is still useful for studying travel elasticity. From the analysis it was found that there was a decrease in travel throughout the entire week and not just on the days with the increased toll, thus supporting the idea of congestion pricing as a travel demand management strategy.

Burris et al. (2000) analyzed data collected from the variable pricing project in Lee County, Florida. As discussed in an earlier section, commuters that travel during the shoulders

of the peak periods are subject to a 50 percent toll savings, but only the travelers that obtain an electronic toll collection (ETC) tag are eligible for this discount. The area has observed a significant shift in traffic from peak to off-peak periods. The Midpoint Bridge has seen a 7 percent increase in traffic during the early shoulder of the morning peak period with a corresponding decrease in traffic during the morning peak period. This study supports the belief that congestion pricing will persuade some drivers to travel at alternate time periods in order to save money.

2.2.5 Congestion Pricing Linked with Advanced Traveler Information

Providing travelers with real time information in conjunction with congestion pricing would provide the most optimal congestion pricing system. Using congestion pricing without providing travelers pre-trip or on-route information is bound to have only limited impacts on traveler behavior because they will be making their travel decisions based on what is expected, not the actual conditions (Emmerink and Verhoef, 1998). Giving travelers access to pre-trip information would allow them to make educated decisions about their travel and let them decide if they are willing to pay the current toll or wait to travel at a later time.

Emmerink and Verhoef (1998) performed a study to investigate the effects on a network using road pricing and advanced traffic information, both together and separately. This model used a network equilibrium model with stochastic link travel costs and assumed that informed travelers would base their decisions on actual travel cost, while the uninformed travelers would base their decisions on expected cost. The study found that using traveler information with congestion pricing worked as well as simply applying a flat toll, but the combination of the two might be more attractive than using a flat toll. It was also found that both uninformed and informed travelers stand to gain in a situation where congestion pricing is used with traveler information.

The importance of using traveler information is also discussed in a road pricing system developed by Najafi et al. (1996). In the pricing system presented, there is a focus on 4 main technical requirements: dynamic vehicle identification at high speeds, dependable data-storage devices, distribution of real-time information through variable-message signs, and efficient data retrieval and processing. Electronic billboards are considered one of the necessary components of the proposed system, in order to inform the public of the applicable tolls.

2.2.6 Case Studies

In order to provide a better understanding of how different types of value pricing projects work and how different projects got started, this section will discuss a few case studies. The three projects to be considered will be the I-10 (Katy) HOV Lane in Houston, Texas; the State Route 91 Express Lanes in Orange County, California; and the Area Licensing Scheme (ALS) in Singapore.

2.2.6.1 I-10 (Katy) HOV Lane in Houston, Texas. Originally the I-10 HOV lane opened in 1984 as a grade-separated, reversible, single-lane HOV facility, that only transit and vanpools were allowed to use. In response to excess capacity, use of the facility was granted to two or more person carpools in 1986, but due to high traffic volumes and diminishing levels of service, the use was restricted to HOVs with three or more occupants in 1988. Although the restriction of three or more occupants applies only during particular times of the peak periods (6:45 a.m. to 8:00 a.m. and 5:00 p.m. to 6:00 p.m.); vehicles with two occupants are allowed to use the facility during all other time periods (Hickman et al., 2000).

In 1996 and 1997 the Federal Highway Administration (FHWA) helped fund a priority pricing study on the HOV lane. The study was conducted by the Texas Transportation Institute (TTI) for the Metropolitan Transit Authority of Harris County (METRO) and the Texas Department of Transportation (TxDOT), to investigate the potential of allowing two-person carpools to buy their way into the HOV lane during restricted times of the peak periods. Based on the results of the study, a demonstration project called QuickRide was launched on January 26, 1998, which allowed two-person carpools to buy their way into the HOV facility for \$2 per trip. The tolls are collected using Automated Vehicle Identification (AVI) tags with an ETC system (ITE Task Force, 1998). During 1998 there were 625 registered users of the QuickRide program (Hickman et al., 2000).

Hickman et al. (2000) evaluated the usage of the QuickRide program by using daily AVI transponder data collected from January 26 to December 31, 1998. The program has attracted more morning users than evening users. Morning use peaks during the middle of the week, while the evening use peaks at the beginning of the week and tapers off. The average travel timesavings were found to be 19.3 minutes for the morning commute and 21.4 minutes for the evening commute. The study found that the demand for the QuickRide program has not been very substantial and that its usage is very infrequent, even though use of the lanes is associated

with a substantial timesavings. This is believed to be because the effort associated with forming a two-person carpool outweighs the timesavings for many people.

2.2.6.2 State Route 91 Express Lanes, Orange County, California. In 1989, the California legislature authorized four toll road projects, two of which would have tolls that vary by time of day, to be carried out by private firms. The right to plan, construct, and operate a toll facility in the median of the existing Riverside Freeway (SR 91) was granted in 1990, to the California Private Transportation Corporation (CPTC). Originally the California Department of Transportation (Caltrans) had planned to build HOV lanes in the median of SR 91 and had cleared the project environmentally, but due to lack of sufficient funds could not construct the project. By using private funds for the SR 91 project, the project could be constructed much sooner, and the funding originally planned for the facility could be reallocated to other projects (Fielding, 1994).

The SR 91 Express Lane project consists of a ten-mile stretch of four express lanes (two in each direction) in the median of the preexisting eight-lane freeway that opened in December 1995. This project was the first in the nation to implement the concept of value pricing. In order to use the Express Lanes, travelers must pay a toll that varies by the time of day based on the level of congestion (ITE Task Force, 1998). Toll levels have been updated multiple times since the start of operation, and they currently vary from \$0.75 during non-peak periods to \$4.25 during peak periods (91 Express Lanes Home Page). Initially vehicles with three or more occupants were allowed to use the lanes for free, but as of January 1, 1998, they were required to pay one half of the toll (ITE Task Force, 1998). In order to use the Express Lanes, travelers must purchase a transponder card. By the end of 1997, more than 86,000 transponder cards had been issued, and approximately 25,000 drivers were opting to pay the toll each day (Schiller, 1998).

The project uses large variable message signs to post the current toll being charged for use of the lanes. From the location of the signs, drivers have about one kilometer to decide if they want to use the Express Lanes or stay on the general-purpose lanes. Once the drivers pass into the Express Lanes, the appropriate toll is automatically deducted from the users account through the transponders they purchased. The system uses antennas to read the account information on the transponder's microchip and deduct the toll, and up to 2,500 vehicles per hour per lane can be processed at speeds greater than 95 miles per hour (Finch, 1996). Vehicles that

enter the facility without a transponder are caught on camera and fined between \$100 and \$300 by mail (Finch, 1996).

The introduction of the Express Lanes has profoundly effected the travel times of the users of SR 91. Caltrans reported that the average travel delay in the free lanes during the climax of the p.m. peak period, dropped from 30 to 40 minutes to five to 10 minutes (ITE Task Force, 1998). After operating for six months, only a small amount of newly generated traffic had been attributed to previous latent demand (Small and Gomez-Ibanez, 1998).

Through surveys conducted by California Polytechnic State University, it was found that about 45 percent of the peak period Express Lane users utilize the facility once a week or less. This suggests that many travelers heavily weigh their decision as to whether or not the timesavings is worth paying the toll. Demographic characteristics of frequent users were also studied and were found quite similar to the SR 91 commuters. In addition, although public opinion of the variable tolls was not very favorable at first, it was found to have gained significant support after two years of operation (ITE Task Force, 1998).

2.2.6.3 Area Licensing Scheme (ALS) in Singapore. It is also useful to consider international experiences with congestion pricing. Although there are a variety of cultural differences, there are still many valuable lessons that can be derived. Singapore's Area Licensing Scheme was the first congestion pricing project adopted and is still one of the most successful.

After considering various options for reducing traffic demand, including "conventional road tolls and higher parking charges," the city of Singapore decided to implement a cordon road pricing system in June of 1975, referred to as Singapore's Area Licensing Scheme (ALS) (Small and Ibanez, 1998, pp. 215). The initial system was a very low-tech, simple one. The tolled area was defined by a single cordon line around the city center, referred to as the restricted zone, and consisted of a 5-kilometer square area. Only drivers that purchased a paper windshield sticker were allowed to enter this restricted zone during the morning peak period. This original system was monitored by visual inspections performed by traffic officers (Harrington et al, 1998).

The fees and structure of the tolling system have varied throughout the years of operation in response to various changes in traffic demand. Fees have ranged from \$1.50 to \$2.50 (US\$) per day for personal automobiles. Originally motorcycles, commercial trucks, and carpools and taxis carrying four or more people were exempt from purchasing the tag, but in 1989 these

exemptions were eliminated for all vehicles except public transit. In addition to the exemption changes in 1989, the restricted time was also changed to also include the afternoon peak period. In 1994, the charging time period was once again extended to include the entire time period between the morning and afternoon peak periods (Small and Gomez-Ibanez, 1998). In addition, an electronic toll collection system replaced the manual system in the spring of 1998 (Berg and Young, 1999)

The ALS has had dramatic impacts on traffic since the beginning of its operation. Initially ALS reduced inbound traffic by 44 percent for all vehicle types in the morning peak period (Menon et al, 1993). Traffic in the half-hour preceding the restricted period increased by 13 percent, and although an exact change in traffic volume following the restricted period was not found, the restricted period had to be extended by 45 minutes during the first month in order to reduce traffic proceeding the restricted period because of high traffic volumes (Small and Ibanez, 1998).

Over the years, there have been dramatic changes in the percentages of vehicle classes using the facility. Initially private car volumes dropped by 73 percent and taxi volumes dropped by 64 percent, while motorcycle volumes were virtually unaffected. The volume of goods vehicles on the other hand, increased by more than 100 percent. Although after the exemption elimination for all vehicles except transit vehicles and the extension of restricted times to the afternoon peak, the volume of goods vehicles decreased by 51 percent and 60 percent for the morning and afternoon peaks respectively. During this same time, private car volumes increased by 10.2 percent in the morning peak due to a decrease in ALS fee but decreased in the afternoon peak because of the new afternoon restrictions. Motorcycle and taxi volumes also declined in the afternoon peak by 54 percent and 11 percent respectively due to the extended restrictions (Menon et al, 1993).

With the traffic volume reductions, the restricted area has witnessed a dramatic increase in travel speeds. Unfortunately with the increase in travel speed in the restricted area, came a decrease in travel speed on roadways outside the restricted area. In 1989, the ring road around the restricted area had an average travel speed of 19 kmh, while the road in the restricted zone had an average travel speed of 31 kmh. One of the criticisms of the ALS is that it has simply pushed congestion from one area to another; although the congestion witnessed on the ring road is not as serious of the congestion that was previously witnessed in the restricted area before

ALS. The widespread traffic improvements in the restricted area more than balance the worsening of traffic on the ring road (Menon et al, 1993).

This case study has shown that travelers do respond to roadway pricing and that with simple structural and fee changes over time a road pricing system can continue to be successful at reducing congestion on the tolled roadway. This case study has also shown that roadway pricing can have adverse affects on roadways that are not tolled, and there must be some way of determining if the deterioration of one roadway is worth the improvements on another.

2.3 ITS BENEFITS

In order to determine whether or not implementing various ITS projects would prove to be worthwhile, it is necessary to have some way of predicting possible benefits of these projects. Properly evaluating ITS projects as they are being designed can help ensure project success. All ITS projects should be evaluated in order to predict critical performance factors in both engineering and marketing aspects (Lee, 2000a). Since developing and evaluating an ITS framework to be used for congestion pricing are the primary goals of this report, it is important to consider the various ways in which the benefits of different ITS projects can be predicted.

From the literature, two main approaches to ITS benefits evaluation have been identified: the goal-oriented approach and the economic analysis approach. With the goal-oriented approach, measures of effectiveness are determined based on the defined goals and objectives of the project. In this case, the success of the project depends on whether the project's goals and objectives were met. This approach is most appropriate at the local or district level of decision-making. The economic analysis approach on the other hand, focuses on whether a project is economically beneficial. This approach would be best suited for project selection at the state level (Peng et al, 2000). The upcoming sections will discuss some of the ways that ITS benefits have been predicted using both methods. In addition, some cases studies of observed benefits will be discussed.

2.3.1 Goal-Oriented Approach

A broad range of studies have been done using the goal-oriented approach for predicting ITS benefits. Wunderlich et al. (1999) used a combination of an ITS evaluation methodology developed by Mitretek, Process for Regional Understanding and Evaluation of Integrated ITS Networks (PRUEVIIN), and traffic simulation to predict the regional and corridor impacts of using different ITS technologies in the Seattle, Washington metropolitan area. The study

considered applications of Advanced Traveler Information Systems (ATIS), Advanced Traffic Management Systems (ATMS), and Incident Management Systems (IMS) all separately and integrated with each other to predict possible effects on the area's transportation system; of special interest were the effects across jurisdictions. The study used peak period delay reduction, travel time reliability, changes in regional mode choice, corridor travel throughput, fuel consumption, emission rates, and various other measures, for evaluating the effects of each application on the roadway network.

Numerous other methodologies and frameworks have been developed for predicting ITS benefits using a goal-oriented approach. Brand (1994) presented criteria and methods that could be used in the evaluation of ITS improvements which could also differentiate between supply and demand impacts of ITS. Underwood and Gehring (1994) developed a framework to be used for benefits assessment, that not only addresses the interests of the traveler but also considers the general public and manufacturers and suppliers. Turner and Stockton (1999) present an evaluation framework that could be used by the Texas Department of Transportation (TxDOT) for evaluation of various ITS projects throughout the state of Texas. Evanco (1996) developed a data fusion framework for the meta-evaluation of ITS effectiveness that could be used for a variety of measures of effectiveness, in order to synthesize results from a variety of projects.

2.3.2 Economic Analysis Approach

There have been various computer software packages and analysis frameworks developed for predicting the potential benefits of deploying different ITS elements using an economic analysis approach. Peng et al. (2000) provide a description of some of the various computer software packages available for predicting ITS benefits. The models discussed include: ITS deployment Analysis System (IDAS) (See Jeannotte et al (2000) for a more detailed description of IDAS capabilities), PRUEVIIN, TRANSIMS, SCReening for ITS (SCRITS), and Metropolitan Model Deployment Initiative. In addition, they provide a break-even analysis of results from SCRITS using the following applications: ramp metering, commercial vehicle operations (CVO) driver kiosks, closed circuit television (CCTV), highway advisory radio (HAR), kiosks, and variable message signs (VMS).

Gillen (2001) reported on results from using IDAS Build I to predict benefits of using various ramp meter combinations and technologies on one freeway segment. The paper also

reports some of the different experiences with using IDAS and a summary of observed benefits from various deployed projects, to help evaluate the results obtained using IDAS.

A paper by Thill and Rogova (2001) discusses a model specifically developed for the state of New York to predict the benefits of using various ITS applications throughout the state. The model consists of a library of modeling tools given the name ITS Options Analysis Model (ITSOAM). It is designed to be used by engineers and planners as a sketch planning tool to help evaluate the significance of potential ITS projects based on an economic assessment.

Zavergiu (1996) developed an ITS benefit-cost framework predicting benefits for not only for the first order beneficiary, the transportation user, it also considers the benefits and costs associated with the second order beneficiaries, transportation infrastructure managers and providers, and third order beneficiaries, the economy and environment. A case study using the evaluation framework is also provided to give a better understanding. Another framework was developed by Lee (2000b) using Seattle's traffic information website as a model.

2.3.3 Observed Benefits

Data collected from ITS projects that have already been deployed, can help with the evaluation of predicted ITS benefits from the different models. If there are multiple projects in existence, they can help give a good range of expected results from deployment of a similar project. Various reports have been written that compile observed benefits from many of these existing projects. Proper (2001), Turner et al (1998), Jernigan (1998), and Apogee/Haigler Bailly (1998) all provide good summaries of various projects throughout the nation. Lee (2000a) provides a summary of benefits observed in New York, Phoenix, San Antonio, and Seattle. A more detailed evaluation of the San Antonio TransGuide system, is provided by Carter et al (2000).

2.4 CONCLUSIONS

At this point in time, the U.S. has had very limited experience with congestion pricing, although the few existing value pricing projects have provided much valuable insight. Some of the projects appear to be more successful than others, but all have shown some positive results. As the congestion problem increases throughout the coming years in many metropolitan areas, congestion pricing may become a more commonly used method for congestion alleviation. All of the studies that have been conducted will be of great help for planning future projects.

From the literature, it is obvious that ITS plays a key role in the use of congestion pricing. It is important for toll collection, enforcement, traveler information, and various other components that will be discussed in further detail in an upcoming section of this report. For most applications, there are a variety of different components that could be chosen to perform the same task, and each should be evaluated for the specific project at hand. In order to do this, it is important to select an appropriate tool for analyzing the benefits of different ITS components based on the project's goals.

CHAPTER 3 DEVELOPMENT OF AN ITS FRAMEWORK FOR CONGESTION PRICING

3.1 CONGESTION PRICING ACTIVITIES

In order to develop an ITS framework, it is important to first consider all of the necessary activities associated with congestion pricing. There must be a method for collecting tolls, a way to inform drivers of the current toll being collected, a means of enforcement, a process for keeping track of the number of vehicles on the roadway, and a way to manage the facility. All of these basic activities are necessary for the deployment of an efficient and successful congestion pricing project.

ITS technologies can be used to provide efficient and reliable solutions for these activities. Use of ITS components can provide travelers with up to date information on the traffic situation as well as the tolls that they can expect. They can also be used to speed up the toll collection process. In addition, ITS technologies can be used for enforcement, tracking and monitoring the number of vehicles using a facility.

The next section will focus on identifying the necessary ITS components for congestion pricing and their associated roles.

3.2 IDENTIFICATION OF NECESSARY ITS ELEMENTS

From the case studies presented in the previous chapter and from various other congestion pricing projects, it is believed that the following elements are necessary for a congestion pricing system: an electronic toll collection system, cameras, variable message signs, vehicle detection devices, and a management center to monitor and control all ITS components. In addition, these technologies must work together as an integrated system in order to be most efficient and successful.

3.2.1 Electronic Toll Collection

In the past, tollbooths were commonly used for the toll collection process. Unfortunately, they do not provide a very efficient system and can cause dramatic delays to travelers. As of a few years ago, 70 percent of the toll facilities in the U.S. had implemented electronic toll collection (ETC) systems in order to speed up the toll collection process (Apogee/Hagler Bailey, 1998). Not only are they quicker for the traveler, they are also much cheaper to operate than a

traditional toll plaza. Use of ETC on the Oklahoma Turnpike has been associated with a 91 percent decrease in operating costs for the facility (Apogee/Hagler Bailey, 1998).

With the technology advancements that have occurred over the last couple of decades, ETC systems have become more reliable and highly developed. Use of electronic toll collection would definitely be necessary for an efficient congestion pricing project. The newer ETC systems are now able to process vehicle information at much higher speeds. Vehicles can maintain their travel speeds when driving through an ETC facility without having to slow down, even at freeway speeds. Advancements have also made ETC systems more dependable in extreme and adverse weather conditions that previously affected system performance.

An electronic toll collection system is comprised of multiple technologies working as an integrated system. First, a transponder, toll tag, or smart card technology is typically used for vehicle identification. There are also multiple devices that can be used to detect and record information from the transponder, which generally include the vehicle account, time and date of transaction, and the fee collected (Najafi et al, 1996). Once data are recorded, it is typically stored and processed in a central computer system in order to charge or deduct the appropriate toll from the vehicle's account. Figure 3.1 shows an illustration of how an ETC system works.

In addition to the various read and write technologies previously discussed, there are also a variety of license plate reader (LPR) systems available that can be used in the electronic toll collection process. These systems make it possible to collect tolls from drivers even if they do not have a transponder in their vehicle. The newest LPR technologies are able to capture and identify the license plate registration number, state, province, and country of origin of a passing vehicle, within milliseconds and are capable of processing all this information at highway speeds (Perceptics, 2001). The systems are typically set up with cameras over each lane, mounted on gantries at entry points along the roadway. This is illustrated in Figure 3.2.

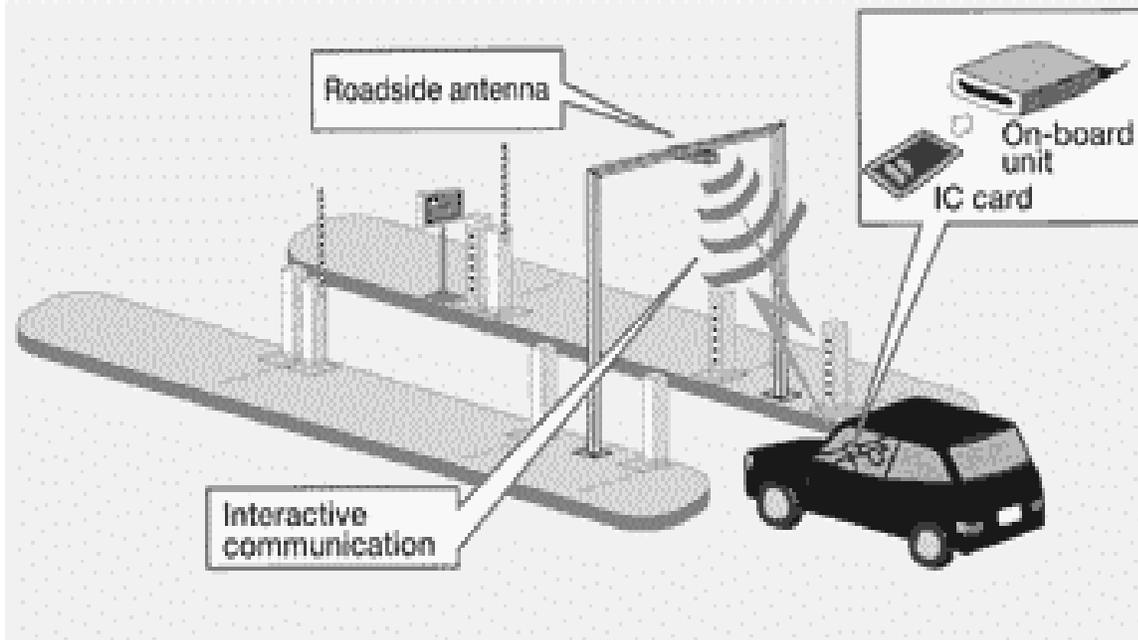


Figure 3.1: Illustration of an ETC system (Highway Industry Development Organization, 2001)



Figure 3.2: Illustration of LPR System Used in Conjunction with Read and Write Technology (AA Roads Homepage, 2001)

LPR systems make it possible for drivers that have not purchased a transponder or those that are visiting the area, to use a tolled facility without having to provide traditional tollbooths in order to collect their tolls. Additionally, toll evasion can easily be enforced with the use of an LPR system, since vehicles do not need necessarily need a transponder to be charged.

With technologies constantly changing and with limited funding available, it is difficult to maintain a facility with state of the art equipment. As a matter of fact, most ETC systems in operation are quite outdated. There are only a handful of facilities that are fully electronic toll roads, two of which include: the Highway 407 Express Toll Route in Toronto, Canada (407 ETR, 2001) and the Melbourne City Link in Melbourne, Australia (Melbourne City Link Authority, 2001). When deciding on specific technologies to use for ETC in a congestion pricing project, it is important to first look at the newest technologies available and not necessarily what has been previously deployed.

Although ETC is the most efficient process, there is still some public opposition. The literature indicates there were two major public oppositions. The first was associated with the privacy of the driver's information. To gain public support, an electronic toll collection system should be designed to secure the privacy of a driver's personal information. The Melbourne City Link was designed with this in mind; the electronic toll tag does not contain information of the vehicle's license plate number, the drivers name, address, or any other personal information (Melbourne City Link Authority, 2001).

The second opposition was related to the cost of paying for the transponder or toll tag. In order to address this concern, drivers must be convinced that the benefits of using ETC, elimination of wait time at a toll facility and a decrease in travel time, will outweigh the cost of purchasing a transponder. Marketing schemes can be used to advertise the benefits of using a transponder to address this opposition.

3.2.2 Vehicle Detection

The main purpose of using vehicle detection devices is to monitor traffic flow. Inductive loops or other detection devices can be placed in the roadway in order to measure traffic flow. A traffic management facility could monitor the flow rate in order to help detect incidents. If flow rates drop below normal, it may be a sign that an incident has occurred. Using cameras in conjunction with detection would provide the easiest and quickest method for detecting whether or not an incident has actually occurred; if a drop in flow rates is identified from loop detection,

cameras can be used to scan the area for a possible incident. If an incident is verified by using the cameras, the information can be passed on to the travelers on the roadway using variable message signs.

The flow rate information generated by the detection devices would also be useful for determining the appropriate toll to charge drivers to use a facility. Since the tolls with congestion pricing are based on the level of congestion, the flow rate could be used as a quantitative measure for assigning the appropriate toll.

The data collected from roadways using detection devices also provides valuable information that can be used for transportation planning purposes. This information can be used to calculate the average daily traffic, peak hour flow, and other traffic characteristics necessary for facility planning.

3.2.3 Cameras

In addition to the cameras used in an LPR system, other cameras can be strategically placed along the corridor for surveillance purposes. They can be used in conjunction with loop detection devices in order to detect incidents more quickly and to help make sure that the appropriate emergency services are sent to the scene. These cameras have the capability to zoom in on different areas of a roadway segment and are able to provide quick information without having to send someone out to a site. Regardless of whether an incident has occurred or not, the cameras can be used to verify the location of traffic slowdowns, which can be relayed to drivers through VMS. These types of cameras are available through multiple manufacturers and are available with various degrees of resolution.

3.2.4 Variable Message Signs

Variable message signs (VMS), also commonly referred to as dynamic message signs (DMS), can be used with congestion pricing to provide travelers with information for two different purposes. First, there must be some way to inform drivers approaching a facility of the current toll being charged. Since tolls vary with congestion pricing based on traffic volume, a traditional roadway sign would not be appropriate. VMS provides the best solution for informing drivers of the varying toll charges.

In addition to toll information, they can also be used to provide travelers with information about prevailing traffic conditions. They can be used to inform travelers of expected delays or

adverse roadway conditions. In the event of an accident, they may be used to warn drivers of the accident up ahead and suggest alternative route choices. Ultimately their main function is to provide travelers that are already in route, with real time travel information.

In the distant future VMS will probably be replaced with on board traveler information systems in all vehicles. Although this remains in the future, it is important to realize that technologies are constantly evolving.

3.2.5 Management Center

Finally, a management center is needed to bring all the ITS components together and to manage the facility. A management center would have all of the data collected and monitored at one location. This is definitely the most efficient way of managing a facility. For instance, if data were collected at one location and variable message signs were operated from another location, it would be hard to provide the most up to date traveler information because there would be a lot of wasted time spent communicating between the two facilities. With a management center, all these tasks would take place at the same location and extra communication time would not be necessary.

3.3 CONCLUSIONS

The effectiveness of almost every ITS component for a congestion pricing project is linked to other components. The most efficient system is an integrated one. In order to reap the greatest benefits from incorporating various ITS components on a roadway system, it is important that the components work together. A good example of how various components work together in incident management is by detecting a traffic slow down through loop detection and using CCTV to scan the area and identify an incident. Once the incident has been verified with the cameras, the information can be transmitted to drivers on the roadway using a variable message sign, to inform them of the incident and to possibly suggest alternate routes. This example shows how ITS components work together to perform a common task.

In this case, the ETC system cannot only be used for toll collection, it can also be used in conjunction with loop detection to determine the number of vehicles on the roadway. The loop detectors can also be used to determine average travel speeds, and from this information the appropriate congestion pricing toll can be determined and displayed on VMS. The cameras can be used to visually inspect traffic flow on various segments of the roadway from a management

center, and they can also be used in conjunction with loop detection for the identification of incidents. VMS can also be used with incident detection to provide drivers information about the incident. Finally a traffic management center is important to monitor all these activities and to process all the information. Integration of all of these elements will be important for the success of a congestion pricing project.

When deciding on the specific ITS technologies to be used in a project, it is important to realize that they will most likely vary from project to project. Since technologies are constantly changing, the technologies used in an existing successful project may not necessarily be the best technologies to choose for a new one.

In addition to the ITS components presented in this report, it may also be beneficial to consider use of other ITS elements. This framework was determined as the minimum components necessary for a successful and efficient congestion pricing project. Other options for providing travelers with pre-trip information should be considered when designing a congestion pricing project but are not as critical as the components discussed. A couple of examples would be to maintain a website with real time traffic information or a traffic information hotline.

Now that the ITS framework has been developed and the role of the various ITS components has been provided, the next couple of chapters of this report will discuss the methods used for evaluating the benefits of using these ITS components.

CHAPTER 4 ITS BENEFITS ANALYSIS TOOLS AND DATA SOURCES

4.1 INTRODUCTION

In order to analyze the benefits of using the various ITS components developed in the congestion pricing ITS framework, two different computer based analysis tools were chosen.

The first one, SCReening for ITS (SCRITS), is an Excel based spreadsheet that can be used for estimating user benefits associated with the deployment of various ITS strategies at a corridor or system level. The other, ITS Deployment Analysis System (IDAS), also calculates relative costs and potential benefits of various ITS deployments at the corridor or system level like SCRITS, but provides a much more detailed analysis.

This chapter will start by providing a description of the capabilities of each of these evaluation tools, as well as some of their deficiencies. A description of the corridor used for the analysis will then be provided, followed by a discussion of the data sources and assumptions used in the analysis. Finally a comparison of the two analysis tools will be provided.

4.2 CAPABILITIES OF SCRITS

Initially SCRITS was developed by Science Applications International Corporation (SAIC) under contract with the Federal Highway Administration for developing planning procedures for ITS. It was primary developed as a “first-cut screening methodology” for analyzing benefits of various ITS applications and is not meant to be used for detailed analysis. Appropriate engineering judgment must be used, when considering the resulting approximations of potential benefits given by SCRITS. The spreadsheet program is based on generic procedures that must be modified to represent specific situations (SAIC, 1999).

SCRITS was developed to be compatible with various types of transportation analysis performed using other types of tools, such as travel demand or simulation models. It was designed to be flexible in order to analyze different areas or regions. It predicts results on a daily level. Some of its common uses include: approximation of user benefits for ITS strategic planning, approximation of user benefits for the evaluation of transportation alternatives for various types of studies, and sensitivity analysis of benefits of ITS applications with certain input assumptions (SAIC, 1999).

It has the capability of analyzing 16 different ITS applications, which include the following:

- Closed circuit television (CCTV);
- Detection;
- Highway advisory radio (HAR);
- Variable message signs (VMS);
- Pager-based systems;
- Kiosks;
- CVO kiosks;
- Traffic information through the internet;
- Automatic vehicle location system for buses;
- Electronic fare collection for buses;
- Signal priority for buses;
- Electronic toll collection;
- Ramp metering;
- Weigh in motion;
- Highway/rail grade crossing applications; and
- Traffic signalization strategies.

These applications were chosen in the development based on a prioritization of analysis needs and an evaluation of available information (SAIC, 1999).

SCRITS only considers user benefits when determining the benefits associated with different ITS applications; it does not account for any benefits associated with agency operations. Although the measures of effectiveness vary by application, the primary measures include changes in: VHT, VMT, emissions (CO, NO_x, HC), vehicle operating cost, energy consumption, and the number of accidents. SCRITS uses these measures to calculate an economic benefit and benefit/cost ratio for most of the ITS applications (SAIC, 1999).

One major shortcoming of SCRITS is that it cannot directly analyze ITS application combinations. When trying to do this, the analyst must determine how the combination of applications, collectively lead to benefits. The problem is in determining collective benefits without double counting. IDAS on the other hand is able to collectively quantify benefits associated with a combination of ITS applications.

4.3 CAPABILITIES OF IDAS

IDAS was developed by a team led by Cambridge Systematics under contract to the Oak Ridge National Laboratory and the Federal Highway Administration, to be used as a sketch planning analysis tool for predicting the impacts of ITS improvements. It was designed “to assist public agencies and consultants in integrating ITS in the transportation planning process” by estimating potential impacts, benefits, and costs of different ITS improvements (Jeannotte et al, 2000, pp. 2).

IDAS directly uses the travel demand models, used by Metropolitan Planning Organizations (MPO) and State Departments of Transportation (DOT). The traffic assignment and model split steps of the traditional planning model, are used to estimate “changes in modal, route, and temporal decisions of travelers resulting from ITS technologies” (Jeannotte et al, 2000, pp. 2).

The IDAS software is equipped with three different resources for conducting ITS analysis, which include: default ITS impact settings, an equipment database spreadsheet, and an ITS library. The default settings are based on observed impacts from various ITS deployments and are documented in the ITS library. The equipment database includes an inclusive record of equipment and costs associated with various ITS improvements. Both the default settings and the equipment database may be modified to match the conditions of the area of interest (Jeannotte et al, 2000).

There are five different analysis modules within IDAS: Input/Output Interface, Alternatives Generator, Benefits Module, Cost Module, and Alternatives Comparison Module. The Input/Output Interface is used to convert the travel demand data to the proper IDAS format. The Alternatives Generator is comprised of a graphical user interface (GUI), that allows the user to “define and code” various ITS improvements on their network. The Benefits Module is made up of four sub-modules: travel time/throughput, environment, safety, and travel time reliability. Benefits are predicted for all four of these sub-modules for all alternatives. The Cost Module can be used by the analyst to define incremental costs associated with different ITS deployments, such as capital costs or operating and maintenance costs. Finally the Alternatives Comparison Module allows the analyst to view information associated with “the value of user benefits, the associated costs, and a comparison of the benefits and costs for different ITS deployment options” (Jeannotte et al, 2000, pp. 3). In determining the associated benefits and costs of

different ITS deployments, IDAS considers changes in user mobility, travel time/speed, travel time reliability, fuel costs, operating costs, accident costs, and noise (Jeannotte et al, 2000).

For the analysis, IDAS creates a control alternative based on the travel demand model data, to serve as a baseline for comparing various ITS alternatives. Other alternatives with various ITS deployments can then be created using the Alternatives Generator. The different alternatives can be analyzed and compared using the Alternatives Comparison Module (Jeannotte et al, 2000).

IDAS has the ability to analyze over 60 different ITS components, which are broken down into 11 categories. These categories include:

- Arterial Traffic Management Systems;
- Freeway Management Systems;
- Advanced Public Transit Systems;
- Incident Management Systems;
- Electronic Payment Systems;
- Railroad Grade Crossing Monitors;
- Emergency Management Services;
- Regional Multimodal Traveler Information Systems;
- Commercial Vehicle Operations;
- Advanced Vehicle Control and Safety Systems; and
- Supporting Deployments.

Unlike SCRITS, IDAS has the capability of analyzing any of the ITS components from the various categories by itself or in combination.

4.4 ANALYSIS CORRIDOR

It was determined that both analysis tools would be used to analyze the benefits of deploying the components of the ITS framework developed in Chapter three, on the U.S. Highway 183 freeway segment in Austin, Texas (Figure 4.1). The segment begins just south of McNeil Road in the north and ends just south of IH-35 in the south.

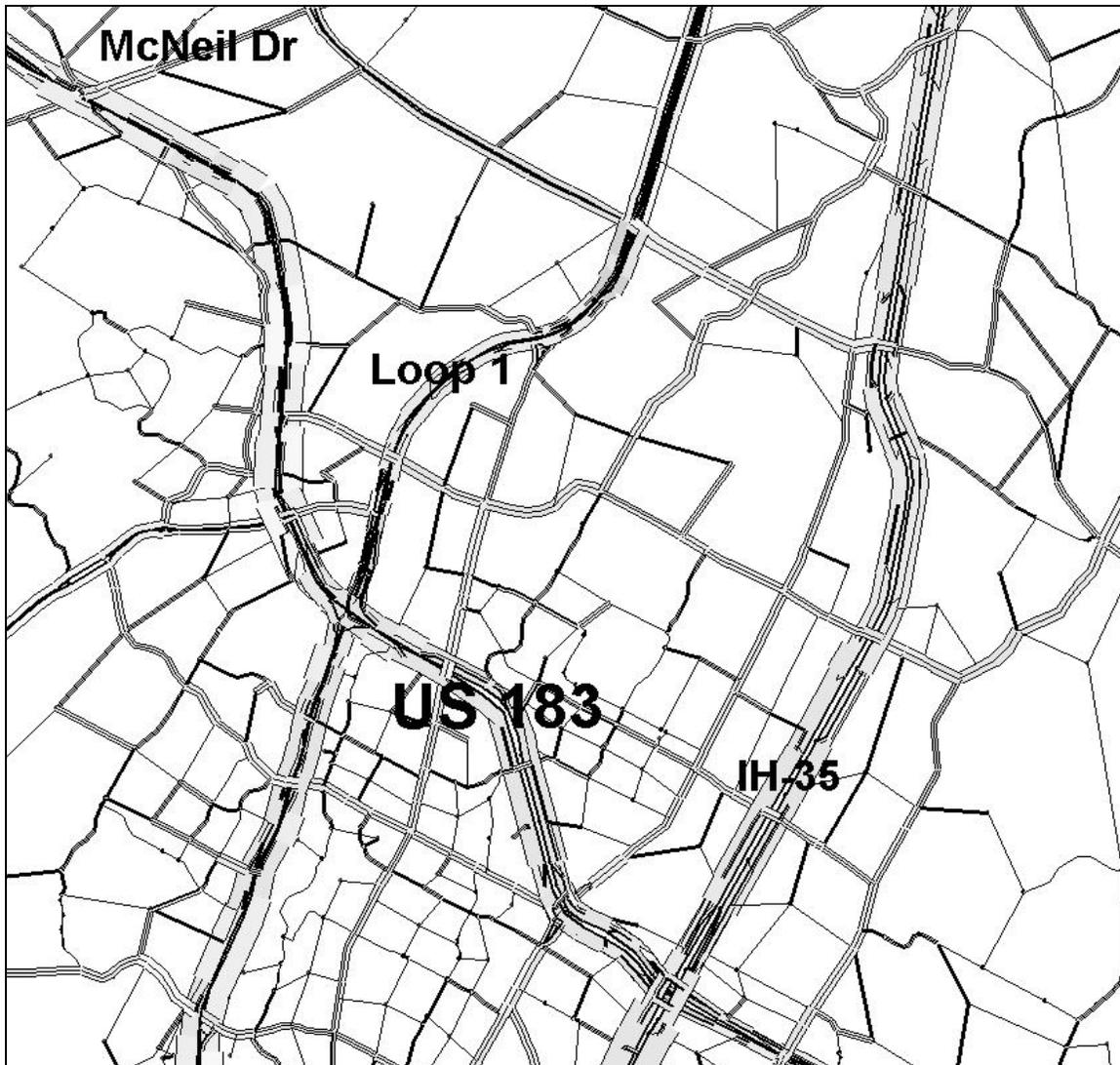


Figure 4.1: Analysis Corridor

It is thought that congestion pricing would be most effective in altering the travel times of drivers, on a roadway that does not have many alternative route choices. This particular corridor is one of the major east/west connectors in the city and does not really have any alternate route choices nearby, except for the frontage roads. The frontage roads run parallel along the entire length of the facility, but cannot provide the same level of service because of many signalized intersections. Further analysis outside of the scope of this report would be necessary to determine possible effects on travel patterns. The intent of this project, is only to determine the possible benefits of using the ITS framework for congestion pricing on the chosen corridor.

For analysis purposes, it was decided that VMS would be placed about one-quarter mile in advance of all entrance ramps in order to provide drivers with toll and traffic information. It is also necessary to place ETC systems at every entrance ramp along the analysis corridor in order to collect tolls and to monitor the facility. In the corridor being considered, there are nine entry points on the northbound segment. One of the entrance ramps connects from IH-35 northbound, and in this case, the ITS components would be placed on IH-35. To connect from IH-35 southbound to US 183 northbound, a driver must exit onto the IH-35 frontage road and enter US 183 from its frontage road. In this case it was decided that a VMS would be necessary on IH-35 southbound, in order to post tolls and traveler information for US 183 northbound. To enter US 183 from Loop 1 (Mopac) northbound, there is one ramp that connects to both northbound and southbound US 183, and all ITS components would be placed on Loop 1 at this location. This would also be the case for southbound Loop 1. On the southbound section of US 183 there are nine points of entry, one of which includes Loop 1 northbound and southbound entering traffic. In addition to the placing these components at the entrance ramps, they would also need to be placed at the ends of the analysis corridor. It was determined that for the entire corridor that there would be 20 ETC and 21 VMS used in the analysis.

Cameras typically have the ability to monitor an area within a half-mile radius. The corridor is approximately 8.5 miles in length so it was decided that 20 cameras placed in sets of two, would be needed to monitor the facility assuming that there are no obstructions. It was decided that two cameras would be installed about every 0.9 mile.

For this corridor it was assumed that a set of loop detectors would be installed roughly every half-mile in both directions. Since the corridor is approximately 8.5 miles in length, a total of 34 sets of loop detectors would be used (17 each direction). Although, US 183 already has some of all of these components installed, it was assumed that no ITS components had been previously deployed on the analysis corridor. A layout of the ITS components is shown in Figure 4.2. The rest of the inputs and assumptions used for analysis will be discussed in the upcoming sections.

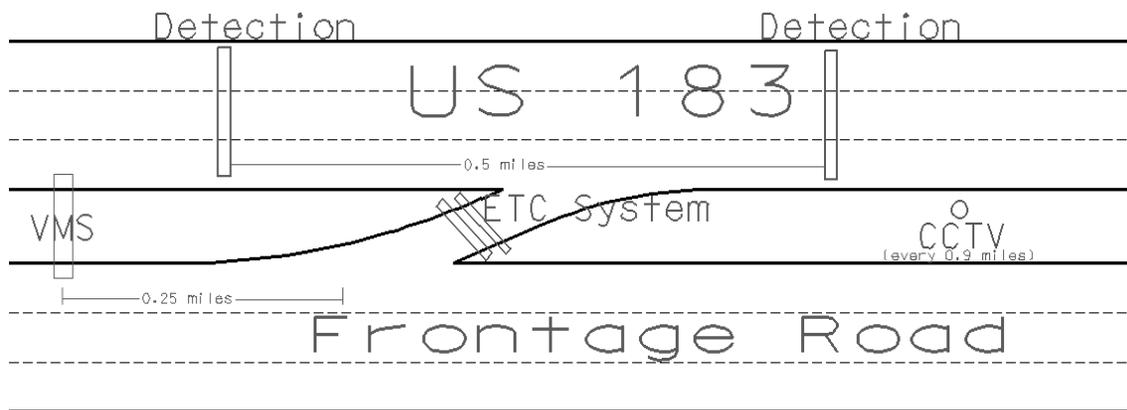


Figure 4.2: Layout of ITS Components

4.5 DATA SOURCES AND VALUES USED FOR SCRITS ANALYSIS

SCRITS was not developed for the purpose of analyzing a congestion pricing project directly, but it was thought that it could be used for looking at the benefits of the individual ITS components. It was determined that SCRITS would be applicable for analysis of these three items: closed circuit television, variable message signs, and freeway traffic detection and information. Although SCRITS also provides analysis for electronic toll collection (ETC), it would not be applicable because the analysis of ETC within SCRITS assumes a roadway that already operates as a toll facility. The benefits are based on changes in processing time for the toll collection process. Since the facility being considered is not already a toll facility, a change in processing time cannot be computed, and hence SCRITS is not applicable for this situation.

For the analysis with SCRITS, service life estimates and estimates of costs for installation and operations/maintenance were provided by engineers at the Texas Department of Transportation (TxDOT). These estimates were based on knowledge of the existing ITS deployments in the area. The traffic volume estimates were made using loop detector information collected in the year 2000, also provided by TxDOT. Assumptions were made for cases in which data was not readily available. The rest next few sections will present the values used in the analysis.

4.5.1 Baseline Data

In order to analyze a roadway segment using SCRITS, it is first necessary to input facility baseline data. The baseline data used in this analysis were as follows:

- Centerline miles of freeway: 8.5 miles
- Proportion of miles with shoulders on at least one side: 1.00
- Weekday vehicle miles traffic (VMT): 877,107 vehicle-miles
- Average weekday daily traffic (AWDT): 105,447 vehicles/day

The preceding information was provided by TxDOT or determined using loop detector information.

- Capacity: 2300 vehicles/lane/hour (according to 1997 HCM)

The following information was either assumed or were default values within SCRITS.

- Ratio of AWDT to AADT: 1.0757
- Recurring vehicle hours traffic (VHT): 35,115 vehicle-hours
- Ratio of non-recurring VHT to recurring VHT: 0.3
- Vehicle occupancy: 1.3
- Cost of time (per person hour): \$11.00
- Average incident duration: 40 minutes
- Freeway accidents per million VMT: 1.1
- Percent of secondary freeway accidents of total accidents: 10 %
- Average cost per accident: \$15,000
- Discount rate: 7%

Once the baseline data have been entered, it is possible to run analysis with SCRITS for different ITS deployments. The data inputs used for each ITS deployment considered are given in the next few sections.

4.5.2 Variable Message Signs

As previously stated, it was decided that 21 variable message signs would be used on the corridor. Cost and service life estimates were provided by TxDOT, while the rest of the values used were either assumed or were default values within SCRITS. The values used in analysis were as follows:

- Average volume per hour past sign: 4300 vehicles/hour
- Number of times/day each sign provides incident information: 1
- Time sign is active for each incident: 1 hour
- Percent of drivers (vehicles) passing sign that save time: 20%
- Amount of time saved by each vehicle passing sign: 3 minutes
- Installation cost: \$2,837,184 (\$135,104 per sign)
- Service life: 20 years
- Annual operating/maintenance cost: \$315,000 (\$15,000 per sign)

4.5.3 Closed Circuit TV

For the installation of 20 cameras, the data inputs were as follows:

- Percent CCTV coverage on freeway before improvement: 0%
- Percent CCTV coverage on freeway after improvement: 98%
- Estimated reduction in average incident duration: 2 minutes
- Savings in VMT per weekday: 0
- Installation cost: \$258,040 (\$12,902 per camera)
- Service life: 5 years
- Annual operating/maintenance costs: \$100,000 (\$5,000 per camera)

4.5.4 Detection

The data inputs for 34 sets of loop detectors were as follows:

- Percent CCTV coverage on freeway before improvement: 0%
- Percent CCTV coverage on freeway after improvement: 98%
- Estimated reduction in average incident duration: 3 minutes
- Savings in VMT per weekday: 0
- Installation cost: \$974,304 (\$28,656 per set)
- Service life: 10 years
- Annual operating/maintenance costs: \$510,000 (\$15,000 per set)

4.6 DATA INPUTS AND ASSUMPTIONS FOR IDAS

It was not possible to directly analyze a congestion pricing system using IDAS, because congestion pricing was not one of the built-in ITS applications of the software. In order to carry out the analysis, it was decided that a congestion pricing system would be examined by adding the individual components, outlined in Chapter 3, to US 183.

Initially it was thought that a congestion pricing system could be modeled in IDAS, by adding ETC, VMS, cameras, detection, and a traffic management center to the analysis corridor. Eventually it was realized that the analysis of ETC in IDAS was similar to SCRITS, in that it also predicts benefits associated with deploying an ETC system on an existing toll road. Since US 183 is not currently a tolled facility, there was no existing toll collection data that could be used; consequently ETC analysis could not be performed using IDAS on this particular corridor. It was therefore determined that IDAS would be used for studying the effects of deploying variable message signs, cameras, detection, and a traffic management center on the analysis corridor.

Since IDAS can predict the benefit of multiple ITS deployments collectively, it was decided that these components would be analyzed in combination. Although in order to compare the results to those of SCRITS, it was decided that the deployments would also be analyzed separately.

For the corridor analysis with IDAS, the travel demand model was obtained from the Capital Area Metropolitan Planning Agency (CAMPO) in Austin, Texas. This travel demand model was generated for the year 2007 using 1997 as the base year. From the model the node coordinates, network links, and origin-destination matrix were extracted in order to run analysis with IDAS. Once all of these files had been imported into IDAS, it was possible to create the various ITS analysis alternatives. It should also be noted that IDAS also uses a discount rate of seven percent for economic calculations, the same used in SCRITS.

4.6.1 VMS Alternative

In the VMS alternative, 21 signs were placed throughout the corridor in the locations previously stated. The signs were all placed on the links of their corresponding freeway (two on Loop 1, two on IH-35, and 18 on US 183), and it was assumed that the signs would be readable from the frontage roads.

When creating a VMS option in IDAS, the user can specify the percentage of vehicles passing the sign that save time, the percentage of time that the sign is turned on disseminating information, and the average amount of time saved in minutes. For this analysis the default parameters were used, which were the same values as in SCRITS and were as follows:

- Percent of vehicles passing sign that save time: 20%
- Percent time the sign is turned on disseminating information: 10%
- Average amount of time savings: 3 minutes

The user also has the opportunity to edit information on all equipment necessary for deployment of VMS. This option allows the user to specify whether the equipment component should be newly installed, not installed, pre-existing, or shared with other equipment. For this analysis it was assumed that all equipment would be installed new, except the traffic management center equipment, which was assumed to be pre-existing. All of the rest of the necessary data were derived from the traffic demand model by IDAS.

4.6.2 Camera Alternative

There were 20 cameras used in this alternative, placed in sets of two. One set was placed at each end of the specified corridor and the other eight sets were spread throughout. There was no way to measure distance in IDAS when placing the cameras, so they were placed using visual inspection to evenly distribute them throughout the corridor, alternating the side of the facility to be placed (one on northbound side, then one on southbound side). Just as in the VMS alternative, all the equipment associated with use of cameras were assumed to be installed new, except the TMC.

4.6.3 Detection Alternative

The detectors were also placed using visual inspection to try to evenly space 17 detectors along the corridor in each direction, with one unit placed at each location. For the detectors it was also assumed that all supporting equipment would be installed new, except the TMC.

4.6.4 TMC Alternative

As far as creating a TMC alternative, the only necessary inputs were the size of the study region and the location of the TMC. For the Austin metropolitan area, it was determined that it would be categorized as a large area with a population greater than 750,000.

4.6.5 Collective System Alternative

The collective system contained VMS, cameras, detection, and a traffic management center, with all inputs the same as prescribed above. The only difference was that all traffic management equipment was shared by the different deployments, except in the case of the TMC the equipment were assumed to be installed new.

4.7 COMPARISON AND CONCLUSIONS

Although both SCRITS and IDAS are ITS sketch planning tools, they are many differences in their capabilities and necessary data inputs. IDAS has the ability to analyze many more ITS deployments when compared to SCRITS, and it is also capable of analyzing benefits over different time periods, while SCRITS can only compute daily or weekly benefits. In addition, IDAS also has the ability to directly analyze the effects of using various ITS deployments in combination, which SCRITS is unable to do. With SCRITS, it is up to the analyst to determine a way to collectively analyze multiple ITS deployments.

The necessary data for analysis with IDAS is much more extensive than the data needed to run analysis with SCRITS. In evaluating the benefits of each ITS deployment, IDAS uses information specific to each link in a corridor, while SCRITS can only evaluate based on corridor level information. In addition, the user must determine the location of each ITS component being deployed when using IDAS, but SCRITS only requires the number of each ITS component.

The results of IDAS are also much more specific than those of SCRITS. SCRITS only breaks the benefit results down into annual time savings (\$) and annual savings in vehicle operating cost (\$). The IDAS results, on the other hand, are much more specific. The benefits are broken down into five main categories, which include: change in user mobility, change in user travel time, change in costs paid by users, change in external costs, and change in public agency costs. Most of these are broken down even further with more specific information. In addition it should be noted here that IDAS is capable of predicting benefits associated with

changes in public agency costs, while SCRITS is only able to predict benefits associated with changes in user costs.

Finally it is important to note that in this particular analysis, the data sources obtained are for two different years. This may be important to consider when trying to compare the results of the two models.

CHAPTER 5 DISCUSSION OF RESULTS

5.1 RESULTS OF SCRITS

SCRITS was used to predict the associated benefits and costs of deploying variable message signs, closed circuit TV, and loop detection as prescribed in the previous chapter. The results are as shown in Table 5.1.

Table 5.1: Results of SCRITS Analysis

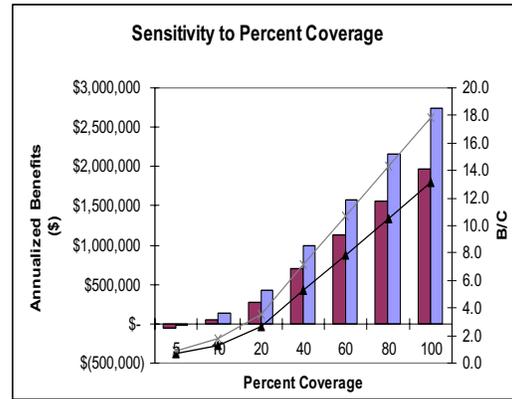
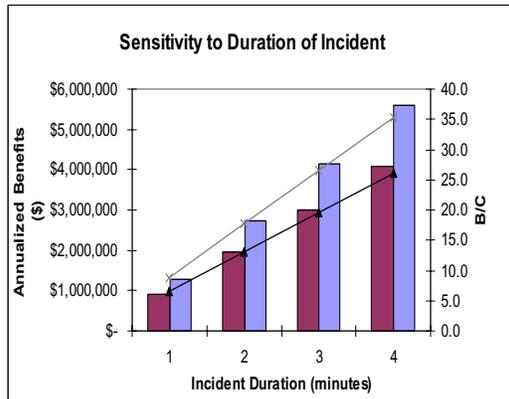
	VMS	CCTV	Detection
Total Annualized Cost	\$581,695	\$162,962	\$648,351
Annualized Benefits Minus Annualized Cost (weekday only)	\$2,679,430	\$1,936,048	\$2,498,244
Annualized Benefits Minus Annualized Cost (full week)	\$3,844,486	\$2,685,931	\$3,621,193
Benefit/Cost Ratio Weekday Only	5.6	12.9	4.9
Benefit/Cost Ratio Full Week	7.6	17.5	6.6

For all three deployments, SCRITS predicted a net benefit greater than the associated cost. Since multiple assumptions were made for the analysis, to further evaluation was necessary. In order to do this, it was decided that a sensitivity analysis and a break-even analysis would be performed on the studied deployments.

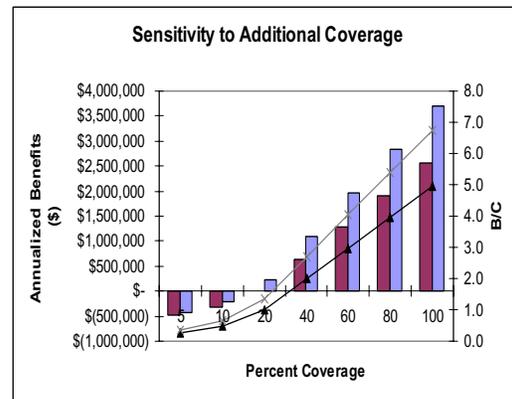
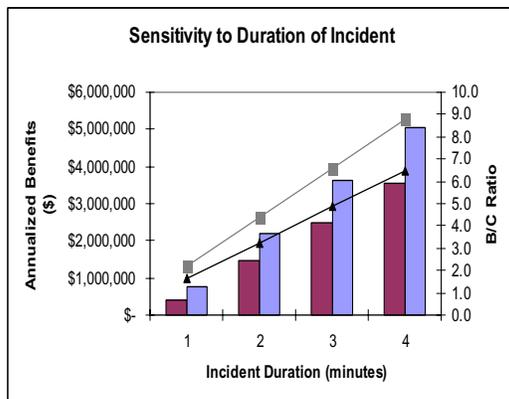
5.1.1 Sensitivity Analysis

In order to evaluate the results of SCRITS for the three ITS deployments, it was decided that the sensitivity of various inputs would be examined. For this analysis, it was assumed that all baseline data would stay the same, as well as the number of components being deployed and their associated costs. The results of all three components are shown in Figure 5.1. Refer to Appendix A for detailed results.

A) CCTV



B) Detection



C) VMS

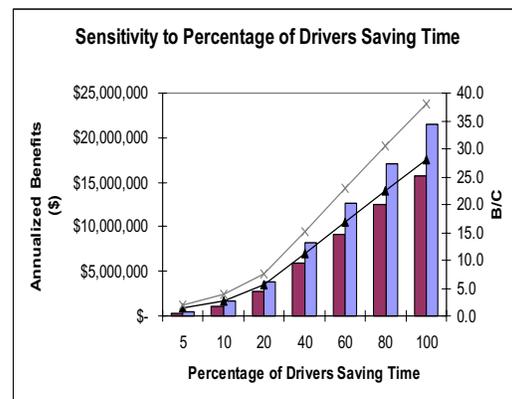
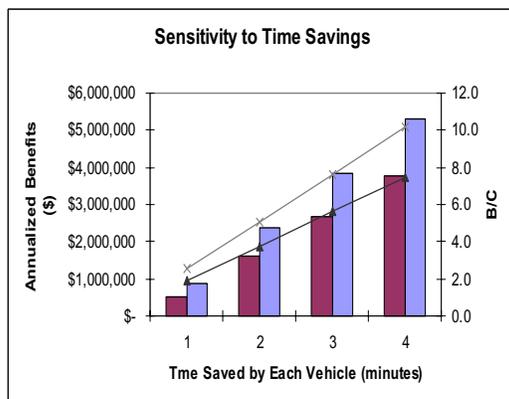


Figure 5.1: Results of Sensitivity Analysis of SCRITS

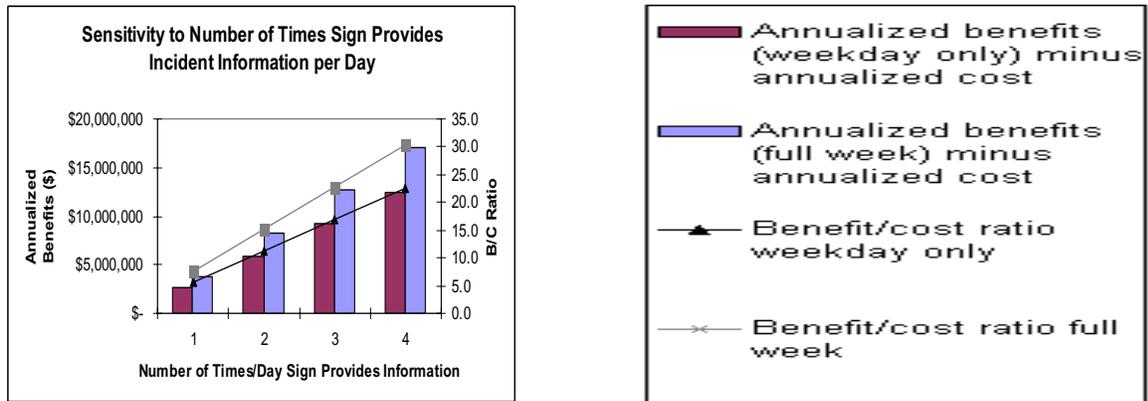


Figure 5.1 Continued: Results of Sensitivity Analysis of SCRITS

In the benefits analysis of CCTV, the results were found to be most sensitive to the change in percent CCTV coverage and change in incident duration. The benefits associated with CCTV are primarily based on incident duration reduction through visual observation of an incident area. It is intuitive that the larger the coverage area, the greater the chance that CCTV can be used to more quickly detect an incident in order to reduce its duration. Also, since the benefits of CCTV are principally based on reduction in incident duration, it is logical to expect that the benefits would be highly dependent on a change in incident duration.

The benefits of detection are also largely based on reduction in incident duration. As with CCTV, the percentage of detection coverage and change in incident duration were found to be the most sensitive variables, which is logical for the same reasons. The benefit cost ratios predicted by SCRITS for detection, were less than half of those predicted for CCTV, for all scenarios. This difference is probably mostly attributed to the greater total annualized cost of detection compared to CCTV, used in this analysis.

In SCRITS, it is assumed that the primary objective of using VMS is to alter the route choices of drivers in order to avoid congestion. It was found that the percentage of drivers passing the sign that save time, the amount of time saved by each vehicle passing the sign, and the number of times per day each sign provides information were the most sensitive variables in this formulation. As the percentage of drivers saving time and the amount of time saved increases, it seems intuitive that the benefits of using VMS would increase. In addition, the more times the signs are used per day are associated with more drivers saving time and hence larger benefits.

5.1.2 Break-Even Analysis

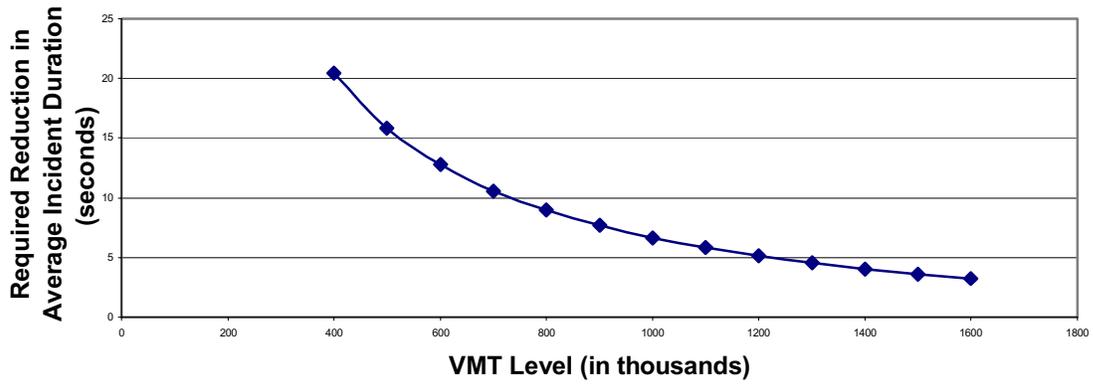
In addition to the sensitivity analysis, a break-even analysis was also performed to examine critical performance measures in SCRITS. Break-even analysis is based on the idea that the benefits are equal to the costs, or that the benefit-cost ratio is equal to one. This analysis is performed by solving benefit cost equations, assuming a benefit/cost ratio of one. In this analysis, the equations used in SCRITS to calculate the benefit cost ratio of each of the three ITS options, were set equal to one. Figure 5.2 shows the results of the break-even analysis for the three ITS options.

The break-even analysis of CCTV was performed by varying the level of VMT in the benefit cost equation, while holding all other values constant as prescribed in the previous chapter, and solving for the required reduction in incident duration to break-even. This analysis indicates that only small changes in incident duration are required to break-even. For the analysis corridor, which has a VMT of approximately 880,000, an incident reduction of about eight seconds is required to break-even, although this value seems rather small.

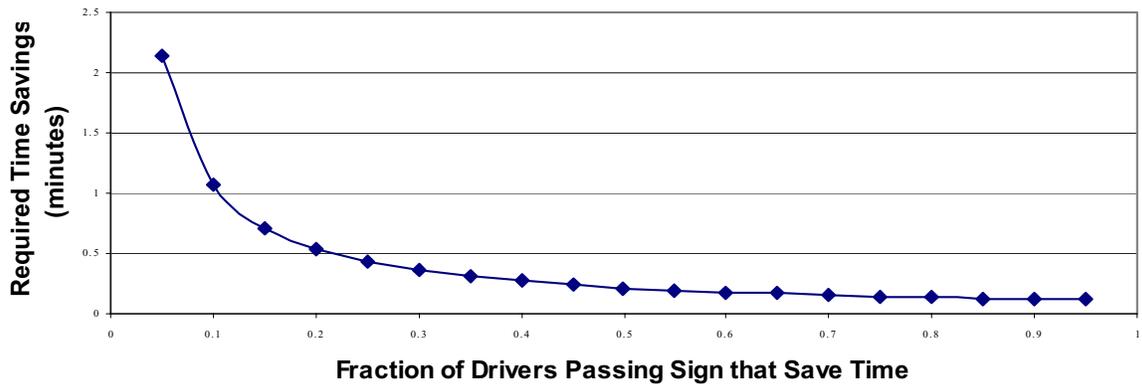
The analysis of detection was executed in the same manner. It also requires a small change in incident reduction to break-even, but the necessary changes are slightly higher. On US 183, an incident reduction of 38 seconds would be required. Once again it is believed that the reason detection needs a larger change in incident duration to break-even is attributable to its higher annualized cost, when compared to CCTV.

The break-even analysis of VMS was carried out by varying the fraction of drivers passing the sign that save time and solving for the required timesavings needed to break-even, using the benefit cost equation with all other values held constant as specified in Chapter 4. Using the assumption that 20 percent of the drivers passing the sign saved time, as was used in this analysis, a required time savings of just over 30 seconds is needed to break-even.

Break-Even Analysis for CCTV



VMS Break-Even Analysis



Break-Even Analysis Detection

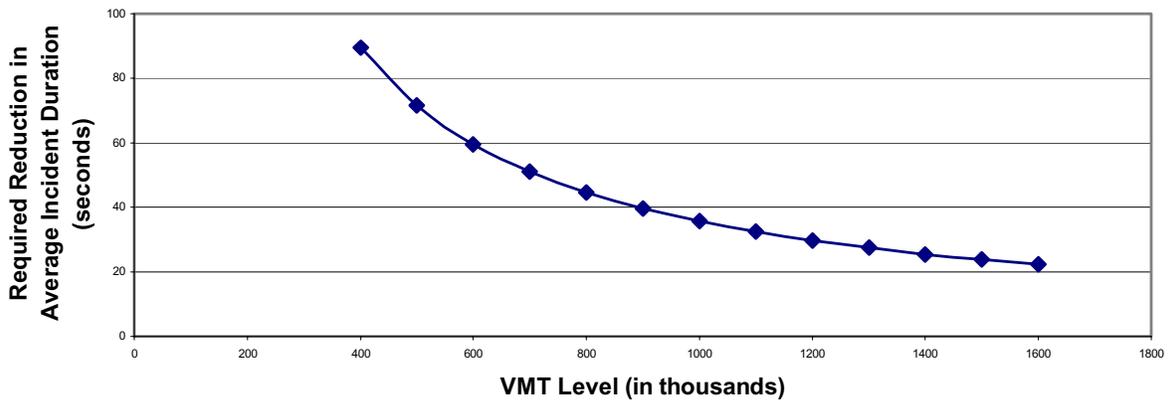


Figure 5.2: Results of Break-Even Analysis Using SCRITS

5.2 RESULTS OF IDAS

After performing analysis with IDAS, it was determined that the program was not going to be able to predict benefits in the manner originally planned. Initially it was thought that IDAS could be used to predict the benefits associated with deploying all of the ITS components separately. Although, after running the first few models, it was realized that IDAS does not calculate benefits of supporting deployments, only their associated cost. CCTV, detectors, and traffic management centers are all classified as supporting deployments in IDAS and so it was not possible to calculate the benefits of deploying these items separately. It was possible to calculate the benefits of using VMS independently though.

The initial plan was to also calculate the benefits associated with deploying an integrated system, which included all of the ITS components, but there were complications associated with this alternative as well. Since VMS was the only deployment for which IDAS predicted benefits, the associated costs of all of the supporting deployments only added to the total annualized cost without the addition of any benefits, which caused a small benefit cost ratio. It was decided that since the benefits of the supporting deployments are derived from how they support other activities, incident management (IM) would also be added to the system and evaluated. This was selected since it requires supporting deployments similar to those necessary for congestion pricing.

The daily benefits predicted for use of VMS and the integrated system with incident management on US 183 are shown in Table 5.2. A complete listing of the results of IDAS are listed in Appendix B.

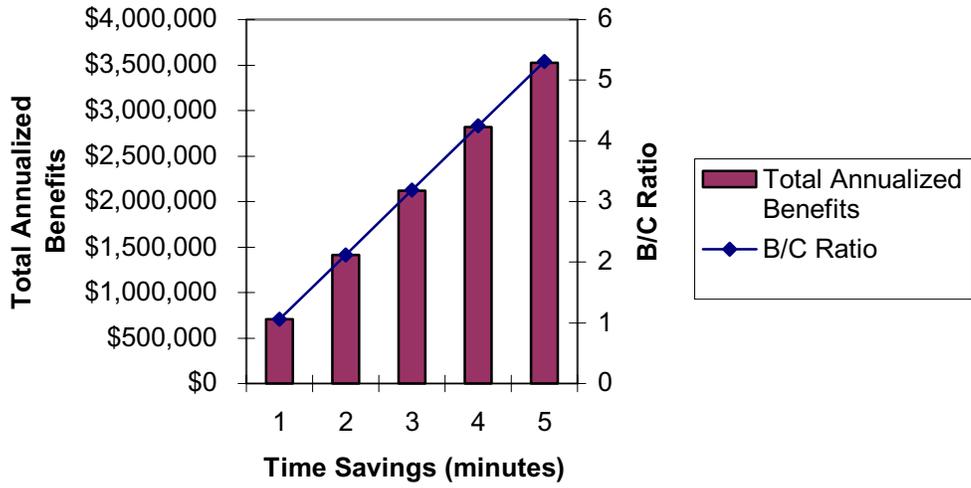
Table 5.2: Results of IDAS Analysis

	VMS	System w/ IM	System
Annual Benefits			
Change in User Mobility	\$2,115,984	\$2,115,984	\$2,115,984
Change in User Travel Time Travel Time Reliability		\$11	
Change in Costs Paid by User Change in User Fuel Costs Change in User Accident Costs		\$416,401 \$103,324	
Change in External Costs Accident Costs		\$18,234	
Total Annual Benefits	\$2,115,984	\$2,653,953	\$2,115,984
Annual Costs			
Average Annual Private Sector Cost	\$664,141	\$6,464,498	\$6,449,151
Total Annual Cost	\$664,141	\$6,464,498	\$6,449,151
Benefit Cost Comparison			
Net Benefit	\$1,451,843	-\$3,810,545	-\$4,333,167
B/C Ratio	3.19	0.41	0.33

As can be seen from Table 5.2, the addition of incident management to the system, added additional benefits to the system. Although the benefit cost ratio was slightly larger after adding incident management to the system, the net benefits were still negative. This is also believed to be due to the high costs associated with the supporting deployments. Without understanding the propriety formulation of the benefits module in IDAS, it is not possible to determine how the benefits are actually calculated. Future research should be conducted to examine the effects of supporting deployments on various ITS systems in IDAS.

In order to examine the outputs of IDAS more thoroughly, it was decided that a sensitivity analysis would be performed. In order to do this, multiple models were formulated using various scenarios of the VMS alternative and the integrated system alternative with VMS, CCTV, detection, a traffic management center, and incident management. The results of the VMS analysis are shown in Figure 5.3 and the results of the system analysis are shown in Figure 5.4.

Sensitivity to Time Savings



Sensitivity to Percentage of Vehicles Passing Sign that Save Time

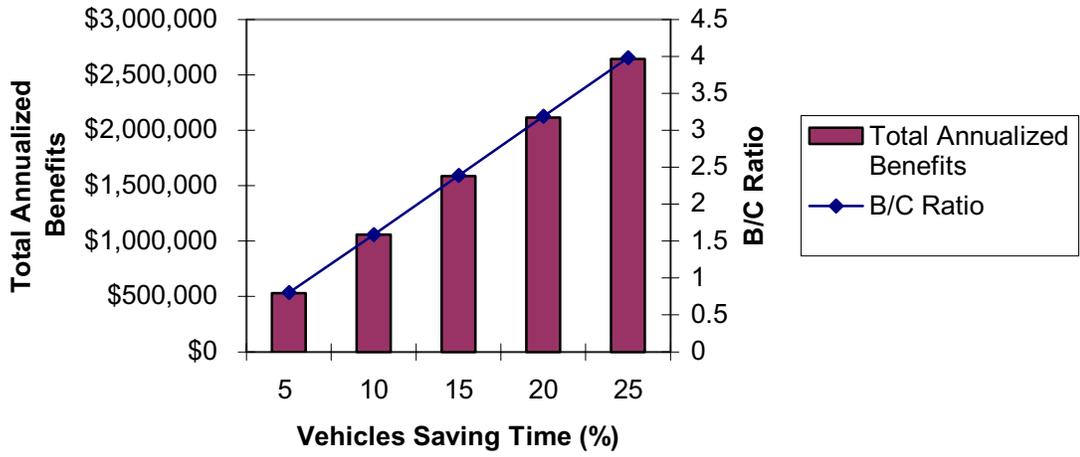
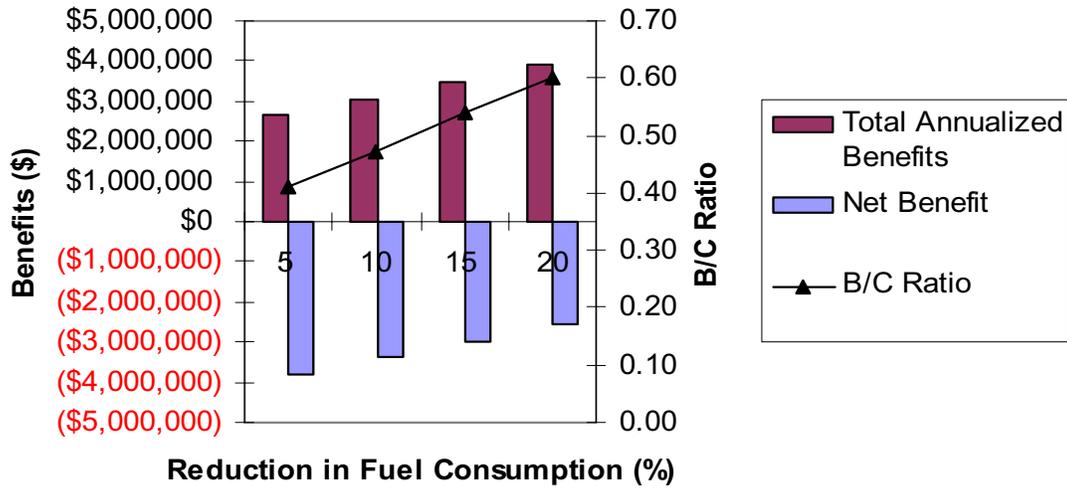


Figure 5.3: Sensitivity Analysis of VMS Using IDAS

Sensitivity to Reduction in Fuel Consumption



Sensitivity to Reduction in Incident Duration

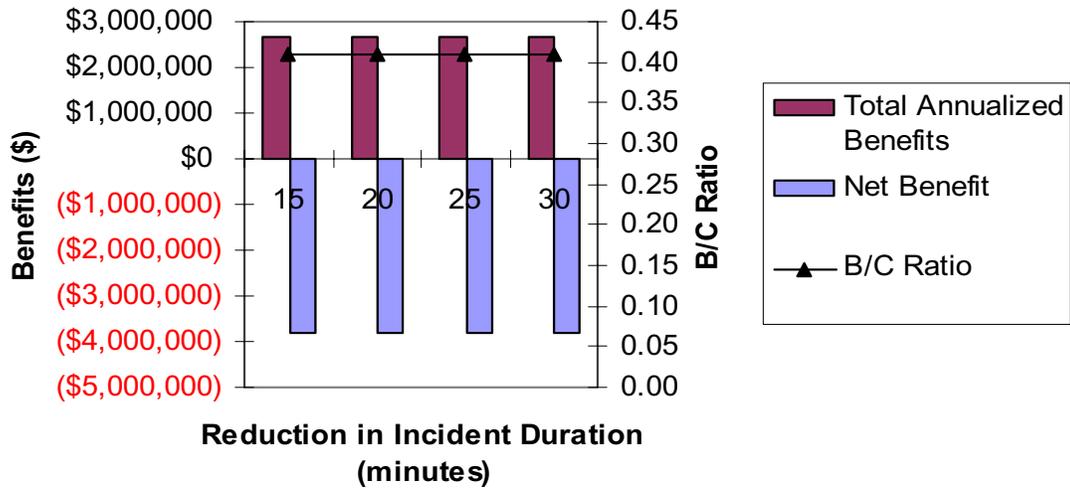


Figure 5.4: Sensitivity Analysis of ITS System Using IDAS

From the results of the VMS sensitivity analysis, it appears that the percent of vehicles passing the sign that save time and the average amount of time savings, significantly impact the net benefits of VMS deployment. A time savings of one minute was associated with an increased benefit of over \$700,000 and a five percent increase in the percentage of drivers saving time raised the benefits by over \$520,000.

The benefits of the integrated system, surprisingly, did not seem to be significantly impacted by a reduction in incident duration. It was thought that greater reductions in incident duration would have had a larger impact on the benefits than what was predicted by IDAS. A five percent reduction in incident duration was only associated with a \$2 to \$3 change in total benefits associated with travel time reliability.

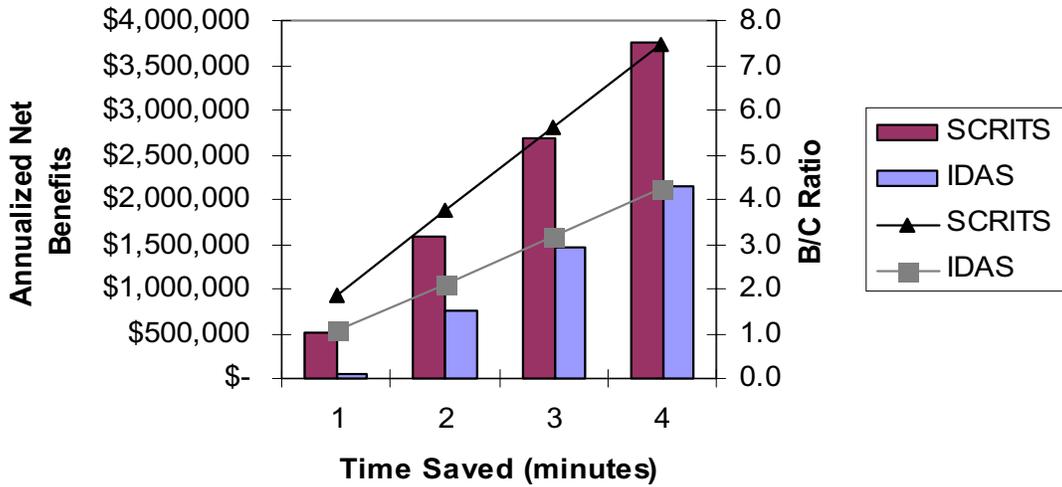
The benefits of the integrated system, associated with a reduction in fuel consumption, were more significant. For every five percent reduction in fuel consumption, the benefits of the system increase by over \$410,000.

5.3 COMPARISON OF RESULTS

As can be seen, it is difficult to compare the results of the two models used in this analysis. In this case, the only results that could be compared would be those of the VMS analysis. The benefits calculated by SCRITS for VMS were almost twice those calculated by IDAS for all models run on the analysis corridor. This is depicted in Figure 5.5.

One difference in the data used for the two analyses that may have caused variation in the results is that the total annual cost used in SCRITS was \$581,695, while the cost used in IDAS was \$664,141. This may have had a slight impact on the difference in benefit cost ratios. Another difference that might be attributable to the variation in results, is that the SCRITS analysis used traffic volumes from the year 2000 and IDAS used the travel demand model forecasted for 2007. There would need to be more common deployments studied in order to do a more detailed comparison of the two analysis tools.

Comparison of Benefits and Benefit Cost Ratios



Comparison of Benefits and Benefit Cost Ratios

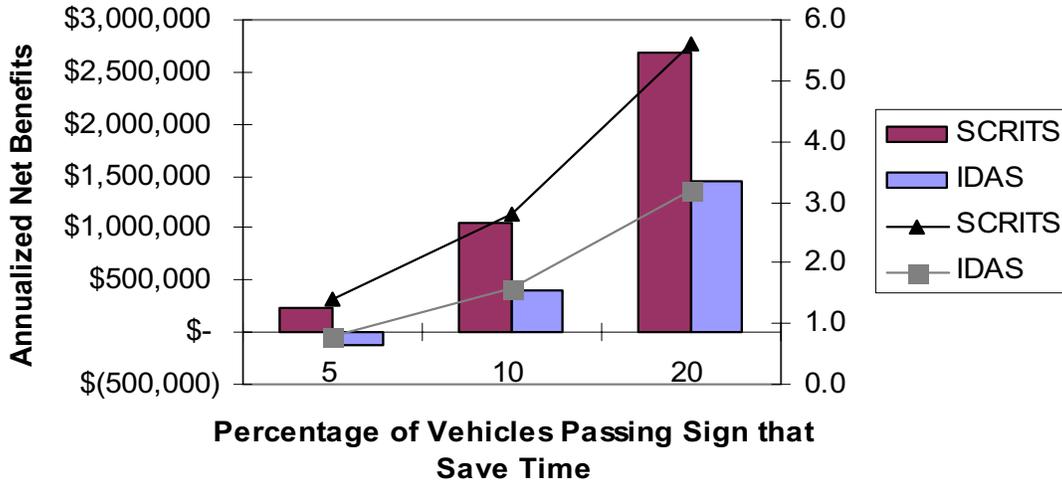


Figure 5.5: Comparison of SCRITS and IDAS VMS Sensitivity Results

5.4 CONCLUSIONS

Overall these analysis tools were not capable of determining the benefits of deploying a congestion pricing system. Since it was not possible to directly analyze a congestion pricing system or to analyze all of the individual components developed in the congestion pricing ITS framework, direct conclusions about the effectiveness of a congestion pricing system were not accomplished.

Additionally, it was difficult to make a comparison of the results of the two models, since it was not possible to analyze all of the alternatives presented in Chapter 4. The only comparison that could be made between the two models was the results of using VMS. Although, it was initially thought that a comparison of the benefits associated with use of CCTV and detection would also be possible, this was found not to be the case since IDAS does not analyze the benefits of supporting deployments.

There were also difficulties in analyzing the integrated system in IDAS, since the benefits of supporting deployments are not calculated. Even with incident management added to the integrated system in order to predict the benefits of the supporting deployments, the predicted benefits seemed rather small, which makes it questionable as to how the model accounted for the various supporting deployments. Unfortunately, without understanding the analysis process used in IDAS, it is not known, how or if they were accounted for in the analysis.

Although these analysis tools did not prove to be all that beneficial in analyzing the congestion pricing ITS framework, they may prove to be more applicable when studying various other deployments. It would be useful to study other system deployments using these tools to see if a comparison could be made.

Future research related to predicting the effects of ITS deployments used with congestion pricing, should focus on using analysis tools more capable of analyzing congestion pricing directly. This may be accomplished by making modifications to existing software packages, in order to predict the benefits of an ITS framework for congestion pricing, or by developing new software specifically for this purpose.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

The overall objective of this study was to develop and analyze an ITS framework to be used in conjunction with congestion pricing. A review of the literature related to congestion pricing and ITS benefits prediction methods was first provided, to serve as a foundation for the development and analysis of the ITS framework. The ITS framework was then developed based on the necessary activities associated with congestion pricing, outlined in the literature, and the available technologies. It was determined that an electronic toll collection system, cameras, variable message signs, vehicle detection devices, and a management center would be necessary for a congestion pricing system.

In order to evaluate the ITS framework developed for congestion pricing, two different ITS benefits analysis tools, SCRITS and IDAS, were used to attempt to analyze the potential benefits of deploying this framework. Although neither analysis tool had the capability of directly analyzing the benefits of a congestion pricing system, it was initially thought that a congestion pricing system could be analyzed by adding the individual elements to the corridor for analysis purposes.

The problem was that neither analysis tool was able to analyze all of the components deemed necessary for congestion pricing. SCRITS was only capable of analyzing VMS, CCTV, and detection, and additionally, was not capable of analyzing multiple components at once. On the other hand, IDAS classified all of the components, except VMS, as supporting deployments. Alternatively, incident management was added to all of the other deployments for analysis in IDAS, because it was thought that the benefits of the supporting deployments would be derived from how they supported this activity. Although there were more benefits associated with this model, the results nevertheless did not seem reasonable. The benefits associated with this system were small compared to the costs, when it was believed that they would have been sufficiently larger due to increased efficiency of the system. It is uncertain how the supporting deployments are taken into account in the calculation of benefits for incident management though, which makes it hard to understand why these values were low.

The only comparison that could be made between the two models was the benefits of VMS. The benefits of SCRITS were almost twice those of IDAS for all alternatives compared, which is in part probably due to differences in the data sources. The traffic data used in IDAS was obtained through the travel demand model, while the traffic data used in SCRITS were

estimates made from loop detector information. To more accurately determine the differences in the calculation of benefits, the same data sources should be used for analysis.

Although these analysis tools were not able to predict all of the benefits associated with using the congestion pricing framework developed on this corridor, they may be more beneficial for analyzing other ITS applications. Future research should look at comparing the results of other ITS applications evaluated by these systems. Aside from the results of the system analysis in this research, both analysis tools appear as if they could be used as a starting point for ITS analysis purposes.

Finally, it is recommended that future related research should consider use of analysis tools directly related to congestion pricing. This may be accomplished through the development of new analysis tools or through modifications of existing ones.

APPENDIX A

RESULTS OF SCRITS

Table A.1: CCTV - Sensitivity of Percent Additional CCTV Coverage

% Passing Sign that Save Time	5	10	20	40	60	80	100
Total Annualized Cost	\$162,962	\$162,962	\$162,962	\$162,962	\$162,962	\$162,962	\$162,962
Annualized Benefits Minus Annualized Cost (weekday only)	\$(55,743)	\$51,461	\$265,829	\$694,403	\$1,122,760	\$1,550,902	\$1,978,831
Annualized Benefits Minus Annualized Cost (full week)	\$(17,439)	\$128,065	\$419,018	\$1,000,701	\$1,582,092	\$2,163,190	\$2,749,999
Benefit/Cost Ratio Weekday Only	0.7	1.3	2.6	5.3	7.9	10.5	13.1
Benefit/Cost Ratio Full Week	0.9	1.8	3.6	7.1	10.7	14.3	17.8

Table A.2: CCTV - Sensitivity of Minutes of Saved by Passing Vehicles

Minutes Saved by Each Vehicle	1	2	3	4
Total Annualized Cost	\$162,962	\$162,962	\$162,962	\$162,962
Annualized Benefits Minus Annualized Cost (weekday only)	\$897,899	\$1,957,440	\$3,015,683	\$4,072,649
Annualized Benefits Minus Annualized Cost (full week)	\$1,276,898	\$2,714,966	\$4,151,272	\$5,585,845
Benefit/Cost Ratio Weekday Only	6.5	13.0	19.5	26.0
Benefit/Cost Ratio Full Week	8.8	17.7	26.5	35.3

Table A.3: Detection - Sensitivity of Percent Additional Detection Coverage

% Passing Sign that Save Time	5	10	20	40	60	80	100
Total Annualized Cost	\$648,351	\$648,351	\$648,351	\$648,351	\$648,351	\$648,351	\$648,351
Annualized Benefits Minus Annualized Cost (weekday only)	\$(487,529)	\$(326,737)	\$(5,246)	\$637,371	\$1,279,504	\$1,921,159	\$2,652,341
Annualized Benefits Minus Annualized Cost (full week)	\$(430,135)	\$(211,961)	\$224,264	\$1,096,216	\$1,967,512	\$2,838,159	\$3,708,164
Benefit/Cost Ratio Weekday Only	0.2	0.5	1.0	2.0	3.0	4.0	5.0
Benefit/Cost Ratio Full Week	0.3	0.7	1.3	2.7	4.0	5.4	6.7

Table A.4: Detection - Sensitivity of Minutes of Saved by Passing Vehicles

Minutes Saved by Each Vehicle	1	2	3	4
Total Annualized Cost	\$648,351	\$648,351	\$648,351	\$648,351
Annualized Benefits Minus Annualized Cost (weekday only)	\$401,801	\$1,450,659	\$2,498,244	\$3,544,578
Annualized Benefits Minus Annualized Cost (full week)	\$776,576	\$2,199,748	\$3,621,193	\$5,040,940
Benefit/Cost Ratio Weekday Only	1.6	3.2	4.9	6.5
Benefit/Cost Ratio Full Week	2.2	4.4	6.6	8.8

Table A.5: VMS - Sensitivity of Percentage of Drivers Passing Sign that Save Time

% Passing Sign that Save Time	5	10	20	40	60	80	100
Total Annualized Cost	\$581,695	\$581,695	\$581,695	\$581,695	\$581,695	\$581,695	\$581,695
Annualized Benefits Minus Annualized Cost (weekday only)	\$233,586	\$1,048,867	\$2,679,430	\$5,940,556	\$9,201,681	\$12,462,806	\$15,723,932
Annualized Benefits Minus Annualized Cost (full week)	\$524,850	\$1,631,395	\$3,844,486	\$8,270,667	\$12,696,848	\$17,123,029	\$21,549,211
Benefit/Cost Ratio Weekday Only	1.4	2.8	5.6	11.2	16.8	22.4	28.0
Benefit/Cost Ratio Full Week	1.9	3.8	7.6	15.2	22.8	30.4	38.0

Table A.6: VMS - Sensitivity of Time Saved by Each Passing Vehicle

Minutes Saved by Each Vehicle	1	2	3	4
Total Annualized Cost	\$581,695	\$581,695	\$581,695	\$581,695
Annualized Benefits Minus Annualized Cost (weekday only)	\$505,347	\$1,592,388	\$2,679,430	\$3,766,472
Annualized Benefits Minus Annualized Cost (full week)	\$893,698	\$2,369,092	\$3,844,486	\$5,319,880
Benefit/Cost Ratio Weekday Only	1.9	3.7	5.6	7.5
Benefit/Cost Ratio Full Week	2.5	5.1	7.6	10.1

Table A.7: VMS - Sensitivity of Number of Times Sign Provides Incident Information

Minutes Saved by Each Vehicle	1	2	3	4
Total Annualized Cost	\$ 581,695	\$581,695	\$ 581,695	\$ 581,695
Annualized Benefits Minus Annualized Cost (weekday only)	\$2,679,430	\$5,940,556	\$ 9,201,681	\$12,462,806
Annualized Benefits Minus Annualized Cost (full week)	\$3,844,486	\$8,270,667	\$12,696,848	\$17,123,029
Benefit/Cost Ratio Weekday Only	5.6	11.2	16.8	22.4
Benefit/Cost Ratio Full Week	7.6	15.2	22.8	30.4

APPENDIX B

RESULTS OF IDAS

Table B.1: VMS - IDAS Results

	A	B	C	D	E	F	G	H	I
Percentage of Vehicles Saving Time	20	20	20	20	20	20	5	10	15
Time Savings (minutes)	3	1	2	2	4	5	3	3	3
Annual Benefits									
Change in User Mobility	\$2,115,984	\$705,328	\$1,410,656	\$2,821,312	\$3,526,640	\$425,050	\$1,055,984	\$1,586,988	\$2,644,980
Change in User Travel Time									
Travel Time Reliability									
Change in Costs Paid by User									
Change in User Fuel Cost									
Change in User Accident Costs									
Change in External Costs									
Accident Costs									
Total Annual Benefits	\$2,115,984	\$705,328	\$1,410,656	\$2,821,312	\$3,526,640	\$531,313	\$1,055,984	\$1,586,988	\$2,644,980
Annual Costs									
Average Annual Private Sector Cost	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141
Total Annual Cost	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141	\$664,141
Benefit Cost Comparison									
Net Benefit	\$1,451,843	\$41,187	\$746,515	\$2,157,171	\$2,862,500	(\$132,828)	\$391,843	\$922,847	\$1,980,839
B/C Ratio	3.19	1.06	2.12	4.25	5.31	0.8	1.59	2.39	3.98

Table B.2: Integrated System with Incident Management - IDAS Result

	A	B	C	D	E	F	G	H
Reduction in Fuel Consumption (%)	5	10	15	20	5	5	5	5
Reduction in Incident Duration (%)	20	20	20	20	15	25	30	20
Reduction in Fatal Accidents (%)	5	5	5	5	5	5	5	10
Annual Benefits								
Change in User Mobility	\$2,115,984	\$2,115,984	\$2,115,984	\$2,115,984	\$2,115,984	\$2,115,984	\$2,115,984	\$2,115,984
Change in User Travel Time								
Travel Time Reliability	\$11	\$11	\$11	\$11	\$8	\$13	\$15	\$11
Change in Costs Paid by User								
Change in User Fuel Cost	\$416,401	\$832,727	\$1,249,052	\$1,666,377	\$416,401	\$416,401	\$416,401	\$416,401
Change in User Accident Costs	\$103,324	\$103,324	\$103,324	\$103,324	\$103,324	\$103,324	\$103,324	\$206,599
Change in External Costs								
Accident Costs	\$18,234	\$18,234	\$18,234	\$18,234	\$18,234	\$18,234	\$18,234	\$36,459
Total Annual Benefits	\$2,663,953	\$3,070,278	\$3,486,604	\$3,902,930	\$2,663,950	\$2,663,957	\$2,663,957	\$2,775,454
Annual Costs								
Average Annual Private Sector Cost	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498
Total Annual Cost	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498	\$6,464,498
Benefit Cost Comparison								
Net Benefit	(\$3,810,545)	(\$3,394,220)	(\$2,977,893)	(\$2,561,568)	(\$3,810,548)	(\$3,810,540)	(\$3,810,540)	(\$3,689,044)
B/C Ratio	0.41	0.47	0.54	0.60	0.41	0.41	0.41	0.43

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